PARKING STRUCTURES

PLANNING, DESIGN, CONSTRUCTION, MAINTENANCE AND REPAIR

Third Edition

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To our colleagues at Walker Parking Consultants/Engineers, Inc.,
All of who have helped make this book possible.

Please visit the Walker Parking Consultants/Engineers, Inc. website at

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

PREFACE

This third edition is written five years after the second edition and thirteen years after the first. To this work are brought: another five years of experience from each of the previous authors, the addition of two more authors, experience gained from a total of 3,000 parking structure design projects, 1,500 parking feasibility studies, and 1,000 parking structure restoration projects. The fifteen chapters from the second edition have been revised and expanded. Six new chapters – on parking planning, pedestrian issues, safety, mechanical parking structures, plazas, and seismic retrofit – have been added. Our intention is to ensure that *Parking Structures* continues as the leader in its field, because owners, designers, and builders can put it to immediate use.

Anthony P. Chrest

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Chapter 1

INTRODUCTION

Anthony P. Chrest

1.1 BACKGROUND

Parking structures are found all over the world. They serve office buildings, shopping centers, banks, universities, airports, train stations, bus stations, and hospitals, in both urban and suburban settings.

Parking structures have been designed and built for decades. Why then, the need for this book?

Parking structure design is more difficult than it first appears, which can lead to defects in the completed building. Yet this need not be so. We hope that our advice will raise awareness of parking structure complexities and lead to improved design, construction, maintenance, and repair.

Parking structures often appear simple, but can be deceptively difficult to plan, design, and construct. Aside from consideration of the impact on traffic in the surrounding streets, attention must be given to entrances and exits, revenue control, internal traffic and pedestrian circulation, patron security and safety, openness requirements, structure durability, maintainability, and other matter not usually encountered in other building types.

As a result, even experienced designers and builders can be caught by practices they have used before, but that will not work in parking structures. Owners, too, may make decisions based on previous experience, but that experience may not apply to parking structures. Much of the advice here will apply to surface parking as well.

1.2 PURPOSE

Our purpose is to explain those peculiarities that set parking structures apart from other building types and to offer advice on how to address them.

A. P. Chrest et al., *Parking Structures*

1.3 PARKING STRUCTURE PECULIARITIES

It's important to realize that building codes recognize two types of parking structures – open and closed. Codes do not require open parking structures to have mechanical ventilation or sprinklers, as do closed structures; so they are less expensive.

For a building code to designate a parking structure *open*, the structure must meet specific requirements of that code. For example, the Uniform Building Code states, in part,

For the purpose of this section, an open parking garage is a structure of Type I or II construction which is open on two or more sides totaling not less than 40% of the building perimeter and which is used exclusively for parking or storage of private pleasure cars. For a side to be considered open, the total area of openings distributed along the side shall be not less than 50% of the exterior area of the side of each tier.

Other codes have similar requirements, differing only in degree. A parking structure not meeting code requirements for openness will be considered *closed.* For a closed parking structure, there are more stringent requirements for ventilation and fire protection.

It is always important, then, when dealing with building departments and code officials, to identify your project properly. In this book, unless we specifically say so, we will address *open parking structures*, though most of the material will apply to enclosed parking garages and surface lots as well.

Chapter 2, new in this edition, addresses planning for structured parking. Chapter 3 addresses vehicular and pedestrian circulation systems. In years past, a 300 to 500-car parking structure was considered average size, and a 1,000-car structure, huge. Today, 1,000 – 3,000 space structures are not uncommon, and structures with 11,000 – 12,000 spaces have been built. With the advent of higher-capacity structures, the old rule-of-thumb approaches to determine numbers of entry and exit lanes, and number of circulation routes, are no longer adequate. Further, parking-related dimensions – parking space width and length, parking angle, and parking module (the clear dimension between opposite boundaries of a parking bay) – are often set by local ordinance. Local ordinances often may be outdated, leading to uneconomical parking structures. The increased size of garages also complicates pedestrian circulation and wayfinding. Chapter 3 in this edition therefore has significantly more information on pedestrian design issues than previously.

Chapter 4 deals with access issues, such as revenue control systems and entry and exit design for peak volumes. As parking structures increase in size, these issues become more significant. Chapter 5 guides one through the labyrinth of building code requirements for parking structures. The conversion to the *International Building Code* during the next few years will challenge both experienced and novice parking structure designers.

In recent years, parking structures have attracted vandals, muggers, and rapists. Patrons have sued owners, operators, and designers for injuries caused by the patrons slipping or tripping inside the structure. Courts have held owners, operators, and designers responsible for security and safety features. Retrofitting may not be able to compensate for poor original design. Chapters 6 and 7 (new in the third edition) address security and safety, respectively.

Chapter 8 addresses mechanical access parking structures, new to North America, and useful in small-site or high land cost applications.

Lighting design, an important part of security and safety in parking structures, occupies Chapter 9. Chapter 10 discusses signage needs. The requirements of the American with Disabilities Act (ADA) as they apply to parking structures are addressed in Chapter 11. Chapter 13 addresses plaza design, sometimes a part of parking structures.

Chapter 12 deals with structural design; Chapter 14 with seismic design. Parking structures have unusual proportions, compared to most buildings. A typical cast-in-place structure might have one-way post-tensioned slabs spanning 18-24 ft, supported by post-tensioned beams spanning 54-62 ft. A precast structure typically has double tees spanning the 54 to 62-foot dimension, supported by spandrel beams spanning 18-36 ft. The floors in adjacent bays slope, so the beams join the columns at staggered elevations. The interior columns between sloped floors may be short and stiff because of the building proportions.

In plan, a parking structure is relatively large. Structures 200-300 ft long and 110-130 ft wide are common. Many structures are much larger.

To this rigid framing system, add the combined effects of camber in beams and floors due to prestressing, vertical and horizontal deflections due to vehicle and people loads, the structure's own weight, wind, earthquake, and construction. To complicate matters further, next add in the effects of structure volume changes due to shortening from prestressing forces, shrinkage, and creep. Finally, add in the effects of severe weather and climate fluctuations. Now we have a system with which many engineers are unfamiliar and that others understand only partially. Even engineers relatively experienced in parking structure design may not always avoid complexities inherent in a particular structure under certain combinations of conditions.

Because the parking structure *is* open, yearly temperature extremes can affect the floor elements, beams, columns, and walls. These elements are accessible in varying degrees to rain, snow, and sun. In climates where pavements are salted to control snow and ice, the salt will increase the number of freeze-thaw cycles and lead to corrosion of the steel reinforcement in floors and in the lower parts of walls and columns.

Other than bridges, no other structure type has to resist such attacks by corrosive environments and deterioration. Unlike most buildings, parking structures have no protective envelope. Unlike most bridges that rain can wash clean, only the roof of a parking structure is entirely open to rain. Designing a parking structure according to highway bridge codes will make it cost more than it should; however, designing the structure according to some building codes, without special attention to its unique exposure, use, and requirements for durability, will produce a poorly performing structure. Chapter 15 offers advice on designing for durability.

A parking structure is a street in the sky. Like a street, it has signs, lighting, traffic controls, and parking spaces. Like a street, it's expected to last and requires periodic maintenance.

In a parking structure there are no carpets, ceilings, or wall finishes to conceal mistakes in forming or finishing. Extra care must be taken, then, to construct the building properly. There is also less leeway with respect to quality control of the concrete and reinforcement to achieve a durable structure. Finishing and curing require more care. These concerns are addressed in Chapter 16 on specifications and Chapter 17 on construction.

Parking structures require at least as much attention to maintenance as any other building – perhaps more. Though there may be only bare concrete to maintain, that concrete is exposed to severe weather fluctuations. Chapter 18 addresses maintenance and repair. Chapters 19 and 20 present in-depth treatments of repair investigation and implementation.

1.4 ORGANIZATION OF THE BOOK

The three major parts of this book will help you deal successfully with the problem areas described in Section 1.3.

No matter how well the structural framing is designed, and no matter how durable it is, drivers must be able to enter and exit the structure, circulate and park with safety and convenience. Patrons, whether driving or walking, should feel safe and secure. Following the Introduction, the first part's next ten chapters address these matters by dealing with functional planning, parking space layout, parking efficiency, pedestrian issues, entrance and exit planning and control, building codes, security, safety, the Americans with Disabilities Act (ADA), lighting, and graphics. An introduction to mechanical parking structures is included.

Having dealt with first things first, the book's second part expands on the subjects of structural design, construction materials and durability, specifications and construction. A chapter on plaza design is included.

To complete the subject matter, the third part's three chapters treat maintenance and repair.

Chapter 2

PLANNING FOR STRUCTURED PARKING

Mary S. Smith

2.1 INTRODUCTION

The following chapter is adapted from a longer discussion on planning and managing parking resources of all types (surface lots, on-street and structured parking) by the author in the *Transportation Planning Handbook*[a].

Parking structures are typically contemplated when there is a perceived need for more parking than can be accommodated in surface lots serving a building or activity center. Parking is an enormous consumer of land and resources. Office buildings in suburban settings typically require 1 sq. ft. of parking for every sq. ft. of leasable space, while shopping centers require as much as 1.5 sq. ft. of parking for every leasable sq. ft. Parking structures are expensive to own and operate; costing up to five times as much as surface parking. Revenue from parking, when there is any, only rarely pays for the cost of structured parking.

Conversely, surface parking is usually not the highest and best use of a parcel of land. Parking structures allow denser development or expansion of an existing land use that otherwise would not be possible. At the start of the new millennium, the realization is slowly dawning that suburban development as practised in the second half of the twentieth century is often not beneficial to the community. Far-flung, low-density suburban

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A. P. Chrest et al., *Parking Structures*

development is a major cause of urban sprawl, with clogged roadways and a deteriorating quality of life in both urban and suburban areas. Acres of free parking, commonly oversupplied and underutilized, result in a density of land use that makes public transportation uneconomical, discourages shared parking and increases the reliance on the personal automobile.

As people recognise the consequences of urban sprawl, the "smart growth" movement is gaining strength. Smart growth advocates denser development along transportation corridors, and/or with residential, office and leisure activities all in close enough proximity to minimize reliance on the automobile.

One of the hottest growth/development markets in the early 1990s, Atlanta now is a "poster child" for all the ills of sprawl and unfettered development, with a federally-imposed road-building moratorium. In turn, however, Atlanta is now a leader in smart growth development. A 145-acre "brownfield" site—formerly a steel mill--in Midtown is proposed to have hotels, high-tech offices, shops, entertainment areas and 3,600 homes, connected by bicycle lanes, walking paths, and public transportation. According to the *The Atlanta Journal-Constitution*[1], "As a development trend, it's called new urbanism. As a practical matter, it's going back to building pre-World War II style hometowns." Mayor Bill Campbell considers the Atlantic Steel project "the most important development project in Atlanta in 50 years, bar none". It also will be a national model for "air-friendly" development, as well as for reclamation of a site contaminated by almost a century of industrial operation. The United States Environmental Protection Agency has awarded it Project XL (eXcellence in Leadership) status. Shared, structured parking is a key component of the Atlantic Steel project, as well as other smart growth developments across the country.

Therefore, it behooves all those involved in planning parking to carefully consider how much parking is really needed, what is the most cost-effective way to develop it, and how to finance and pay for it. This chapter is devoted to facilitating that process.

2.2 How Many Spaces Are Needed?

Parking generation is defined as the peak accumulation of parked vehicles generated by the land uses present under any given set of conditions. Parking demand is the number of spaces that should be provided for a building or group of buildings, that typically includes a small cushion of extra spaces over and above the expected peak accumulation of vehicles on a design day.

Parking demand for a specific land use varies widely from one location to another. The variations reflect the density of development, availability of public transportation, local policies, price of parking and local economic vitality levels. In activity centers such as the central business district (CBD), parking demand is often reduced because of the interrelationship of related activities. A sensible approach to determining parking demand is to start with a national standard that assumes virtually a 100% modal split to private automobiles and then adjust for local conditions.

A variety of issues that affect the specific parking demand of a property are discussed in the following paragraphs.

Units. Parking requirements are generally stated as a ratio of *x* spaces per *y* unit of land use. Most ratios employ the sq. ft. (or sq. m.) of building area. Other appropriate units may include dwelling units, hotel rooms, seats or persons.

In the past, parking ratios were typically stated as one space per *y* sq. ft. Most standard-setting groups today have adopted the spaces/1000 sq. ft. (spaces per 100 sq. m.) convention, because it is easier to compare standards and estimate requirements in one's head.

Likewise, most older standards employed a calculation methodology based on "net floor area" (NFA) that is calculated inside-to-inside of exterior building walls. Today, virtually all employ "gross floor area" (GFA), which is outside-to-outside of exterior walls. For purposes of calculation of parking requirements, the vehicular parking and loading areas and the floor area occupied by electrical, mechanical, communications and security equipment, are deducted from the floor area before application of the ratios.

Ratios for land use types that frequently accommodate multiple tenants often are stated in "gross leasable area" (GLA), which is the gross floor area available for leasing to a tenant. Generally, GLA is GFA minus permanently designated common spaces such as stairs, elevator lobbies, exit corridors, malls, atriums etc. For example, enclosed shopping malls do not generate significantly more parking demand than those with open air courtyards or strip malls of the same GLA. In smaller buildings, the difference between GLA and GFA is negligible; however, as building size increases, the use of GLA rather than GFA results in a reduction of parking demand of 10% or so.

Further, because multiple tenancies in a building tend to average out the peak parking needs of an individual tenant, demand ratios typically reduce as buildings get larger and/or house multiple tenants, as long as parking is shared. It should be noted that size has the reverse effect on shopping centers. This is because the size usually reflects its focus—neighborhood, community or regional—and thus reflects differences in shopping and parking patterns.

Design Day and Hour. An important concept in parking analysis is the selection of an appropriate design day and hour. It is not feasible to design the parking system for the peak accumulation of vehicles that might conceivably ever occur and have a substantial number of spaces sit vacant for the 8,759 remaining hours of operation per year (assuming the building is open 24 hours per day, 365 days a year.) At the same time it is not appropriate to design to an average condition and have an insufficient supply for half of the hours in a year. The traffic engineer does not design the street system to handle the peak volumes that will ever occur. *Shared Parking*[2] employs the 90th percentile ratio of the peak hour occupancies observed, as does Salzman[3]. *Parking Generation*[4] presents regression curves for the average of the peak accumulations observed; however, in a subsequent article[5], the ITE committee suggested the 85th percentile as an appropriate design standard. Weant and Levinson[6] and Smith[7] generally employ the 85th percentile, as does the Parking Consultants Council[8].

Effective Supply. Another important concept in determining the required number of spaces is that of the effective supply, as it is known in the parking industry. A parking system operates at optimum efficiency at somewhat less than its actual capacity. It is unrealistic to expect an arriving parker to find the last available parking space in a system without significant frustration and the resulting perception that parking is inadequate. Therefore it is important to have a cushion of extra spaces in the supply to account for operating fluctuations, vehicle maneuvers, misparked vehicles, snow cover, and minor construction, etc. Because "perception is reality", parking "demand" must include this effective supply cushion. Thus:

Parking demand = parking generated + effective supply cushion.

The factors that affect the degree of adjustment required to compensate for effective supply include the size of the parking system, the type of users (familiar versus unfamiliar), the degree of turnover, and restrictions, if any, on usage, either individually or by areas. Where there is a mix of parking facilities with varying characteristics, such as at a hospital or university, it is generally appropriate to assign effective supply factors to the individual facilities and then compare the design day/hour accumulation of vehicles (the parking generation rate) to the adjusted supply. However, this is cumbersome, if not totally impractical, to include in standards for the recommended number of parking spaces, such as zoning ordinances or industry publications. Therefore, such requirements must include an effective supply factor of 5 to 10 percent over the anticipated design hour accumulation of vehicles within the requirement. *Recommended Zoning Ordinance Provisions,* and *Shared Parking* include such adjustments, although the specific adjustment is not generally clearly stated, while the use of a higher percentile standard for a design hour by ULI in *Parking Requirements for Shopping Centers*[9] also provides for effective supply considerations. Therefore, the stated standard ratios are "parking demand" for the design hour, but with the understanding that each provides a reasonable effective supply cushion for design purposes on the design day.

Accessory Uses. Areas associated with a land use that are not the principal activity generator, but are a necessary part of the required operation, are called accessory uses. Some argue that storage, stock, office and kitchen spaces should be calculated at different rates than the principal areas of retail or restaurant. However, most national studies and standards have been based on inclusion of accessory space in the overall GFA of the principal use.

Complementary Uses. When space in a multi-tenant building is used or leased by a different land use that is designed to serve or enhance the primary one, the tenancy is known as a complementary use. While the complementary use may normally have significantly different parking characteristics, the interrelationship with the primary use results in lowered parking demand, usually through shared parking effects. For example, the parking needs of a sandwich shop in a multi-story office building can be figured at the same rate as the office space. There must, however, be a limit on how much space is leased to secondary uses before it becomes a mixed use, with shared parking considerations. For example, a strip center with a substantial portion of its space leased to restaurants will have a significantly higher parking demand—as much as four or five times higher--than one leased solely to retail uses. The Parking Consultants Council (PCC) of the National Parking Association (NPA)[10] recommends that a maximum of 10% of the GLA be occupied by complementary uses without the building being considered a mixed use with multiple tenancies.

2.2.1 Summary of Recommended Parking Ratios

Table 2-1 presents recommended ratios for parking demand for various uses. The ratios include an effective supply factor over a design day/hour accumulation of parked vehicles. For further discussion on the needs of individual uses, the reader is referred to The Transportation Planning Handbook[11].

Table 2-1. Summary of Space Requirements[12]

Use	Parking Demand Ratio
Residential	
Single Family Dwelling Unit	2/Dwelling Unit
Multi-Family Dwelling Unit	
Studio	1.25/Dwelling Unit
1 bedroom	1.5/Dwelling Unit
2 or more bedrooms	2/Dwelling Unit
Accessory Dwelling Unit	1/Dwelling Unit
Sleeping Rooms	1/Unit or Room plus 2 for owners/managers
Elderly Housing	0.5 / Dwelling Unit
Group and Nursing Homes	0.33 / Resident
Day Care Center	1/employee plus 1.2/person (licensed capacity enrolment), plus 1drop-off space/8 enrolees permitted
Commercial Lodgings	1.25/Sleeping Room or unit plus 10/1,000 sq. ft. (10.8/100 sq. m.) rest/lounge plus 20/1,000 sq. ft. (21.9 /100 sq. m.) meeting room plus 30/1,000 sq. ft. (32.3 space/100 sq. m.) exhibit/ballroom
Hospital/Medical Center	0.4 /employee plus 1/3 beds plus 1/5 daily outpatient treatment plus ¼ medical staff. (Medical centers and teaching hospitals add 1/student or faculty/staff)
Retail	
General Retail	3.3/1,000 sq. ft. (3.6/100 sq. m.) of GFA)
Convenience Retail	4/1,000 sq. ft. (4.3/100 sq. m.) of GFA
Service Retail	2.4/1,000 sq. ft. (2.6/100 sq. m.) of GFA
Hard Goods Retail	2.5/1,000 sq. ft. (2.7/100 sq. m.) GFA interior sales space plus 1.5/1,000 sq. ft. (1.6/100 sq. m.) of interior storage and exterior display/storage areas
Shopping Center	See Table 2-2
Food and Beverage	
Fine Dining	20/1,000 sq. ft. (21.5/100 sq. m.) GLA
Eating and Drinking	25/1,000 sq. ft. (26.9/100 sq. m.) GLA
Family Restaurant	12/1,000 sq. ft. (13.2/100 sq. m.) GLA
Fast Food	10/1,000 sq. ft. (10.8/100 sq. m.) GLA for kitchen, serving counter and waiting area plus 0.5/seat provided
Office and Business Services	
General Business	3.6/1,000 sq. ft. (3.9/100 sq. m.) of GFA up to 30,000 sq. ft. (3,300 sq. m.); thereafter 3/1,000 sq. ft. (3.2/100 sq. m.) GLA
Consumer Service	4/1,000 sq. ft. (4.3/100 sq. m.) of GFA up to 30,000 sq. ft. (3,300 sq. m.); thereafter 3.6/100 sq. m. (3.3/1,000 sq. ft.) GLA
Data Processing/ Telemarketing/ Operations	7/1,000 sq. ft. (7.5/100 sq. m.) of GFA up to 30,000 sq. ft. (3,300 sq. m.); thereafter 6/1,000 sq. ft. (6.5/100 sq. m.) GLA
Medical Offices (not part of hospital campus)	6/1,000 sq. ft. (6.5 /100 sq. m.) of GFA up to 5,000 sq. ft. (5,500 sq. m); thereafter 5.5/1,000 sq. ft.

Use	Parking Demand Ratio
	(5.9/100 sq. m.) GLA
Medical Offices (on hospital campus)	5.5/1,000 sq. ft. (5.9/per 100 sq. m.) of GFA up to 5,000 sq. ft. (5,500 sq. m); thereafter 5/1,000 sq. ft. (5.4/100 sq. m.) GLA
Industrial	
	2 /1,000 sq. ft. (2.2/100 sq. m.) GFA plus any required spaces for office, sales, or similar use as the use may require.
Storage/Wholesale Utility	
	0.5/1,000 sq. ft. (0.5/100 sq. m.) GFA plus any required spaces for offices, sales, etc.
Educational	
Elementary and Secondary	1.2/ classroom plus 0.25 per student over the driving age
College and University	To be established by the Zoning Administrator based on a study of parking needs
Cultural/Recreational/ Entertainment	
Convention Center	20/1000 sq. ft. GLA of exhibit, ballroom & meeting
Public Assembly	.25/person in permitted capacity
Cinemas	Single screen: 1/2 seats Up to 5 screens: 1/3 seats Over 5 screens: 1/3.5 seats
Theatres (live performance)	1/2 seats
Arenas and Stadiums	1/3 seats
Recreation facilities	2/ player or 1/3 persons in permitted capacity

Source: Adapted from *Recommended Zoning Ordinance Provisions for Off-Street Loading Space*, Washington, D.C.: National Parking Association

2.2.2 Mixed Uses and Shared Parking Analysis

The shared parking demand methodology developed by the Urban Land Institute (ULI) is designed to determine the peak accumulation of vehicles for the specific mix of uses proposed for a development. As cited in the ULI report, some of the factors that affect the parking demand for mixed-use projects include:

The time of year, the day of the week, and the hour of the day: The fact that parking demand for each component may peak at different days of the week, or hours of the day generally means that fewer parking spaces are needed for the project than would be required if each component were a freestanding development. An obvious example is that restaurant parking needs peak in the evening when office parking needs are significantly lower. Shared parking "smoothes" the peaks and valleys in demand common with single use developments. Figure 2-1 presents some of the variations in parking needs in uses commonly found in mixed use projects.

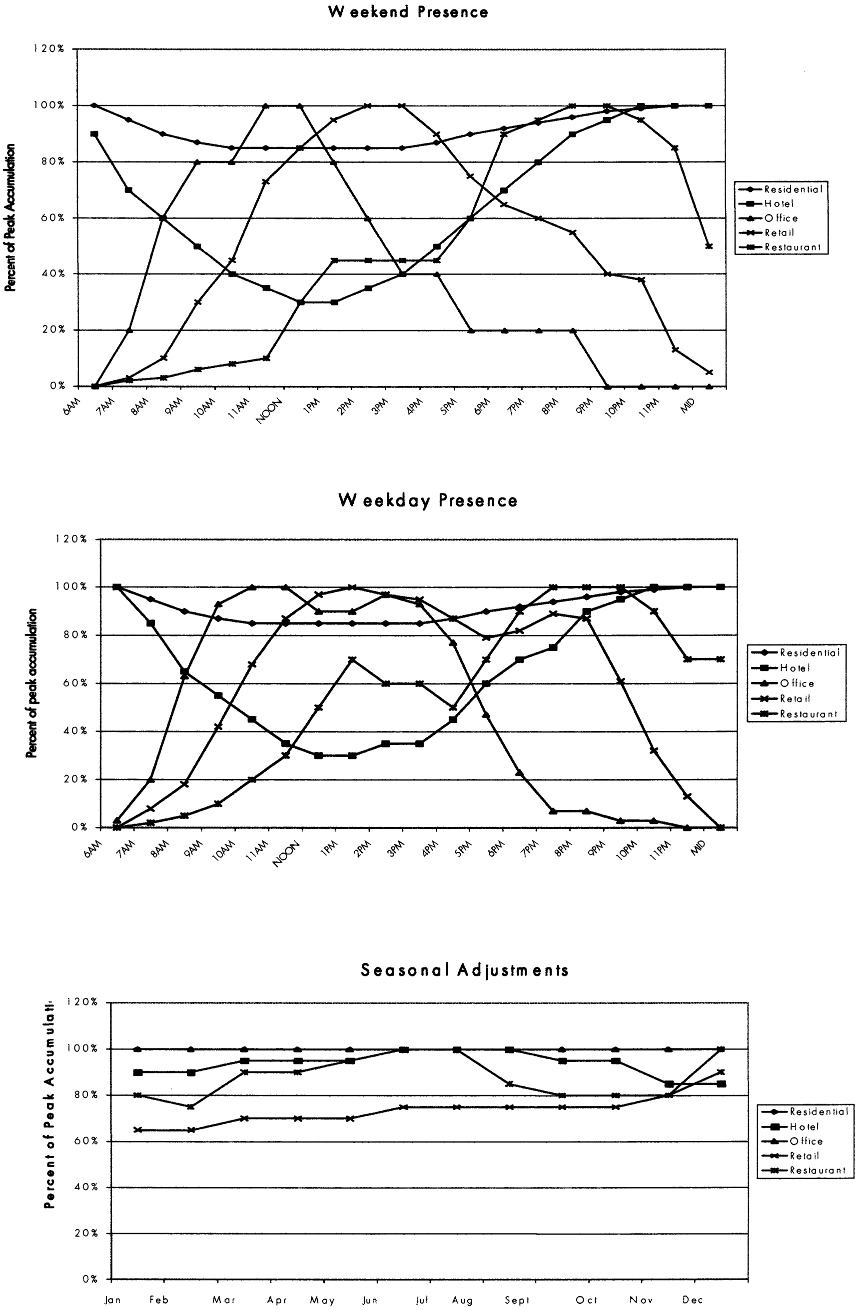

Figure 2-1. Variations in parking demand by time of day and seasonally.

Captive markets: The term "captive market" was originally borrowed from market researchers who use it to describe people who are already present in the immediate vicinity at certain times of day. In shared parking analysis, it is used to adjust the parking needs and vehicular trip generation rates due to the interaction among uses. A vehicle trip is not generated when the patron is already on-site or nearby and walks to the specific tenancy. Captive market effects accrue not only from the on-site development, but also from nearby uses. Indeed, while the methodology for determining shared parking is relatively new, a fundamental component in downtown development going back to the earliest days of the automobile, is the sharing of parking among businesses.

In parking analysis, we have to use the complementary factor, or as we call it, the **non-captive ratio**, which is the percentage of parkers who are **not** already counted as being parked. Generally, we try to count vehicles as being generated by the land use that was the primary trip purpose or generates the longest duration. For example, for a convention center and hotel complex, those attending the convention and staying in the hotel are counted in the hotel demand, then the demand generated at the convention center is reduced accordingly.

Development synergy and multi-purpose trips: Certain developments achieve much greater interaction between uses than others do. When such synergy exists, a highly successful project may have **lower** parking demands and trip generation rates than if the uses were built separately and achieved more typical patronage levels when standing alone. For example, a restaurant may have much greater noontime patronage than it would otherwise have, simply because it is located within walking distance of a large employment center. Therefore, it may have more customers per day while still having a lower noontime parking demand, due to the captive market effects, than a freestanding, everyone-must-drive restaurant.

One aspect of development synergy that must be carefully assessed is that the length of stay may be longer. The planner must consider the effects of sequential visits to venues within a development (that add to parking needs without generating additional trips) as well as simultaneous ones (that do not generate additional demand.) For example, when the family goes to today's "retail-dining-entertainment" center on a Saturday afternoon, they may split up with the children going to a movie, one parent to the sports bar and the other shopping. At that point, all three destinations are visited without increasing parking demand. However, when they meet for dinner and end up staying four hours (rather than the two hour average stay for the regional shopping center of the 1980s), the parking demand is increased for the late afternoon/early evening time period over the typical model for demand at shopping centers. This synergy is reflected in the use of relatively high peak parking demand ratios but there is then some moderation reflected in the non-captive ratio.

A 1999 update of *Parking Requirements for Shopping Centers* found the appropriate adjustments for parking needs at a retail/dining/entertainment center to be as seen in Table 2-2.

The shared parking methodology, including the effects of captive market and development synergy was recently reviewed and validated by a subcommittee of ITE. The methodology is presented in a flow chart in Figure 2-2.

Although not a standard part of a shared parking analysis, breaking the demand ratios into visitor and employee components often is a significant benefit to the analysis. First, where there is significant transit availability and/or transportation demand management (TDM) concerns, employee parking demand will be affected more than visitor demand. Also, the design of the parking system, particularly if parking is to be shared with adjacent land uses, may be more effective with this stratification. For example, with a downtown retail/dining/entertainment project, only the visitor demand on a weekday afternoon may be accommodated in spaces developed on-site. Employees will be expected to park in other downtown locations, and the weekend parking plan may rely on parking serving downtown office space on the weekdays. This shared parking may help make the downtown project economically viable with structured parking, although careful planning of parking management tactics will be needed to keep employees out of the customer parking.

Table 2-2. Recommended Parking Ratios [9]

	Percentage of GLA in Restaurant, Entertainment, and/or Cinema Space		
Center Size (GLA in Square Feet)	0-10%	11-20%	>20%
Less than 400,000	4.0	[a]	Shared parking
400,000 – 599,999	4.0-4.5 sliding scale [b]	[b]	Shared parking
600,000 and over	4.5	[b]	Shared parking

[a] For each percent above 10 percent, a linear increase of 0.03 spaces per 1,000 square feet should be added to the base ratio.

[b] Recommended parking ratio increases/decreases proportionally with center's square footage.

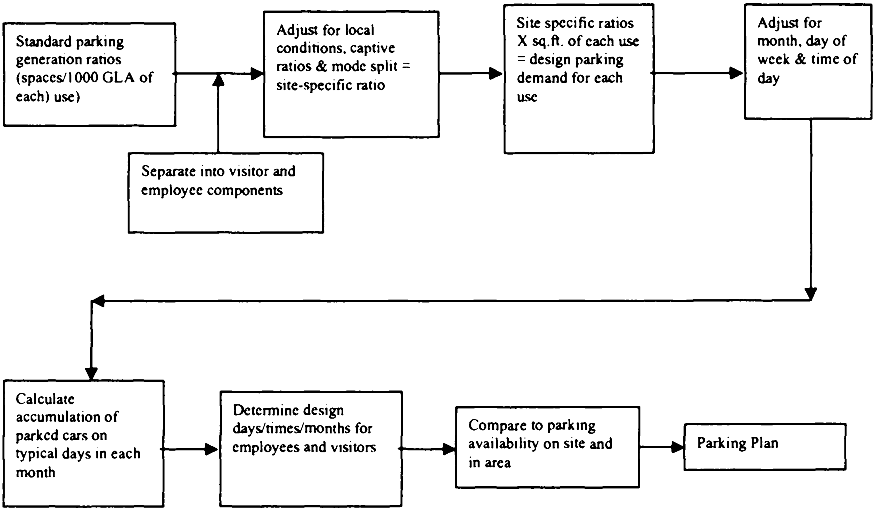

Figure 2-2. Shared Parking Analysis Methodology

2.3 The Cost of Parking

Before discussing the analysis of options for meeting parking needs, it is helpful to place the cost of parking in context. From a financial respect, parking is a land use of extremes: the vast majority of parking in the United States is provided free to the parker and is considered little more than a necessary evil. However, where parking is market-priced to the user, it can be an amazingly profitable enterprise. It is a little known fact that parking at airports is the first or second largest generator of net income supporting the airport operations. And commercial parking operations in the core areas of our major cities are so profitable that mergers and acquisitions, IPOs, and due diligence became the buzz words of the commercial parking industry in the 1990s.

The cost of parking has become an issue as the efficiency of transportation and control of urban sprawl has become a priority. Many of those concerned with encouraging alternative modes argue that the user should be charged the actual cost to own and operate a parking space in order to make a fair comparison between mode choices. In other cases, institutions and communities have faced substantial "sticker shock" when faced with tough decisions regarding building structured parking.

The cost of parking facilities has two distinct components: the capital cost (or cost to own, which includes construction and financing) and the operational cost. Discussion of construction and operational costs herein is provided primarily for comparison of options and understanding the order of magnitude of parking costs. The dollar values should be considered no more than a "snapshot in time."

2.3.1 Capital Cost

The *construction cost* is the total amount paid to the contractor(s) for building a parking facility. The *project cost* adds so-called soft costs, beginning with the design fee and reimbursable expenses, the cost of surveys, geotechnical testing etc.; and materials testing during construction. Additional services not covered by the standard design contract, such as full-time on-site representation, feasibility studies etc., are also added. The cost of land acquisition, demolition and site preparation are also considered part of project costs. Finally, financing costs are added. Table 2-3 provides a format for understanding all of the components that normally go into the estimate of project cost for a parking structure.

During the planning stage, the project budget will include an *estimated construction cost* that represents an estimate of what a contractor would bid for the project based on the contract drawings plus *design contingencies* (for issues not yet addressed in the design) and the *field contingency* for unforeseen site conditions and changes to the design during construction.

The design contingency is generally carried as 15% of the estimated cost at completion of the Schematic Phase, 10% at the end of Design Development and 5% at the end of preparation of Construction Documents to allow for market conditions at the time of bid. A 5% field contingency is also recommended. Traditionally, once the project was bid and awarded, correction of minor errors and omissions in the design drawings was paid out of the field contingency. A federal study[13] of design-caused changes concluded that the Owner should anticipate and carry at least a 2% contingency for deficiencies in designs produced in accordance with customary architectural/engineering practices. The report notes that almost every design is unique and that it would be "prohibitively expensive and time consuming" to require the design team to produce "perfect" plans and specifications. This is not to say that the Owner should not seek a designer with a superior track record in the quality area, which today is usually measured by monitoring design-caused change orders. The remainder of the field contingency is for owner–requested changes/clarifications, and unforeseen field conditions.

Table 2-3. Project Cost Estimate

Land Cost		**Construction Cost**	
Acquisition	$	General Conditions	$
Closing Costs	$	Site Work	$
Special Assessments	$	Concrete	$
Demolition	$	Precast Concrete	$
Off-Site Improvements	$	Masonry	$
Environmental Remediation	$	Moisture Protection	$
Subtotal	$	Enclosed Spaces	$
Design Cost		Finishes	$
Prime Design Contract	$	Specialities	$
Specialty Consultants	$	Equipment	$
Zoning	$	Elevators	$
Code	$	Mechanical	$
Landscaping	$	Electrical	$
Interior Design	$	**Subtotal**	$
Elevator/Escalator	$	**Contingencies** [a]	
Traffic	$	Schematic 5%	
Security	$	Design Development 5%	
Graphics	$	Bid Contingency 5%	
Surveys	$	Construction Contingency	
Geotechnical Investigation	$	Owner Changes 2%	
Environmental Assessment	$	Design Changes 2%	
Field Representative	$	Other 1%	
Testing Services	$	**Subtotal**	$
Subtotal	$	**Total Construction Budget**	$
Development Cost		**Other Owner Cost**	
Parking Studies	$	Owner's Agent/Rep	$
Legal	$	Construction Manager	$
Financial	$	Fixtures and Equipment	$
Administrative	$	**Subtotal**	$
Insurance	$	**SUMMARY**	
Development Consultants	$	**Land Cost**	$
Pre-Development Fees	$	**Design Cost**	$
Historic Preservation	$	**Development Cost**	$
Utilities, Taxes	$	**Construction Budget**	$
Relocation	$	**Other Owner Costs**	$
Subtotal	$	**TOTAL PROJECT COST**	$

[a] As phases are complete, that portion of the contingency budget is deleted from the estimate.

Table 2-4 further delineates the components that go into a construction cost estimate for a parking structure project. Those less familiar with parking structure construction often miss important elements of the construction budgets.

Table 2-4. Construction Cost Estimate Breakdown

01000	**General Conditions**	$	**07000**	**Moisture Protection**	
00100	Bond	$	07570	Sealers	$
00110	Insurance	$	07910	Expansion Joints	$
00120	Building Permit	$	07920	Caulk and Sealers	$
00130	Mob/Overhead/Sup	$	07930	Traffic Topping	$
02000	Gen Contr Fee	$		**Subtotal**	$
	Subtotal	$	**08000**	**Enclosed Spaces**	
02000	**Site Work**		08100	Stairs	$
02060	Demolition	$	08110	Tower-Stair/Elevator	$
20110	Site cleaning	$	08300	Rolling Grilles	$
02200	Exc. – Common	$	08400	Offices	$
02250	Fill – Granular	$	08500	Storage Rooms	$
02260	Shoring	$	08600	Mech/Elec Rooms	$
02300	Foundations	$	08700	Retail Areas	$
02511	Asphalt paving	$		**Subtotal**	$
02521	Curb	$	**09000**	**Finishes**	
02522	Concrete Driveways/ Roads	$	09920	Floor Striping	$
02523	Walks	$	09950	Paint/Stain Bms & Clg	$
02700	Storm Water Retention	$		Sack & Paint Arch Concrete	$
02810	Irrigation	$	09990	Misc. Painting	$
02831	Fencing	$		**Subtotal**	$
02900	Landscaping	$	10000	**Specialties**	
	Subtotal	$	10440	Signs	$
03000	**Concrete**		10500	Louvers/Sound Walls	$
03301	Slab-on-Grade	$		**Subtotal**	$
03303	Retaining Walls	$	**11000**	**Equipment**	
03304	Bumper Walls, Ext	$	11150	PARCS	$
03304	Bumper Walls, Int	$		**Subtotal**	$
03305	Curbs	$	**14000**	**Elevators**	
03306	Pour Strips & Washes	$	14200	Elevators	$
03307	Bollards	$		Escalators	$
03370	P/T Beams, Cols, Slab	$		**Subtotal**	
03371	Ramps	$	**15000**	**Mechanical**	
03373	Occ Space P/T Slab etc.	$	15200	General Plumbing	$
	Subtotal	$	15300	Standpipes	$
03400	**Precast Concrete**		15300	Sprinklers-Parking	$
03410	Structural Precast	$	15510	Ventilation-Parking	$
03450	Arch'l Precast	$	15520	Occupied Space Plumbing	$
04000	Masonry	$		Occupied Space HVAC	$
04220	Brick	$		**Subtotal**	
04230	Block (Fire Wall)	$	**16000**	**Electrical**	
	Subtotal	$	16100	Electrical System	$
05500	**Metals**		16200	Occupied Space	$
05550	Arch'l Grillage	$		Emergency Generator	$
05521	Piperails	$		Transformer	$
05600	Cables	$	16800	Security System	$
	Subtotal	$		**Subtotal**	$

Construction costs for parking structures vary substantially by locality, primarily due to labor costs and construction practices. The northeast has higher union costs than the southeast; the midwest has higher costs for durability issues than the southwest. California and Florida lead the country in the delivery of parking projects by the design/build delivery system; this has allowed designers to put the "lessons learned" regarding construction efficiency into practice on traditional design/bid projects, resulting in generally lower costs for any project delivery system in those markets.

Market factors also can cause significant variations even within one construction season. Because 60% or more of a parking structure's cost will be in the concrete structural system and associated items such as expansion joints, sealers etc., the capabilities and workload of local cast-in-place and precast concrete contractors will have a substantial impact on the cost of the facility. Timing is everything; if a structure is bid after most of the contractors have booked work for the season, the bids will escalate.

The construction cost is usually stated in cost per sq. ft. (sq. m.), and cost per space for comparison with industry norms and other projects. Cost per sq. ft. gives an idea of the basic elements and amenities incorporated into the design—for want of a better term, the quality of the finished building. The cost per space reflects both the *efficiency* (sq. ft. or sq. m. of parking area per space) of the parking design and the cost per sq. ft. In two different projects, the same level of architectural, durability and engineering systems can be provided resulting in a cost of say $30/sq. ft. ($322.9/sq. m.) for both. However, if one achieves an efficiency of 300 sq. ft./space (27.9 sq. m. per space) and the other 350 sq. ft./space (32.5 sq. m. per space) the more efficient design will cost $9,000/space, or 14% less, than the $10,500/space cost of the less efficient design.

The efficiency of parking designs varies widely and therefore is a major factor in the cost per space. Note that any mixed-use area (for example retail at grade) should not be included in the efficiency calculation to avoid distorting the comparison. A typical structure with circulation through the parking areas can achieve efficiencies of 270 to 350 sq. ft./space, (25 to 28 sq. m. /space.) Efficiencies below 300 sq. ft./space were almost never seen prior to the downsizing of the automobile in the 1970's and the subsequent development of compact-only stalls. Given that the latter are now in disfavor in many locales, efficiencies of 300 to 325 sq. ft. /space (28 to 30 sq. m. /space) are the goal of most designs at the turn of the millennium. Efficiencies of over 330 sq. ft./ space (31 sq. m. /space) usually reflect a site constraint requiring short rows or single-loaded aisles and should be avoided if at all possible. Short-span garages (with columns between parking spaces rather than between bays) will have efficiencies over 350 sq. m. /space (28 sq. m. /space), but may be dictated by mixed use above. Facilities with special requirements for express ramps and loss of parking areas to toll plazas or other parking-related functions will also have efficiencies of 330 to 375 sq. ft./space (31 to 35 sq. m. /space.) Table 2-5 compares efficiency and cost per unit area to cost per space.

Surface lot parking is obviously the least expensive to construct; in year 2000 dollars, the range is $5 to $10/sq. ft. (approximately $50 to $100/sq. m.) depending on requirements for drainage, lighting and landscaping. With 300 to 350 sq. ft. per space, the cost per space can run from $1,500/space to $3,500/space.

With efficiencies in the 300 to 350 sq. ft. range, the cost per space can vary from $6,000 per space in an extremely economical facility to as much as $14,000 in one with a very high level of service, amenities and architectural treatments.

These figures will not cover the cost of incorporating occupied and/or leasable space into a parking facility. In many urban environments, providing retail space at grade is a highly desirable means of enlivening and maintaining a pedestrian-friendly sidewalk at the street level. Further, the income from leasable space typically will throw off net income to support the parking development.

Underground parking costs vary widely; the number of floors below grade and the soil conditions affect the cost dramatically. Underground parking costs increase significantly for each level deeper into the ground. A common rule of thumb is that the first level fully underground costs 1.5 times the above grade costs, and with the multiplier doubling for each additional level below. Therefore, the second level below grade may cost 3.0 times, the third 4.5 times, etc. Of course, you average the cost of each floor back with the levels closer to grade. So, while an above grade structure with 333 sq. ft. per space efficiency and a generous budget of $33/sq. ft. would cost $10,000/space, one with one level below grade and the same efficiency may cost $15,000 and one with two levels below grade might cost ($15,000 + $30,000)/2 or $22,500/space.

Those multipliers do not include any plaza areas at street level, which are often a part of underground parking projects. As landscaped plaza levels are typically twice as expensive to build as a parking floor, a one level structure below grade with a plaza level could cost as much as ($15,000 for one below grade level + $20,000 for a plaza at grade)/1 = $35,000/space. However, in this case, as more levels below grade are added, the plaza cost is spread over more spaces; the two parking level example would cost ($15,000 + $30,000 + $20,000)/2 parking levels = $32,500/space.

In most cases, the owner would not expect the parking users to pay for the cost of the plaza, but it is necessary to understand what it does to the cost per space, because all too often someone will divide the total construction

Table 2-5. Construction Cost per Parking Space

	Sq. Ft./Space	250	275	300	325	350	375	400
	Sq. M./Space	23.2	25.09	27.9	30.2	32.5	34.8	37.2
Cost/Sq. Ft.	Cost/Sq. M.							
Surface Lot								
$5.00	$55	$1,250	$1,375	$1,500	$1,625	$1,750	$1,875	$2,000
$7.50	$82	$1,875	$2,063	$2,250	$2,438	$2,625	$2,813	$3,000
$10.00	$110	$2,500	$2,750	$3,000	$3,250	$3,500	$3,750	$4,000
Above Grade Structures								
$20.00	$219	$5,000	$5,500	$6,000	$6,500	$7,000	$7,500	$8,000
$22.50	$247	$5,625	$6,188	$6,750	$7,313	$7,875	$8,438	$9,000
$25.00	$274	$6,250	$6,875	$7,500	$8,125	$8,750	$9,375	$10,000
$27.50	$301	$6,875	$7,563	$8,250	$8,938	$9,625	$10,313	$11,000
$30.00	$329	$7,500	$8,250	$9,000	$9,750	$10,500	$11,250	$12,000
$32.50	$356	$8,125	$8,938	$9,750	$10,563	$11,375	$12,188	$13,000
$35.00	$383	$8,750	$9,625	$10,500	$11,375	$12,250	$13,125	$14,000
$40.00	$438	$10,000	$11,000	$12,000	$13,000	$14,000	$15,000	$16,000
Below Grade Structures								
$50.00	$548	$12,500	$13,750	$15,000	$16,250	$17,500	$18,750	$20,000
$60.00	$658	$15,000	$16,500	$18,000	$19,500	$21,000	$22,500	$24,000
$70.00	$767	$17,500	$19,250	$21,000	$22,750	$24,500	$26,250	$28,000
$80.00	$877	$20,000	$22,000	$24,000	$26,000	$28,000	$30,000	$32,000
$90.00	$986	$22,500	$24,750	$27,000	$29,250	$31,500	$33,750	$36,000
$100	$1,096	$25,000	$27,500	$30,000	$32,500	$35,000	$37,500	$40,000

cost by the number of spaces and wonder why in the world you were willing to pay over $30,000 per parking space.

The costs mentioned above also do not include "beefing" up the structural system and/or other provisions for construction buildings above parking, the other common reason for building underground parking. Further, when parking is provided under a building, it typically is built "short-span," which greatly affects the efficiency and only marginally reduces the construction cost (10% or so.) For example, if the two level underground structure above costs $22,500 per space with an efficiency of 333 sq. ft. per space, or $67.57/ sq. ft., putting a building on top may result in an efficiency of 433 sq. ft. per space with a cost of say $60/sq. ft. or $25,980 per space.

Exclusive of land and financing costs, the project cost will typically be 10 to 15% over the construction cost at the completion of the project. Land costs can dramatically affect the capital cost of parking. As seen in Figure 2-3, assumptions have been made for the cost per space for facilities ranging from surface lots to six level structures.

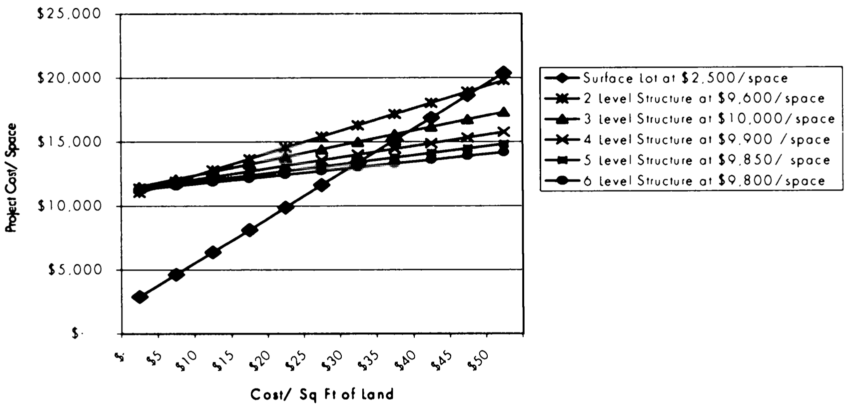

Figure 2-3. Land Cost Impact on Project Cost

A 15% factor for project costs (on both construction and land cost) is included. There is a convergence of all options at a land cost of $30/sq. ft. wherein virtually all the options have the same overall project cost per space of about $12,000. Below this land cost, surface parking is the most cost-effective and there is some cost benefit in going "out" on a couple levels rather than "up" to four or more levels. Above land costs of $30 /sq. ft., higher structures are more feasible, and the cost of multi-story structures converge so there is not much difference according to number of levels.

Financing costs include the cost of obtaining the financing; where reasonably conventional financing is to be obtained, the cost of financing would typically be added into the amount borrowed and is another 10 to 15% of the project cost. For early project planning, a reasonable assumption is that a total project cost, including a 25% factor for all soft costs, will be financed over 20 years for the structures and land acquisition, but over 10 years for the lots. Parking facilities are rarely financed for longer terms because they typically begin to require significant restoration and/or refurbishing at that age.

2.3.2 Operating Costs

To determine operating expenses for parking facilities, one must first define what is included. The following categories are included in operating expenses:

- Labor Costs (wages and benefits)
- Management Fees/Costs
- Security Costs
- Utilities
- Insurance
- Supplies
- Routine Maintenance
- Structural Maintenance
- Snow Removal
- Elevator/Parking Equipment Maintenance
- Other Expenses

Taxes, whether sales, property, parking, or some other type, are not included here due to the wide range of taxes among facilities. A municipally-owned structure for instance, would likely pay no property tax, while a privately-owned structure could have a substantial property tax bill.

Pittsburgh, Pennsylvania, has a substantial parking tax (at this writing it is in excess of 20%), while other locales may have little or no such tax. Debt service is also not included in these figures, as it is not considered an operating expense.

The data in Table 2-6 was gathered from a survey sent to operators of parking structures throughout the United States. The numbers reflect data from 150 parking structures.

Table 2-6. Operating Expenses for Parking Structures

	Median Annual Cost per Space
Cashiering Salaries & Benefits	$184.57
Management Costs	$57.69
Security Cost	$90.65
Utilities	$50.00
Insurance	$13.76
Supplies	$6.61
Routine Maintenance	$37.02
Structural Maintenance	$38.07
Snow Removal	$4.07
Elevator/Parking Equipment Maintenance	$6.07
Other Expenses	$75.43
	$564.03

Source: Walker Parking Consultants, 1999 Operating Expense Survey

According to this survey, the overall operating expenses for a typical parking structure were $564 per space annually as of 1999. More than half of the operating costs ($333) are associated with revenue collection and security. The "Basic Operating Expense" for a non-attended facility with no security cost was $231/space/year in 1999 dollars. However, the reported structural maintenance numbers are about half of what we recommend our clients to spend on structural maintenance so as to avoid major future restoration projects. Therefore, the recommended "basic" cost per space would be about $267 per space per year, and the overall median cost should be $600/space/year. The basic cost to operate an unattended surface lot is estimated at $100/space per year (with $20/space per year for snow removal). Including revenue collection and security, the overall cost would be $433/space per year.

Larger structures located in warm climates may have lower costs than this, but smaller structures located in the Snow Belt can expect to spend a greater amount per space, especially if an adequate amount is spent on structural maintenance.

The size and age of a structure make a difference, but clearly, hours of operation and type of use have the greatest impact on the bottom line. A facility with the primary purpose of providing parking for retail/dining/entertainment uses requires more cashiers than a general parking facility serving daytime commerce in a downtown. Security costs can be a huge variable, ranging from $0 to $300/space/year. Utility costs, again due to location and type of lighting, as well as type of structure, also make a significant impact on the total picture. They ranged from less than $25/space to over $260 per space in this survey. Many of the respondents reported little or no cost in one or more areas, presumably because accounting practices do not "charge" the parking system for those expenses.

2.3.3 Total Cost to Own and Operate

Table 2-7 cross-tabulates project cost per space versus annual operating cost per space to show the monthly revenue required per space to break even. First, let's consider the situation where the cost of land is not considered in the cost of the parking facility. This situation may be because the owner long ago purchased the land and considers it "paid for." An unattended structure, with a $10,000 per space construction cost, and $250/space per year in operating expenses, with no land cost consideration will cost the owner $119/space per month. It is also the cost per month that must be charged for employee parking in an unattended facility at an institution. However, if the structure is attended and the annual cost to operate is $600, the annual cost to own and operate is $148/space/month. This cost would compare to a construction cost of $3,000/space, and $100/space per year for unattended surface parking, or $38/space per month. If the lot is attended, the operating costs could shoot up to $400/space per year, increasing the total cost to $63/space/month.

The many institutions charging employees $10/ month or less for surface parking are not even charging enough to recover costs of owning and operating surface parking, resulting in the aforementioned "sticker shock" when trying to figure out how to pay for structured parking that will be costing the institution about $150/month, presuming attended parking.

Including land at $30/sq. ft. under a three level structure or $10/square foot for surface parking, the capital cost per space is increased by at least $3,000 per space, which puts the structure capital cost at $13,000 and the surface lot capital cost at $5,500/space. The annual cost to own the unattended structure has climbed to $150/space/month, while the unattended lot cost has climbed to $62 /space/month. This gives an idea of the cost of "free" parking that is buried in tenant rent at new office buildings and retail centers, in Year 2000 dollars. An attended parking structure with land at this cost would cost $180/space/month to own and operate.

2.4 EVALUATION OF PARKING OPTIONS

An owner faced with evaluating parking options has a daunting task. The many variables that affect construction cost, land cost, and operational costs make a consideration of financial impact an important factor in early in the site selection process.

Table 2-7. Monthly Revenue Required per Space

Project	Annual Operating Cost per Space												
Cost/Space	$50	$100	$150	$200	$250	$300	$400	$500	$600	$700	$800	$900	$1,000
$1,000	$14	$18	$22	$26	$31	$35	$43	$51	$60	$68	$76	$85	$93
$2,000	$24	$28	$32	$36	$40	$45	$53	$61	$70	$78	$86	$95	$103
$3,000	$34	$38	$42	$46	$50	$54	$63	$71	$79	$88	$96	$104	$113
$4,000	$43	$48	$52	$56	$60	$64	$73	$81	$89	$98	$106	$114	$123
$5,000	$53	$57	$62	$66	$70	$74	$82	$91	$99	$107	$116	$124	$132
$6,000	$63	$67	$71	$76	$80	$84	$92	$101	$109	$117	$126	$134	$142
$7,000	$73	$77	$81	$85	$90	$94	$102	$110	$119	$127	$135	$144	$152
$8,000	$83	$87	$91	$95	$99	$104	$112	$120	$129	$137	$145	$154	$162
$9,000	$93	$97	$101	$105	$109	$113	$122	$130	$138	$147	$155	$163	$172
$10,000	$102	$107	$111	$115	$119	$123	$132	$140	$148	$157	$165	$173	$182
$12,500	$127	$131	$135	$140	$144	$148	$156	$165	$173	$181	$190	$198	$206
$15,000	$152	$156	$160	$164	$168	$172	$181	$189	$197	$206	$214	$222	$231
$17,500	$176	$180	$185	$189	$193	$197	$205	$214	$222	$230	$238	$247	$255
$20,000	$201	$205	$209	$213	$217	$222	$230	$238	$247	$255	$263	$272	$280
$22,500	$225	$230	$234	$238	$242	$246	$255	$263	$271	$280	$288	$296	$305
$25,000	$250	$254	$258	$262	$267	$271	$279	$287	$296	$304	$312	$321	$329
$27,500	$275	$279	$283	$287	$291	$295	$304	$312	$320	$329	$337	$345	$354
$30,000	$299	$303	$307	$312	$316	$320	$328	$337	$345	$353	$362	$370	$378

Note: Interest Rate = 7%

An issue that is important in evaluating alternative sites and options for parking expansion at an existing property is the *cost per added space.* When there is existing parking on the site of a proposed structure, those spaces must first be torn up and rebuilt at new construction costs before any new spaces are added.

Another issue that we will introduce here is a comparison of options that add structured parking, but generate more revenue than a surface parking lot or lower cost structure. A final issue is a comparison with remote parking and shuttle bus service. This comparison may be considered by an airport or a university with lots of land being held for future expansion or a hospital facing the sticker shock of building a structure.

Table 2-8 gives a comparison of the capital costs of six alternative parking options to gain 500 spaces at a hospital located on the fringe of a business district. Option F, leasing a remote lot and running a shuttle operation has no capital cost, presuming that the shuttle service is contracted.

Option A – building on a site already owned, but without parking is obviously the most cost-effective from a capital standpoint at $3,750/added space. Option B is to assemble a site by acquiring a full block of older tract housing and develop a 500 space surface lot. Land acquisition and demolition costs $10/sq. ft. ($110/sq. m.) and results in a cost per added space of $7,750 for B1. If the land costs $20/sq. ft. ($274/sq. m.) as in B2, the cost per added space jumps to $11,750, more than building a structure.

Option C is to develop a structure on part of the raw land used for surface parking in option A; the cost per space and the cost per added space are identical at $12,500. Option D is to build a structure on the site of an existing 100-space parking lot. A 600-space, seven level structure would be required to add 500 spaces, at a project cost per added space of $15,000/added space, about $2,500 more per added space than Option C.

Option D is building a seven level structure for 530 spaces. It is assumed that this is on the side of the hospital towards the business district and has a land cost of $30/ sq. ft. In addition, it has 10,000 sq. ft. of leasable retail space at grade. An additional 3 spaces/1,000 sq. ft. or 30 spaces are provided to serve the retail during the daytime, when the hospital requires 500 spaces; however, in the evening and on weekends, significantly more spaces are available to "share" with not only the retail in the facility but the remainder of the area. Option E2 adds 10,000 sq. ft. of retail at grade. The construction cost to provide a "warm, lit white box" to a tenant is assumed to be $100/sq.ft. or $1,000,000. This option has a project cost per added space of nearly $15,150 per space.

Table 2-8. Comparison of Parking Alternatives

		Site A	Site B1	Site B2	Site C	Site D
Footprint (English)		**260' by 615'**	**260' by 615'**	**260' by 615'**	**120' by 250'**	**120' by 250'**
Footprint (metric)		**79 m by 188 m**	**79 m by 188 m**	**79 m by 188 m**	**36.5 m by 76 m**	**36.5 m by 76 m**
Existing Parking Spaces		**None**	**None**	**None**	**None**	**None**
Land Acquisition		**No**	**Yes**	**Yes**	**No**	**No**
Size of Structure		500	500	500	500	600
Number of Floors		Surface	Surface	Surface	6 levels	7 levels
Land Cost/sq. ft.		—	$10	$20	—	—
Construction Cost/Space		$3,000	$3,000	$3,000	$10,000	$10,000
Construction Costs		$1,500,000	$1,500,000	$1,500,000	$5,000,000	$6,000,000
Land Acquisition		—	$1,600,000	$3,200,000	—	—
Other Project Costs	25%	$375,000	$775,000	$1,175,000	$1,250,000	$1,500,000
Total Project Cost		$1,875,000	$3,875,000	$5,875,000	$6,250,000	$7,500,000
Project Cost Per Space		$3,750	$7,750	$11,750	$12,500	$15,000
Project Cost Per Added Space		$3,750	$7,750	$11,750	$12,500	$12,500
Financing Term (years)	8%	10	10	10	20	20
Annual Debt Service		$279,400	$577,500	$875,500	$636,600	$763,900
Annual Capital Cost/Space		$559	$1,155	$1,751	$1,273	$1,273
Annual Operating Cost/Space		$400	$400	$400	$600	$600
Total Annual Cost per Space		$959	$1,555	$2,151	$1,873	$1,873
Required Revenue/Space/Month		$80	$130	$179	$156	$156

An Option E has been included – acquiring a similar sized parcel and Option F, although not shown in the table, assumes leasing underused land at a distance of 1 mile from the hospital at an annual cost of say 10% of its land value of $10/sq. ft. The annual lease would therefore be $1/sq. ft., or $325/parking space. However, if the property has to be improved, its annual cost would be essentially the same as Option B1.

As might be expected, building surface parking on raw land already owned is the most cost-effective, but it is also the least realistic—few owners with parking problems would have this much raw, undeveloped land available! It might be somewhat easier to find a location on an existing campus for the structure in Option C, which is similarly the most cost-effective among the structure alternatives. Building a surface lot on low-cost land within walking distance is also very cost-effective. In addition, it has the advantage of "banking the land" for future expansion of the hospital.

Even with expensive land and the retail, Option E at $15,148/added space is only a little more expensive than Option D's $15,000/ added space, because the latter requires building 20% more spaces to replace those lost on the surface lot. Moreover, Option E will have income from the retail space rental, as well as the additional shared parking on evening and weekends.

An operating cost for each of the scenarios has been estimated for Table 2-8. Note that capturing the evening and weekend revenue from the commercial district increases the operating cost of Option E. Also, the cost of financing each project has been added to Table 2-8. Note that the annualized cost per space is given so that one can begin to understand the revenue that must be generated from each space to pay for it.

While building surface parking on land already owned or purchased at $10/sq. ft. are quite cost effective, a surface lot on land at $20/ sq. ft. is going to cost more to own and operate than a structure built on land already owned.

Option F is to be served by shuttle buses operating on the 8 to 10 minute headway commonly recommended for minimum acceptability to employees. In this case we are assuming operation at this headway from 6 am to 9 am and from 2 pm to 6 pm, or seven hours per day. In between, there are five hours of operation with a van operated "on demand" to take employees who leave during that period back to the parking lot. With a one-mile travel distance to the hospital and back to the lot again, three buses are required during the scheduled bus operation. The annual operating cost of the shuttle service is assumed to be $125,000/bus per year, or $250/space per year. Security at this remote site is more expensive as well, bringing the operating cost of the surface lot to $500/space/year. Including the lease cost of $325/space/yr, the total annual cost is therefore $1,075/space per year, or $90 per space per month. A shuttle operation developed using 500 underused parking spaces within one mile (if one could find it) is then competitive with the construction of a surface lot on land already owned.

However, if the property is unimproved, and the capital costs are per Scheme B2, with \$1155/space/yr instead of \$325, the overall cost to own and operate a shuttle lot would be \$2,230 space/year, or \$186/space/month. Thus, operating a shuttle lot in the short term would cost about the same as building a structure. Overtime, the cost of leasing operating the shuttle would increase, while the capital portion of the costs in sites C and D would remain fixed; therefore, over time, the structure becomes a better option.

2.4.1 Paying for Structured Parking

Combining the construction, financing and operating costs for the options in Section 2-4 gives a picture of the overall annual cost per parking space for this institution. The monthly revenue to break even gives a pretty good idea of what would have to be charged hospital employees if the spaces were largely used by employees. Let's assume, however, that about half of this structure serves patients and visitors, and about half serves employees and medical staff willing to pay for covered, close-in parking in this location. Let us further assume that right now, the parking is all in surface lots offered free to users.

The visitor parking will be moved into the structure and the hourly rate will be a fairly low hourly rate (say \$1/hr) to a maximum of say \$5/day. An employee parking in the structure at daily rates would pay \$100/month to park. This fee is substantially more than the \$10 to \$25/month employee parking charges typically found at hospitals that do charge for parking. The remaining 500 spaces on the campus are operated as employee spaces for \$10/month.

If the structure experiences an average of 80% occupancy between 9 am and 4 pm on weekdays, and 50% occupancy from 4 pm to 8 pm, each space would generate 7 hrs x 0.8 x \$1 + 4 x 0.5 x \$1 = \$7.60 /day. Let's discount that back to \$7.50 to account for the small number of visitors who stay more than 5 hours. With an average of 20 weekdays per month, the revenue for visitor parking on this basis would be \$150/month for the 250 visitor spaces. For employee parking in the new facility, it is assumed that it is priced as premium parking. Those choosing this premium parking are likely to be folks working 9 to 5 on weekdays, rather than the rotating shifts operating 24 hours a day. With monthly parking, one can normally oversell this type of parking 15%; that is, sell 15% more passes than spaces available, due to normal absenteeism. Therefore the income from the monthly parking is \$50 /month x 1.15 = 57.50/month. The overall average revenue per space will be \$103.75/month/space, which we have rounded back down to

$100/space/month. The remaining 500 surface lot spaces generate $10/month, which is used to subsidize the overall parking program. The oversell of those spaces, however, is 200% due to multiple shifts and 7 day a week operation of the hospital. Therefore the revenue per space is $30/space/month. Therefore the total gross revenue used to pay for the development of additional parking is $130/month/space, for options A, B1, B2, and C. Option D, however, has 100 more employees paying $ 50/ month, but 100 fewer paying $10. This adjustment lowers the overall revenue per space to $109 space/month.

Option E however, can capture additional revenue by filling the spaces in the evenings, and charging for parking on weekends. Let's assume that the commercial district near by is a retail/dining/entertainment district, which has enough parking for daytime needs, but needs 200 more parking spaces on evenings and weekends. In addition 30 more spaces are provided to capture revenue from the leased retail space, and revenue would also be captured from about 100 spaces in the structure used by hospital visitors on the weekend days. The additional revenue per day is assumed to be 3 hr x $1 x = $3/day for 20 weekdays per month for 200 spaces, or $12,000/ month. The 30 additional daytime spaces generate $7.50/day, or $4,500. On Saturdays, those same 200 spaces also generate $10/day x 4 Saturdays/month, or another $8,000/month, with half that on Sundays. The hospital visitor revenue on weekends is calculated at 100 x 4 hrs x $1/hr = $400/Saturday, with half that much collected on Sundays. Therefore the net increase in parking revenue is $29,100 per month. In addition, the retail space is leased at a net annual income of $15/sq. ft., after cost of leasing, etc., or $12,500 per month. Overall, the incremental revenue per space per month in the garage is $41,600. Therefore, the average revenue per space in Option E is $178/space/month.

Conversely, to get employees to use the shuttle to the surface lots a reverse psychology is employed. The employees parking in the shuttle lot will park free of charge. However, parking fees for the remaining 500 spaces on the campus will be imposed. The revenue from the on-campus parking is precisely the same as for the options where 500 spaces are added closer to the campus; therefore, the overall gross revenue to pay for the parking system expansion is $100/month. Moreover, in addition to the $90/space monthly operating cost for the shuttle lot, if leased, the existing lots must be controlled, and the operating cost per space of those 500 spaces is $400/space/year or $33/space/month. Therefore the total cost of operation of F1 has increased to $123. The final option, F2, assumes that instead of leasing the shuttle lot, property is purchased and a lot constructed. As previously noted, this increases the annual cost to own and operate to

$186/space/month, and the $33/space/ month to control the on campus lots must also be added.

Table 2-9 compares the revenue and operating expenses for each option in Year 2000 dollars.

Table 2-9. Net Annual Income (Loss) For Parking Alternatives

	Revenue	Capital and Operating Expenses	Net Revenue
Option A	$780,000	$479,400	$300,600
Option B1	$780,000	$777,500	$2,500
Option B2	$780,000	$1,075,500	-$295,500
Option C	$780,000	$936,600	-$156,600
Option D	$784,000	$1,123,900	-$339,900
Option E	$1,279,200	$1,345,700	-$66,500
Option F1	$600,000	$537,500	$62,500
Option F2	$600,000	$1,115,000	-$515,000

The only options that "pay for themselves" based on the above analysis are building a surface lot on land already owned; buying $10/sq ft. land and developing a surface lot; or developing a shuttle program leasing already existing but unused parking within one mile of the hospital. The next best option, surprisingly, is purchasing land to develop a parking structure that can also serve a nearby retail/entertainment district in the evenings and on weekends. That option only loses $66,500 per year. Buying expensive land for a surface lot loses nearly $300,000 a year. The next best structure option is building on underused surface are; it only loses $156,600 per year; however, if you have to build 600 spaces to get a net add of 500, the annual loses are more than doubled to almost $340,000/year. The least desirable option is purchasing distant land and developing a shuttle lot.

However, there is one more issue to be addressed in the decision making process: inflation of revenue and operating expenses as compared to level debt service on a capital investment, that also has a residual value at the end of the financing term. In order to evaluate that aspect, the net present value of the investment must be determined. Table 2-10 presents the net present value, with the following assumptions:

- The discount rate is 10%.
- The operating expenses inflate at 3% per year.
- The revenues inflate at 2% per year

Table 2-10. Net Present Value of Parking Alternatives

	Net Present Value
A Surface Lot on land already owned	$5,226,700
B1 Surface Lot on land purchased for $10/sq. ft.	$4,995,200
B2 Surface Lot on land purchased for $20/sq. ft.	$4,763,800
C Structure on vacant land already owned	$3,947,700
D Structure on existing parking lot	$3,256,900
E Structure with retail at grade	$7,327,200
F1 Shuttle to leased parking lot	$57,800
F2 Shuttle to lot on land purchased for $10/sq.ft.	($390,600)

Because the tendency of institutional owners is not to raise rates as fast as inflation, the parking revenues are assumed to go up at a slower rate of inflation than operating expenses.

Clearly, considering the value returned over time, the best option is to purchase land and develop a structure that has retail at grade and can capture parking in the evenings and on weekends. The surface lot options all follow together in a group as the next most viable alternatives. Building a structure on vacant land already owned then follows, with a structure built on an existing parking lot also a "good" investment. The net present value of the leased shuttle lot is essentially nil, but over a period of 20 years, it will "cost" the hospital roughly $5 million dollars more than the surface lot options. And if the lease is lost and structured parking then has to be built, inflation only increases the capital as well as the operating expenses, further increasing the "sticker shock" down the road. The option of purchasing property to develop a shuttle lot actually has a negative net present value and is certainly not a viable option.

2.5 CONCLUSIONS

Structured parking isn't cheap; at the turn of the millenium, it requires $150-200 per space in revenue per month to recover the capital and operating costs of building an above-grade structure on land already owned. Very few situations allow that cost to be charged to visitors, much less employees or monthly parkers; therefore parking development usually must be subsidized by other funding sources. Conversely, it is not unheard of for commercial and airport parking facilities to generate $500/month per space or more for high-turnover, short-term parking.

Therefore, it behooves those contemplating the development of structured parking to first, not overbuild parking and second, do it right the first time. Building a well-designed parking structure can yield a significant return on an investment in good planning and design; however, poor planning and/or design can leave an owner with unhappy users and a constant drain on resources. This chapter has been dedicated to good planning early in the process; the remainder is devoted to improving the understanding of those issues that maximize the return on investment in superior parking design.

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[3] Salzman, Gerald, "Hotel Parking: How Much is Enough?," *Urban Land* January, 1988 (Washington DC: The Urban Land Institute.)

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[7] Mary Smith, "Zoning Requirements", *Dimensions of Parking* (Washington DC: The Urban Land Institute, 1993.)

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[11] *Transportation Planning Handbook* (Washington DC: The Institute of Transportation Engineers, 1999)

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Chapter 3

FUNCTIONAL DESIGN

Mary S. Smith

3.1 INTRODUCTION

Parking structures have many things in common with buildings, but also have unique differences. An elemental one is that there must be a vehicular circulation system that provides access from one floor to the next. Cars cannot use the elevators and stairs that provide circulation for pedestrians. The circulation system can be quite complex and difficult to understand for a lay person looking at drawings. Just because it is complex does not mean that it will be confusing to the parker; on the other hand, some systems are confusing to the unfamiliar user. It is important, therefore, that the owner have a basic understanding of the issues in order to intelligently review and approve designs. An owner will have to live with the functional system on a day-to-day basis, and will quickly find out if the functional design is not successful.

Many factors affect the selection of the best functional design for a particular parking facility:

type(s) of users	dimensions of site
pedestrian needs	parking geometrics
wayfinding	peak-hour volumes
floor-to-floor height	flow capacity

This chapter provides guidelines for the functional design. If these guidelines are followed, the most frequent pitfalls can be avoided. It should be noted, however, that the guidelines do not cover all the minute details

A. P. Chrest et al., *Parking Structures*

that must be considered in the preparation of documents for construction. Only experience can teach all the little tricks that maximize user acceptance while minimizing cost.

3.2 THE LEVEL-OF-SERVICE APPROACH

Over the years parking designers have developed quite a number of "rules of thumb" for elements of functional design. These rules prescribe, for example, the maximum number of turns or spaces passed in the path of travel.[1] Professional judgement is still required to apply the rules to a specific situation; some rules are more important than others with some types of users. For example, it is desirable to route unfamiliar users past as many spaces as possible in a small to moderate-size facility. However, if most users park in the facility every day, it is desirable to get them in and out as fast as possible, which usually means minimizing the number of spaces passed. Thus, no one set of design standards is suitable for all situations.

Traffic engineers have similar problems in designing streets and intersections; the degree of congestion that is acceptable to users and the community varies substantially. To overcome this problem, traffic engineers developed a system of classifying conditions by levels of service (LOS). For traffic at signalized intersections, conditions of virtually free flow and no delays are LOS A, the highest level of service. As congestion increases, the level of service decreases. The lowest LOS, F, is popularly (or unpopularly to those caught in it) called "gridlock." LOS E is the maximum flow of cars that can be accommodated before conditions begin to jam. The LOS system is used to reflect the acceptability of a parameter to the users or a community. Most roadways that are new or are being improved are designed to attain an LOS of C or better in the peak hours in suburban settings. Commuters in our major urban centers tolerate LOS D, and efforts to mitigate the conditions would not be initiated unless the LOS drops to E or even F. In a small town, however, a street condition of LOS B may generate an outcry for traffic improvements.

Therefore, issues related specifically to the user can be addressed by selecting a level of service appropriate to the circumstance. Table 3-1 relates level of service criteria to the needs/concerns of users.

Table 3-1. Level of Service Criteria

Design Consideration	Chief Factor	Acceptable Level of Service D	C	B	A
Turning radii, ramp slopes, etc.	Freedom to maneuver	Employee			Visitor
Travel distance, number of turns, etc.		Visitor			Employee
Geometrics	Freedom to maneuver	Employee			Visitor
Flow capacity	*v/c* Ratio	Employee			Visitor
Entry/exits	Average wait	Visitor			Employee

A major factor in selecting LOS is the familiarity of the user. The turnover rate in a facility also plays a role. When arriving and departing vehicle activity is sustained at high levels throughout most of the day, a better level of service should be provided than if there is one rush period of a half-hour in the morning and another short one in the evening. If employees represent the end of the scale with high familiarity/low turnover, visitors usually represent the converse situation of low familiarity/high turnover. There are, of course, exceptions; the multi-day parker at the airport can be unfamiliar with the system. Finally, the more urban and congested the setting of the facility, the more tolerant users are of lower levels of service. LOS D is generally only used in the core areas of the largest cities (New York, Los Angeles, Chicago, and San Francisco) where land values and parking fees are at a premium level.

As seen in Table 3-1, most criteria dictate a higher level of service for visitors than for employees. However, certain criteria, generally those concerned with travel time and average wait, can result in reversal — i.e., providing a higher level of service for employees than visitors.

There also may be competing objectives that require compromising one criterion for the sake of another. For example, increasing the floor-to-floor height improves LOS, but may increase the ramp slopes, which would lower the LOS of that criterion.

In many cases the specific type of user plays a major role, even within the same land use type. Is the user a family going to a theme park (loaded down with strollers and diaper bags) or a group of adult friends going to a football game? Is it an elderly couple meeting the family at the airport or is it a business traveller?

Are there choices/alternatives for the user? Is the user a shopper who has a number of choices or a visitor who comes to the site for a reason that will not be heavily influenced by parking convenience, such as to visit a specific doctor? Is it the only parking choice for the person, such as in the suburban office building, or is there a variety of parking options at various prices and walking distances such as in a central business district?

How long is the person going to stay — a few minutes, a few days? How often does the user park in the facility? Will the person park there every day or once a year? Is it a "stressful" situation such as hurrying to the airport or going to the hospital versus a more routine commute or shopping trip?

What are the users' expectations? Is the location suburban or urban? Is it the lot in front of a convenience center or an overflow lot used at the regional shopping center only at Christmas season? Is it a suburban office park where convenience is part of the marketing of the building to tenants or a special event facility where congestion and long walking distances are anticipated? Is it a corporate headquarters where the image of the corporation is an issue, or a "spec" office building?

In each of the above paired questions, a better level of service should be afforded to the former than the latter type of user.

It is also critically important to understand that a system could be quite consciously designed with LOS A for most parameters, but with LOS D for one or more components. For example, airport parking structures are typically designed to LOS A, except for queuing at the toll plaza, which might fall to LOS C or even D on busy days. This difference generally relates to the fact that activity at the toll plaza is highly variable. It simply is not feasible to staff enough booths to keep queuing to LOS A at peak periods because the booths would be grossly under-used the rest of the shift. Also airport users, even frequent travellers, tolerate (if not expect) some queuing in peak hours. Another example might be an urban parking structure. While users expect more congestion and a lower level of service than they would in a suburban setting, security considerations might dictate that certain parameters be designed to LOS A, even though others are designed to LOS D.

The same parameters might also be designed to different levels of service at different points within the system. For example, we consider that the parking used on average or typical days at shopping centers should be designed for LOS A. For busy Saturdays, LOS B should be maintained, and the parking that is only used for a few hours on the busiest days of the year might be designed for LOS C.

The level-of-service approach is applicable to a number of design considerations in parking facilities, including entry/exits, geometrics, flow capacity, travel distance and spaces passed, turning radii, and floor slopes. The old rules of thumb have thus been transformed into levels of service for these areas, as will be discussed later in this chapter on functional design and in the next on access design.

3.3 CIRCULATION SYSTEMS

3.3.1 The Building Blocks

Four very basic building blocks are used in any parking facility design: "level" parking bays, "level" drive aisles without parking, "sloped" parking bays, and "sloped" drive aisles without parking. (See the Glossary for definitions of level and sloped floors in parking connotations.) Sloped drive aisles without parking are also called ramps. There are three ramp subtypes: circular or express helixes, express ramps, and speed ramps (Figure 3-1). Speed ramps are defined as short ramps that connect floor areas at elevations less than a full story apart. For example, speed ramps connect the two "trays" of a split-level structure, or make up slope differentials for a site that is too short to allow a sloped parking floor to achieve the necessary rise in elevation.

Almost all functional systems are composed of the four basic building blocks assembled in one of two forms of a helix for circulation through the facility (Figure 3-2).

The basic forms of the helix are the single-threaded helix, which rises one tier (usually 10 to 12 ft.) with every 360 degrees of revolution, and the double-threaded helix that rises two tiers with every 360 degrees of revolution. The reason the latter is called a double-threaded helix is that because, by rising two tiers per revolution, two "threads" may be intertwined on the same footprint. A double-threaded helix thus allows a vehicle to circulate from the bottom to the top (or the top to the bottom) of a facility with roughly half the number of turns and driving distance. Express helixes can be either single or double threaded, as can parking bays.

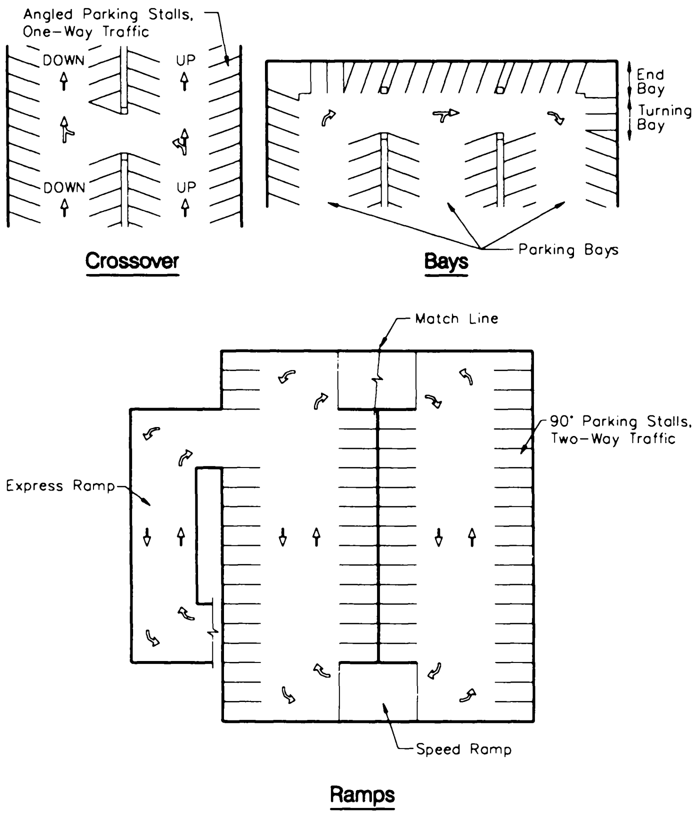


Figure 3-1. Some basic parking terms

There is also a triple-threaded helix, but it is seldom used. The triple-threaded helix rises three levels with each 360 degrees of revolution and has three threads intertwined.

3.3.2 Wayfinding and Pedestrian Concerns

Wayfinding is the ability to understand where you are and where you want to go in a building and then to find the path of travel to get there. Later, you must find your way back to the exit. Wayfinding design involves the total planning of the functional design to enhance this ability. It is much more than signage or graphics.

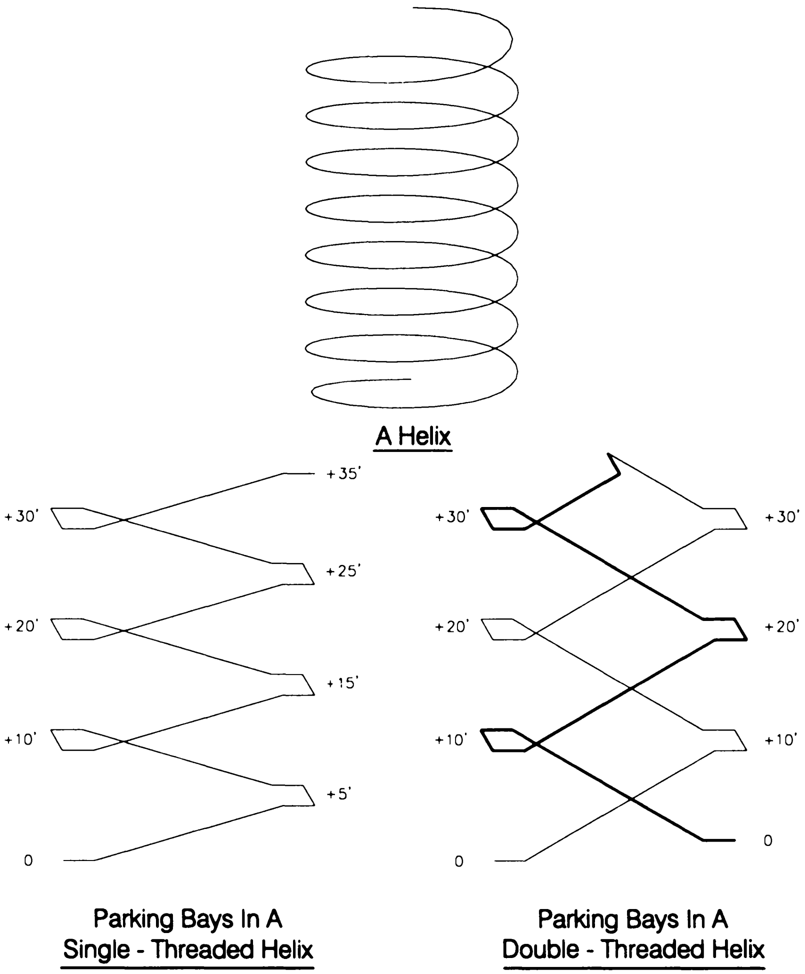


Figure 3-2. Helixes are used to provide floor-to-floor circulation in parking facilities

In fact, if signage is critical to wayfinding, a parking facility, in particular, is in trouble. When Jerry Seinfeld devotes an entire episode of his television show to getting lost in a parking structure, it is clear that wayfinding in parking facilities is a universal concern to users and owners alike. A key goal of wayfinding should be that the people know where they are and where they want to go with a minimum of signs. Therefore, wayfinding is discussed in this chapter on functional design rather than in Chapter 10, Signage.

Although wayfinding is a relatively new buzzword in the design industry, the individual concepts or components have long been known. Indeed, many are simply common sense. Wayfinding design provides a framework to draw all of these individual considerations into a cohesive, single focus. It also reflects the much higher emphasis today on designing for the specific needs of the users.

Table 3-2 provides guidance for level of service of parameters that affect wayfinding and pedestrian considerations. With the increasing global sales of this text, recommendations have also been developed for European and Asian parking conditions. The design vehicle (as will be further discussed in the section on parking geometrics) is significantly smaller almost everywhere else in the world than in North America. Further, the difficulty and cost of developing parking is significantly higher than in the US, and government policy is typically to discourage parking.

Therefore, parkers in facilities in Europe and Asia are frequently simply happy to find a space and typically accept tighter dimensions than parkers in North America. Therefore, the recommended level of service criteria for European and Asian parking in Tables 3-2 are not simply a conversion to metric dimensions, but reflect both a smaller vehicle and generally tighter dimensions.

Obviously, wayfinding is not a major concern for a use that predominantly generates regular users. For example, more than 90% of the parking spaces at office uses (excluding medical and certain consumer service offices) are used by employees of the tenant(s.) It is generally not necessary to place a high priority on wayfinding, especially if a convenient parking area is reserved for visitors. However, many of the features that enhance wayfinding also enhance passive security, and thus some of the same design features might be a priority for parking facilities where wayfinding is not a high priority.

In parking facility design, wayfinding is necessary for both drivers and pedestrians. The following discussion will follow the progress of the typical user through the parking facility. First, the driver must find and recognize the building as a parking facility. While it is appropriate to make the parking facility's architecture compatible with that in the area, hiding or camouflaging the structure should not be the goal. The well-known architect Stanley Tigerman took the opposite tack and designed the facade of a parking structure in downtown Chicago to look like the front grille of a car! Whimsy aside, the most important thing is to make sure the vehicle entrance is clearly identifiable to a driver who may be dealing with many visual distractions. Canopies or portals are often valuable in this effort.

Table 3-2. **Recommended Parameters for Wayfinding**

Design Standards For:	United States (English Units)				Europe and Asia (Metric Units)			
	LOS D	LOS C	LOS B	LOS A	LOS D	LOS C	LOS B	LOS A
Maximum walking distance								
Within parking facilities								
Surface lot	1400'	1050'	700'	350'	500m	375m	250m	125m
Structure	1200'	900'	600'	300'	400m	300m	200m	100m
From parking to destination								
Climate controlled	5200'	3800'	2400'	1000'	1400m	1050m	700m	350m
Outdoors, covered	2000'	1500'	1000'	500'	700m	525m	350m	175m
Outdoors, uncovered	1600'	1200'	800'	400'	600m	450m	300m	150m
Clear height[1]								
Beam/slab construction[2,3]	7'0"	7'8"	8'4"	9'0"	2.2m	2.4m	2.6m	2.8m
Other construction types[4]	7'8"	8'4"	9'0"	9'8"	2.4m	2.6m	2.8m	3.0m
% spaces on flat floor	0%	30%	60%	90%	0%	30%	60%	90%
Maximum distance to open side[5]	250'	200'	150'	100'	75m	60m	45m	30m
Light court/yard width:height ratio	1:4	1:3	1:2	1:1	1:4	1:3	1:2	1"
Parking ramp slope	6.5%	6%	5.5%	5%	6.5%	6%	5.5%	5%

[1] Minimum straight vertical clearance to any construction (signs, lights, piping, structural elements, etc.) Structures will typically be signed with 2" to 4" less vehicular clearance. Van accessible spaces under ADA require 8'2" minimum vertical clearance.

[2] Minimum 15' between beams in any direction.

[3] LOS D clearance for P/T design set by minimum 7'0" overhead as required by all codes.

[4] Precast tees, waffle slab, flat slab, etc.

[5] From any point on the floor to an opening on a side qualifying as open under the prevailing building code.

Upon turning into the facility, the parker must find the entrance area to be welcoming and well-lighted. The parking control equipment, if any, should be placed to allow the patron to recognize its presence. Where exit or restricted lanes are provided in the same area as the visitor entrance lanes, the driver must have adequate sight distance to determine which lane to enter.

It is often desirable to give the driver no choices immediately after entering. Driving the length of the structure before any further decisions are required will often help the driver become acclimated to the facility.

A primary element of wayfinding design is to provide visual cues. A simple, easily understood traffic pattern that is repeated on every floor greatly eases wayfinding. It is desirable to route unfamiliar drivers past visual anchors such as the main stair/elevator tower shortly after reaching each floor. This routing begins to orient the parker for the pedestrian mode. Certainly, turning traffic away from the tower and requiring a circuitous route back to it should be avoided. In larger facilities, light wells and other architectural features may also serve as visual anchors.

The minimum width of light wells that are also courts or yards separating buildings for the purposes of required fire separations and/or natural light and ventilation, are prescribed by building codes, as discussed in Chapter 5. However, the width of a light well also helps to define the sense of space therein, particularly where it is serving as a pedestrian collector. At the same time, excessive width does little to add to the pedestrian experience. An architectural rule of thumb for such spaces is that the width should equal the height. See Figure 3-3.

Visibility across the parking floor to the destination is another key to wayfinding. Why is it that shoppers will accept relatively long walking distances at the suburban shopping center, but complain about parking around the corner downtown? Because the shopper can see the shopping center entrance from the moment he or she leaves the car. While one might think that this phenomenon primarily affects pedestrian wayfinding, visibility while driving is equally beneficial.

Both security and wayfinding have caused a shift away from complicated sloping parking floor designs to ones that maximize the number of spaces on flat floors. In parallel, there has been a shift toward maximizing the slope of parking ramps. Where the site is long, the tendency is to keep the sloping portion to a minimum, with the remainder flat, instead of using a longer, gentler slope.

Other issues affecting visibility are the floor-to-floor height and structural system. It is generally recognized that a cast-in-place post-tensioned (CIP P-T) parking structure has a higher perceived ceiling height than other systems. This structural configuration also enhances other functional/wayfinding issues:

Figure 3-3. A light well that is also serving as a pedestrian collector requires a clear width appropriate to its height.

signage is more visible; lighting more uniform. CIP P-T construction also tends to result in more openness along bumper walls both at interior sloping ramps and exterior walls. When precast concrete is the preferred structural system, the same level of service can be achieved by increasing the floor-to-floor height (see Section 3.3.3 for further discussion of floor-to-floor heights). Because signing and lighting flat slab, waffle, and other conventionally reinforced structural systems is even more difficult, floor-to-floor heights must be carefully considered with those systems. For this reason, the level of service herein is based on the clear height, but different recommendations are provided for systems having large soffit areas that increase the perception of ceiling height as compared to those with either a flat slab or more closely spaced structural elements.

Once the driver has found a space and parked the car, pedestrian considerations come into play. The first issue is helping the parker remember where the car is parked. Here signage **is** critical, and it is explored in Chapter 10. Wayfinding for the pedestrian is greatly enhanced by visibility across the parking floor, as previously discussed. Acceptable walking distances and visibility are closely related. Fruin[2] stated:

> There are indications that the tolerable limit of human walking distance is more situation-related than energy related. ... The tolerable walking distance for a given design situation is related to such factors as the trip purpose of the individual, the available time and the walking environment.

We would expand Fruin's list of variables affecting acceptable walking distance to include: the type of users, frequency of occurrence or use, the familiarity of the user with the facility, expectations/concerns of the user (including security), line of sight to destination, the degree of weather protection along the path of travel, the perception or absence of barriers or conflicts along the path of travel, and cost of alternatives to walking, if any. Many of these elements are directly associated with wayfinding.

Table 3-2 presents guidelines for acceptable walking distances. For further information on the development and application of these guidelines, see Smith and Butcher, 1994.[3]

The walking path of travel is also a consideration. It is generally desirable to orient parking aisles toward the pedestrian destination. In a free-standing parking facility, that destination will usually be the main stair/elevator tower. When bays are oriented transverse to this path, pedestrians will cut through between parked vehicles, which at best is not very user-friendly and at worst can cause security and safety concerns. If necessary or appropriate, it may be desirable to have cross aisles aligned with the stair/elevator tower or, in the case of direct connection to the ultimate destination, the building entrances. However, our experience is that pedestrians will always take the perceived shortest path, including cutting between cars.

Proper location of stair/elevator towers in the overall path of travel to the ultimate destination is also important. Just as the pedestrian wants to see the tower from within the structure, so does the tower serve as a beacon for the pedestrian returning to the parking facility. Circuitous routes to, into, and out of these towers must be avoided.

Once the parker has retraced the route to the parking stall, wayfinding returns to a vehicular mode. The exit route should be equally simple and understandable. Keeping the exit route to the shortest path of travel is often a high priority, as previously mentioned.

3.3.3 LOS Criteria for Vehicular Travel Components

The most fundamental determinants of the appropriate geometrics of any vehicular route are the design vehicle and its turning radius. In addition, appropriate clearances must be maintained to allow for the range of variation in driver faculties and skill. The level of service criteria recommended herein for the design of non-parking roadways and express ramps are based primarily on standards established by the American Association of State Transportation Officials (AASHTO)[4]. The AASHTO design vehicle for passenger cars is not generally adjusted for changing vehicle sizes and has been set at 7 ft by 19 ft for more than thirty years. This vehicle is larger than the vast majority of the vehicles used for personal transportation both in the US and in Europe and Asia. The minimum turning radius of the outside front tire of this vehicle at speeds less than 10 mph is 24 ft. Over time, we have found it appropriate to design most "through" traffic vehicular components, such as express ramps and roadways, to the AASHTO design criteria. However, we use moderated criteria reflecting a more realistic vehicle size for the design of parking geometrics (the dimensions of stalls and aisles to allow comfortable turn of vehicle into and out of the stall.) This philosophy reflects both differences in appropriate speed and in user comfort.

Table 3-3 presents recommended dimensions for non-parking roadways and express ramps. Figure 3-4 delineates the application of some of those dimensions to design conditions. Similarly, Table 3-4 provides parameters for the design of parking areas. Note that the geometrics for parking stalls are presented later in this chapter. Figure 3-5 delineates the application of these parameters to typical design situations.

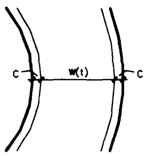
Note that the turning radii employed for non-parking ramps at higher levels of services are greater than those for parking areas. This difference reflects the appropriate speed of the vehicle and the distractions that occur in parking areas due to parking and unparking vehicles.

A very important design consideration for both parking and express ramps is providing transition to avoid breakover effects. It is generally advisable to limit the height of vehicles entering a parking facility to two to four inches less than the actual overhead clearance because the vehicular clearance is impacted by sloping floors. Floor-to-floor heights generally are dependent on the depth of the structural system used (for beams and floor elements) and the desired clearance. The minimum floor-to-floor height in post-tensioned parking facilities is 10'-0", which provides overhead clearances of 7'-0" to 7'-4", depending on the structural depth of the system. A facility with 7'-0" clearance to meet code would then be signed with 6'-8" to 6'-10" vehicular clearance. Some short-span designs

Table 3-3. Recommended Design Parameters for Nonparking Roadways and Express Ramps

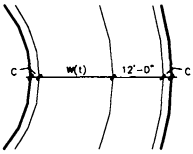
Design Standards For:		United States (English Units)				Europe and Asia (Metric Units)			
		LOS D	LOS C	LOS B	LOS A	LOS D	LOS C	LOS B	LOS A
Lane width straight,	W_s	10'0"	10'6"	11'0"	11'6"	2.7m	2.85m	3m	3.15m
One lane[1]									
Multiple lanes		9'0"	9'6"	10'0"	10'6"	2.5m	2.65m	2.8m	2.95m
Clearance to obstructions[2]	C	0'6	1'0"	1'6"	2'0"	0.15m	0.3m	0.45m	0.6m
Radius, turning (outside front wheel)[3,4]	R_T	24'0"	30'0"	36'0"	42'0"	7.3m	9.1m	10.9m	12.7m
Lane width, turning[5,6]	W_T	13'6"	13'6"	13'6"	13'6"	4.0m	4.0m	4.0m	4.0m
One lane									
Ea add'l lane		12'0"	12'0"	12'0"	12'0"	3.5m	3.5m	3.5m	3.5m
Circular helix outside diameter[7]	D_o								
Single-threaded[8]		60'0"	74'0"	88'0"	102'0"	18m	22m	26m	30m
Double-threaded[9]		80'0"	95'0"	110'0"	125'0"	24m	28m	32m	36m
Express ramp slope		16%	13.33%	10.67%	8%	16%	13.33%	10.67%	8%
Transition length	T	10'0"	11'0"	12'0"	13'0"	3m	3.3m	3.6m	3.9m

[1] Use 15 ft (4.5m) lane to pass breakdown, all LOS.
[2] From edge of lane to wall, column, parked vehicle, or other obstruction, per AASHTO 1990 Figure 111-25.
[3] LOS D per AASHTO 1990 Figure 11-1.
[4] Left turns at radius are LOS ( )+; right turns are LOS ( )–.
[5] LOS D per AASHTO 1990 Figures 111-23, except c is reduced to 2 ft (.6m) per Figure 111-25. See Also Figure 3-6.
[6] Use 20' (6m) lane to pass breakdown, all LOS, per AASHTO 1990 Figure 111-25.
[7] Helix diameter is out-to-out walls (6" (.15m) walls assumed); provide 20 ft (6m) clear between walls to permit passing breakdowns.
[8] Turning radii/lane width increased 3' (1m) due to multiple turns.
[9] Ramp slope, minimum lane width, and clearance to walls control dimensions for double-threaded helix.



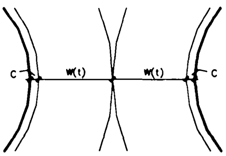
ONE LANE CURVED RAMP

LOS	W(t)	C
A	13.5'	2.0'
B	13.5'	1.5'
C	13.5'	1.0'
D	13.5'	0.5'



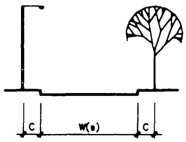
TWO LANE CONCENTRIC

LOS	W(t)	C
A	13.5'	2.0'
B	13.5'	1.5'
C	13.5'	1.0'
D	13.5'	0.5'



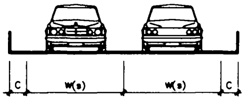
TWO LANE NONCONCENTRIC

LOS	W(t)	C
A	13.5'	2.0'
B	13.5'	1.5'
C	13.5'	1.0'
D	13.5'	0.5'



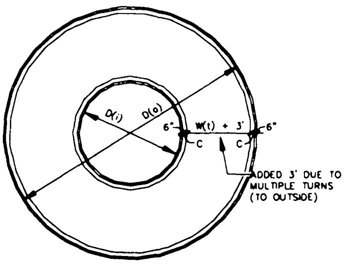
ONE WAY TRAFFIC

LOS	W(s)	C
A	11.5'	2.0'
B	11.0'	1.5'
C	10.5'	1.0'
D	10.0'	0.5'

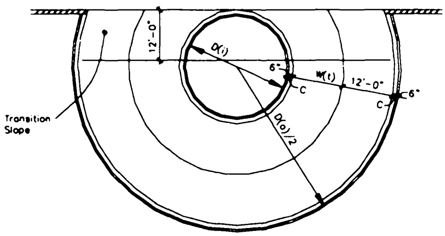


TWO WAY TRAFFIC

LOS	W(s)	C
A	10.5'	2.0'
B	10.0'	1.5'
C	9.5'	1.0'
D	9.0'	0.5'



One Way, Single - Threaded Helix



Two Way, Single - Threaded "Half" Helix

Figure 3-4. Key dimensions for non-parking roadways and ramps

Table 3-4. **Recommended Parameters for Parking Areas**

Design Standards For:		United States (English Units)				Europe and Asia (Metric Units)			
		LOS D	LOS C	LOS B	LOS A	LOS D	LOS C	LOS B	LOS A
Radius, turning (outside front wheel)[1,2]	R_T	24'0"	26'0"	28'0"	30'0"	7.3m	7.9m	8.5m	9.1m
Turning bay, clear between columns[3]	T								
One lane		14'6"	15'9"	17'0"	18'3"	4.25m	4.65m	5.25m	5.65m
Two lanes, concentric[4]		26'6"	28'0"	29'9"	31'0"	7.75m	8.25m	8.75m	9.25m
Two lanes, non-concentric		29'0"	31'6"	34'0"	36'6"	8.5m	9.3m	10.5m	11.3m
360-degree turns to top		7	5.5	4	2.5	7	5.5	4	2.5
Short circuit in long run[5]		400'	350'	300'	250'	150m	125m	100m	75m
Travel distance to crossover[6]		750'	600'	450'	300'	250m	200m	150m	100m
Spaces searched/compartment size[7]									
Angled		1600	1200	800	400	1600	1200	800	400
Perpendicular		1000	750	500	250	1000	750	500	250
PARC lane width		9'0"	9'3"	9'6"	9'9"	2.6m	2.7m	2.8m	2.9m

[1] LOS D per AASHTO 1990 Figure 11-1.

[2] Left turns at radius are LOS ( )+; right turns are LOS ( )–.

[3] Clear between face of columns; add 3 ft (1 m) from face of column to back of first stall per Figure 3-4.

[4] If flow is low turnover and/or predominately one-way, can reduce 3 ft (1 m.)

[5] To shorten exit path of travel.

[6] In one-way designs it is necessary to continue on the inbound path of travel before connection to the outbound path.

[7] Spaces passed on primary search path; or spaces per floor in express ramp design.

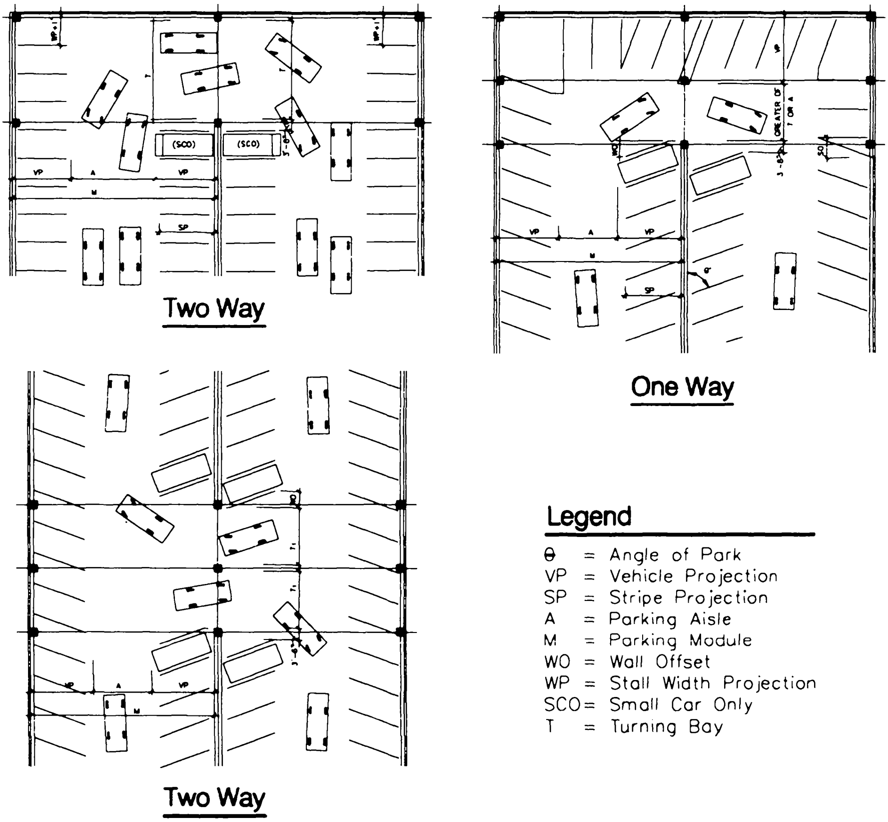


Figure 3-5. Parking area layout parameters

get by with floor-to-floor heights less than 9'-6". Vehicular clearances must also include allowances for light fixtures, signage, and piping. Lights are usually tucked up between beams and/or stems in long-span, prestressed structural systems and thus do not affect clearance considerations. However, it is usually desirable to hang signs below tee stems, as discussed in Chapter 10.

It is a little-known fact that model building codes originally specified a 7'-0" **maximum** overhead clearance for parking facilities because this would keep out motor homes, heavier trucks, and other vehicles that weigh more than the design loads required elsewhere in the code. Committees revising national codes did not realize the connection with design loads and have altered the requirement to 7'-0" **minimum**. However, all standard production vans sold in America are 6'-10" in height or less and can be accommodated in facilities with 7'-0" vehicular clearance. Vans modified with "pop tops" or flashing lights, or sometimes just special antennas, may not be able to traverse a structure with 7'-0" vehicular clearance. The Americans with Disabilities Act requires that 8'-2" vertical clearance be provided for the path of travel to/from van-accessible spaces, which generally requires increasing the floor-to-floor height to 11'-2" to 11'-4". It is only necessary to provide this clearance along the path of travel to and from the required van-accessible stalls. This standard will still exclude paratransit and camper vehicles, which are simply too heavy compared to the design loads employed for parking facilities.

When there is a difference in slope of 10% or more between two sections of floor slab, a transition slope is required to prevent the vehicle from "bottoming out" (Figure 3-6). This condition typically occurs in express ramps. In general, the transition area should have one half the slope of the differential slope. Length of the transition slope is presented in Table 3-3.

Speed ramps are limited to rises of 5 ft. or so, and even then they must be extended somewhat into the aisle because the overall ramp length, including transitions, must be 41.25 ft. to achieve LOS D design (10' x 8%) + (21.25' x 16%) + (10' x 8%) = 5.0'.

Turning bay widths are related to the radius of turn of a vehicle making a "U" turn from one bay to the next. (See Figure 3-5.) The turning bay dimensions shown in Table 3-4 are for the clear width between face of columns. Note that for comfortable turns, the first parking stall in each row must be held back from the face of the column as seen in Figure 3-5. With two-way traffic flow, the first stall on either side of the turning bay must be held back from the column face; 3'-6" is recommended to provide the same comfort of turn as elsewhere. With one-way traffic flow and angled parking, the natural offset of the back end of the last parked vehicle as one approaches the turn serves to provide an adequate radius for the approach to the turn.

With any significant degree of turnover, a two-way turning bay has to be large enough to allow two vehicles to pass each other. However, where there is low turnover and it is less likely that two vehicles will have to pass each other in the turn, the dimension can be reduced by 3 ft.

Minimizing the number of turns (in terms of 360-degree revolutions) in the path of travel has long been a priority of parking designers. See Figure 3-2. There is a tendency for the driver to become disoriented, almost dizzy,

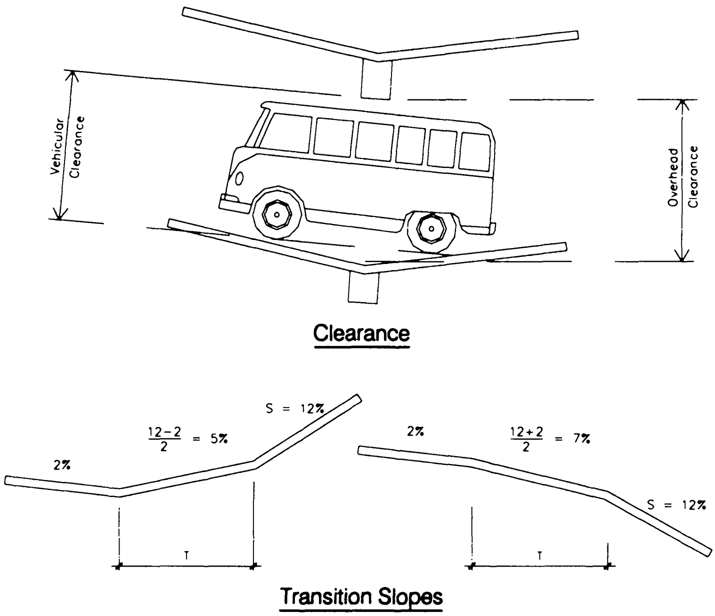


Figure 3-6. Transition slopes are required to avoid break-over problems.

when there are too many turns in the path of travel. It is also important to reduce the number of decision and/or conflict points. While having spaces off the main path of travel helps flow capacity (as will be discussed later in this chapter), it greatly complicates wayfinding for the unfamiliar user. Therefore, it is desirable to select a parking circulation system that naturally leads parkers past all the spaces once and only once.

Conversely, when a driver is in the exit mode, short circuits that reduce the travel distance are equally desirable. There is a point at which the number of spaces that must be searched to find an available one becomes excessive. In a larger facility, it is desirable to break the system into smaller "compartments" with express ramping systems to speed users to a floor with available spaces and return them to the street. The system becomes a series of "parking lots" stacked vertically. The driver then should only have to search a limited area of stalls for a vacant parking space. Another option is to simply break the structure into two (or more) structures with independent circulation systems.

3.3.4 Dimensions of Site

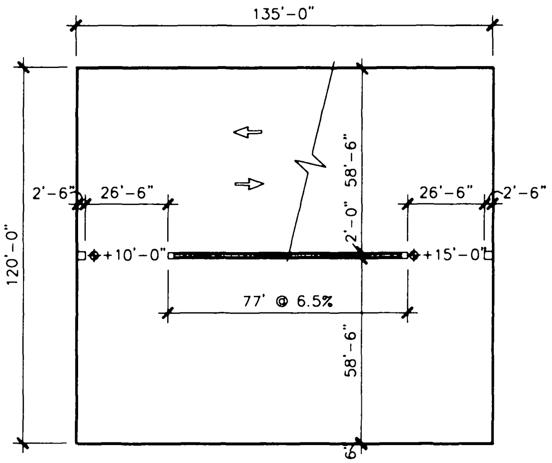
The clear ceiling heights and slope of the elements as presented in the previous section are key factors that affect the way in which our building blocks are assembled on a particular site. To determine the minimum length of a site in the longitudinal direction of sloped parking bays, one must add dimensions of turning bays at the end, plus structural clearances to achieve the out-to-out length of the site. Crossovers can be sloped at the same rate as parking bays if the crossover is centered at the crossing point of the "X" formed by the two bays. See Figure 3-7.

In a single-threaded configuration that rises one-half tier along each parking bay, the length of the structure must be at least 135 ft. for two-way traffic and LOS D design; LOS A design requires a significantly longer site at 187 ft.

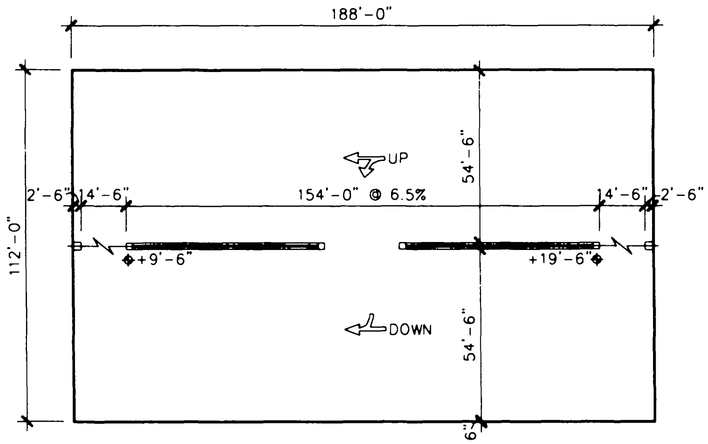
A structure with 10 ft. floor-to-floor height and one way traffic flow on a double-threaded helix requires a site length of 188 ft., only 1 ft. more than a single-thread designed to LOS A. Achieving LOS A for the double-threaded design, however, requires 281.5 ft. A single-threaded system with a straight run that goes up a full floor must have a site at least 188 ft. long for one-way traffic (212 ft. for two-way traffic) at LOS D. To meet LOS A parameters, the structure length increases to 271.5 ft. for one-way designs and 297 ft. for two-way designs. For a double-threaded helix, the same structure lengths as those for full-floor single-threaded helixes apply if the crossover is sloped as previously discussed.

If a sloping parking bay is desired, but the structure length must be less than the dimensions needed to rise the desired run, speed ramps must be used at the turning bays to make up the difference. As long as the slope of the speed ramp does not exceed the slope used for parking bays, end-bay parking can be used. Therefore if the speed ramp is 36 ft. long and LOS D slopes are being used for parking areas, a rise of more than 2′–4″ in the speed ramp will necessitate the elimination of end-bay parking (36' x 6.5% = 2.34').

In sum, the length of the site impacts the type of system used; speed ramps, however, can be used when the site is short. The width of the site also impacts the selection of a system as it determines the number and module width of parking bays that can be placed on the site. The out-to-out width of the structure includes not only the wall-to-wall dimension necessary to achieve the module, but also the structural dimensions of the walls, etc. One of the chief factors influencing structure width is whether one-way or two-way traffic flow is employed.



Single - Threaded Helix
Two way Traffic, 90° Parking
LOS D Dimensions



Double - Threaded Helix
One way Traffic, 75° Parking
LOS D Dimensions

Figure 3-7. To determine structure dimensions, structural clearances, turning bay dimensions, module widths, and rise/run must all be included

3.3.5 One-Way or Two-Way Traffic Flow?

Is one-way traffic flow with angled parking better than two-way traffic flow with perpendicular parking? Or vice versa?

Among the chief advantages of two-way design are benefits created by its wider aisles, including a better angle of visibility when searching for a space, and the ability to pass another driver who has stopped to wait for a space about to be vacated. The wider aisles are also safer for pedestrians.

Also, two-way traffic flow follows its own pattern rather than one that is forced or regimented; thus a driver can't make a mistake and turn the wrong way down a one-way aisle.

Adherents of perpendicular parking claim it is more efficient than angled, especially as compared to flatter angles, such as 60 degrees. However, this is often an overstated benefit. While a 90-degree layout makes more efficient use of parking aisles, the larger turning bays required for two-way traffic often result in no greater efficiency and sometimes less.

In a structure with a big footprint, five bays of 75-degree angled parking will provide more spaces than four bays of 90-degree stalls in approximately the same overall width, thereby increasing capacity and/or reducing the height and mass of the facility. The result: greater efficiency for real cost advantage.

In addition, one-way design with angled parking makes it easier for drivers to enter/exit stalls. By contrast, getting properly aligned in a two-way design's perpendicular stalls can require some maneuvering.

Field studies of how well cars were parked in stalls of various angles have shed light on this issue. At 90 degrees, fewer cars were parked at the intended angle than at 60 degrees. Cars were also more likely to be centered in angled stalls.

With many two-way designs, drivers pass all stalls on the way both in and out of a parking structure. With one-way design, which separates inbound and outbound traffic, drivers can be routed past half the stalls entering and half leaving; thus the number of times a driver must stop and wait for a car to park/unpark is, on average, halved.

Even when alternative one-way and two-way designs each have adequate flow capacity, the two-way system will usually have more congestion.

Other benefits of one-way design/angled parking accrue in lots as well as structures. Conflicts between two vehicles approaching an open stall from opposite directions do not occur. When a vehicle is backing out, angled parking provides better visibility. The potential for accidents is also reduced, because there are fewer decisions to be made and fewer conflict points with everyone driving in one direction.

Only one-way design allows the angle of parking to be altered to accommodate changes in car sizes. If sizes get smaller, the angle can be swung closer to 90 degrees; if bigger, the angle can swing the other way. If a parking facility is to be in service for several decades, such flexibility is quite beneficial.

In general, each project has its own particular requirements that will result in some of the advantages of a particular traffic system being more important than others. Two key considerations in determining which system is better are size and flow capacity.

In a surface parking lot, flow capacity is usually not a critical factor, as there are generally not a great many vehicles in motion at any one time, even with high turnover. The previously discussed benefits of two-way design may make it the best choice.

In a multilevel parking structure, a single parking aisle may need to accommodate peak-hour volumes associated with 1000 or more spaces. If so, most of the advantages of one-way design come to the fore, making it the system of choice.

There are, of course, alternative systems that provide significant flow capacity, such as the exterior express ramps commonly seen in airport parking structures. Such a structure is then equivalent to a series of parking lots stacked vertically.

Our own design solutions illustrate a pragmatic approach. For example, a 6000-space, seven-level retail parking structure was designed with two-way traffic because of its advantageous search pattern. Another 7500-space airport parking structure with a like number of levels was designed with one-way traffic due to its specific requirements.

A last word of advice is this: if you think about how the average driver will find an available space and later exit the facility, and also how peak-hour volumes are accommodated, the best design will probably become clear.

If one-way flow is desired, it is strongly recommended that angled parking stalls (not perpendicular to the driving aisle) be used (Figure 3-8). A one-way design allows the intended traffic flow to be self-enforcing. With perpendicular or 90-degree parking, one user who ignores the signs and proceeds the wrong way will cause problems for other drivers who are following the intended circulation pattern, especially if the turning bays are designed for one-way traffic. Therefore, if 90-degree parking is employed, design the system to accommodate two-way traffic. Conversely, if you want two-way traffic, do not use angled parking. The latter combination causes problems when a driver coming from one direction sees a space intended for the opposite approach and attempts several maneuvers to enter the stall. In addition to delaying traffic flow, this driver is very likely to park improperly, encroaching on an adjacent stall.

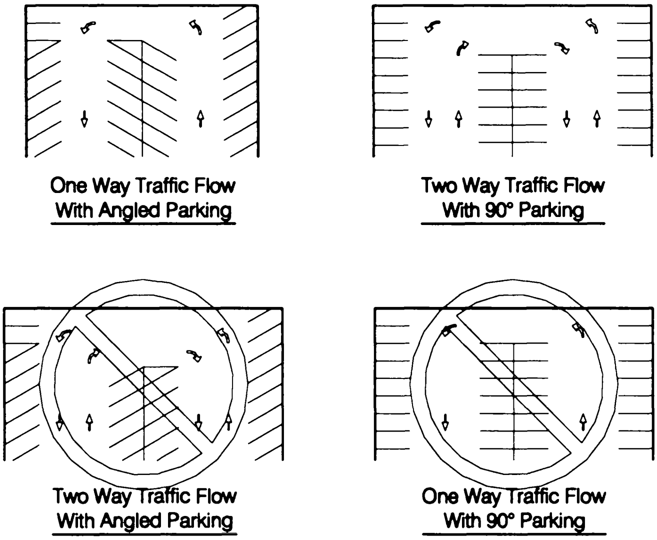


Figure 3-8. One-way traffic flow systems should have angled parking. Two-way traffic flow systems should have 90-degree parking

3.3.6 Selection of Circulation System

Most of the common circulation systems used in parking structure design have been given names that in general relate to the pattern of traffic flow and the number of parking bays. A two-bay single-threaded helix must have two-way traffic unless a circular helix or an express ramp provides a way down (Figure 3-9).

Obviously, what goes up must come down. Single-threaded helixes may, however, be provided in combinations known as side-by-side helixes or end-to-end helixes to achieve one-way traffic flow (Figure 3-10). Note that three-bay side-by-side helixes must have 90-degree parking and two-way traffic flow in the middle bay.

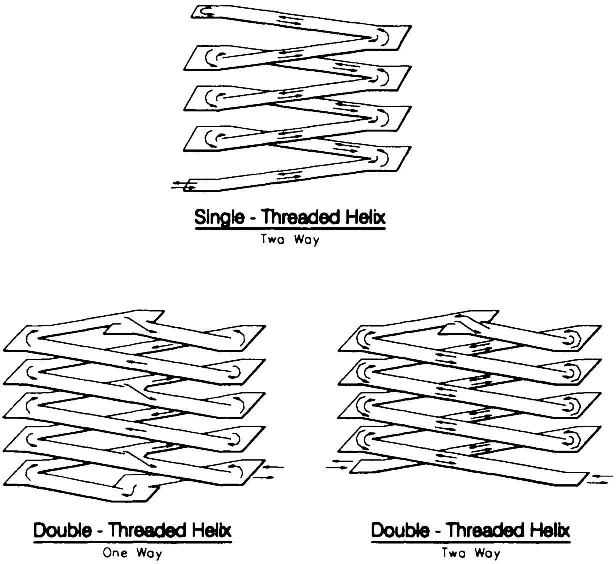


Figure 3-9. When only two parking bays are provided, a single-threaded helix must have one-way traffic, while a double-threaded helix can have either one-way or two-way flow.

Another type of single-threaded helix is the split level (Figure 3-11). In this system, the level parking bays are stepped at half-tier intervals, with speed ramps making up the difference in elevation between the parking bays.

Single-threaded helixes are very repetitive and easy to understand for the user. In the split-level and the side-by-side with either three or four bays, much of the floor area is level. Side-by-side single threads also tend to have the best visibility across the structure of any sloping parking bay design, thereby enhancing passive security (which is discussed in Chapter 4). Most architects prefer to work with level façade elements, although a creative architect can either hide or emphasize a sloping parking bay on the exterior.

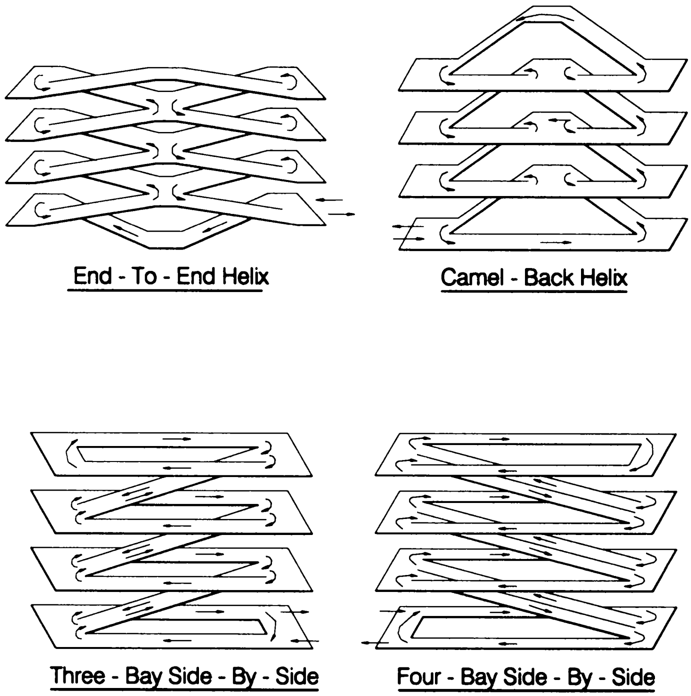


Figure 3-10. Combinations of single-threaded helixes

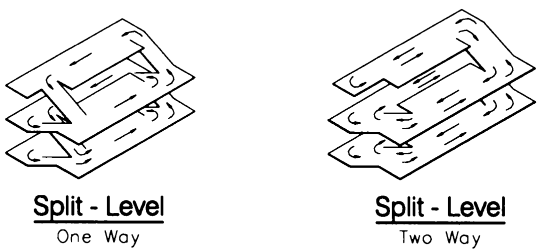


Figure 3-11. Split levels may have either one-way or two-way traffic flows.

A negative aspect of any single-thread design is the number of revolutions required to go from bottom to top or from top to bottom. Table 3-4 gives guidelines regarding the LOS for the number of turns. Double-threaded systems (shown in Figure 3-2), which by definition go two tiers per revolution, become progressively more desirable as the number of floors increases.

One-way traffic flow can be provided in the two-bay configuration of a double-threaded helix. One thread goes up while the other thread goes down. To get from the inbound "up" thread to the outbound "down" thread (presuming the structure rises above street level), a crossover is provided. This crossover is physically possible where the two sloping bays cross each other in the center of the structure. Depending on the type of user, crossovers are often provided only at every other tier. (See the guidelines for travel distance "up" to a crossover in Table 3-4).

Two-way traffic is sometimes used on a double-threaded helix. In this case, the driver can travel back down the same thread, and crossover between threads is not required. Interconnection between the threads can occur only at the top and the bottom of the structure. Two-way traffic on a double-threaded helix results in two up threads and two down threads. This extra path of travel may or may not be advantageous, as will be discussed later.

Like single-threaded helixes, double-threaded helixes may also be provided end-to-end or side-by-side when a structure is very large (generally over 1500 spaces). In such a case, the facility is usually treated as two separate structures, with crossover from one helix to the other allowed, but not encouraged. With one-way traffic there will be two up and two down threads; with two-way traffic there would be four ups and four downs. This type of facility tends to be very confusing to the user, and "lost cars" are a frequent problem. Therefore, unless there is a capacity problem that requires more than one circulation route (to be discussed in Section 3.5), multiple double-threaded helixes are usually avoided.

Several common systems provide double-threaded helixes in two bays with additional level bays off the primary circulation patterns. In such a case, the level bay may provide the crossover from the up circuit to the down circuit. Single-threaded helixes likewise may have "level" bays off the circulation route. In some cases the same sloping parking bay configuration can have different traffic flow, resulting in either a single- or double-threaded helix circulation pattern (Figure 3-12).

A structure with a very large footprint may also have just one or two bays sloping with the remainder level. In general the larger the number of level parking bays, the better the visibility for wayfinding, patron comfort, and security. Express ramps are often employed when the goal is to have all parking on level floors. Sloping parking bays or express ramps are usually combined with flat parking bays to achieve a single-threaded helix configuration (Figure 3-13). However, double-threaded systems can also be used when height and number of turns are considerations.

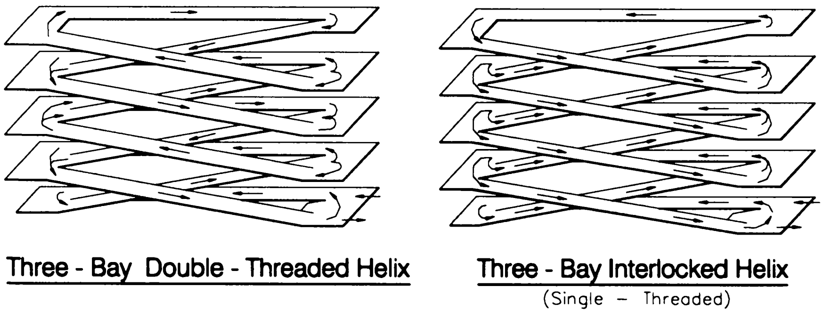


Figure 3-12. Sometimes traffic may be routed in either a double-threaded or single-threaded pattern on the same configuration of parking bays.

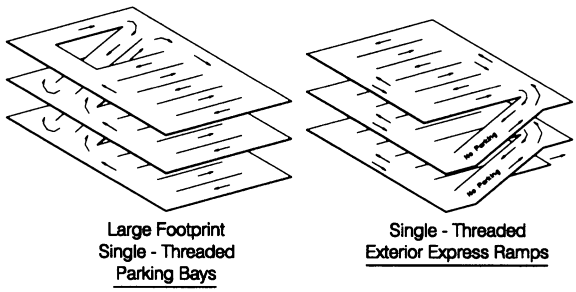


Figure 3-13. Adding level bays off the primary circulation route results in more decisions for the driver

In general, concerns for patron comfort, visibility, and ease of orientation all encourage the use of single-threaded schemes for facilities that will serve large numbers of infrequent users. If the users are present every day, however, they will get to know the system and become frustrated by long search routes and circuitous exit routes. Therefore, sloping parking bays in double-threaded patterns are generally preferred for office parking and other situations with predominantly every day users.

3.4 PARKING GEOMETRICS

An important step in functional design is selection of the parking geometrics. The most critical dimensions are the stall width and the parking module. Parking designers consider the module dimension to be more important than the aisle dimension because the aisle is merely the space left when vehicles are parked opposite each other. The aisle is theoretical; the module is the dimension needed for construction.

The first major concern is the vehicle door opening dimension. For long-term parking (3 hours or more), studies[5] have shown that a door opening clearance of 20 in. between parked vehicles is acceptable. For high turnover parking, a door opening clearance of 24 in. provides a better level of convenience for the more frequent movements.

The second major concern is vehicle movement into the stall. As the angle of parking is rotated from 90 degrees toward 45 degrees, the parking module may be reduced while providing similar maneuverability (i.e., one turning movement) into the stall. The module width is dependent to some extent on the stall width. A narrower stall requires a wider module to achieve the same comfort as a wider stall with a narrower module. Stall widths greater than the minimum provide higher levels of comfort for turning movement and door opening. Increasing stall width is generally a more economical method for increasing comfort than increasing the module.[6]

3.4.1 The Impact of Vehicle Sizes on Parking Dimensions

High gasoline prices and governmental regulations resulting from the Arab Oil Embargo of 1973 fueled the trend to small cars in North America. In the short term, manufacturers were forced to make smaller cars to meet government air quality and fuel efficiency standards. However, over time, they were able to improve aerodynamics, reduce weight and fine-tune other factors that allowed them to meet the standards with the larger vehicles Americans clearly prefer. Small car sales have significantly declined and the very small car—like the Ford Fiesta-- has disappeared from the market. What remains is a large percentage of the market hovering within a few inches of the traditional boundary between large and small—while the centroid of the market slowly inches upward, year after year. While the "upsizing" of cars seems to have slowed, the public is turning to larger and larger light trucks, vans and (sport) utility vehicles (LTVUs). These vehicles are not technically considered "cars" in US regulations, thereby skirting the fuel efficiency rules, nor have they traditionally been considered in parking design.

3.4.1.1 US Vehicle Sales Trends

Walker Parking Consultants has been tracking the sizes and sales of the vehicles typically used for personal transportation in the United States since 1983. The analysis is based on the data in the *Annual Market Data Book* published each spring by *Automotive News*. Information provided includes sales of vehicles in the preceding calendar year and specifications for vehicles in the current model year. It is important to note that the analysis is not exactly straightforward, because the data is reported by calendar year, not model year. For example, when a restyled 2000 model is sold in the fall of 1999, the sales are not reported separately from the 1999 model also sold in that year. Further, the sales are not always broken into sub-models that vary in size. This is particularly true of LTVUs; for example, sales are reported for all Ford F series trucks in one line item even though there are different base sizes for the F150, F250 and F350 models, not mention extended cabs and beds for each base size. Among 1999 models, the lengths of trucks within the F series varied from 17 ft to 21.5 ft and the widths varied from about 6'-6" to 6'-8". Various industry sources have been used to apportion the sales to size classifications. The important thing to note is that a single, consistent methodology has been applied to the evaluation of vehicles sold since 1983, yielding a means of monitoring critical trends in vehicle sizes.

To analyze the change of vehicle sizes over time, automobiles and LTVUs have been classified by the footprint or area of the vehicle, expressed in sq. ft. or sq. m. This leads to the assignment of vehicles to one of seven classes, as follows:

	Square Meters			Square Feet		
Class 5:	5.00	to	5.99	53.82	to	64.57
Class 6:	6.00	to	6.99	64.58	to	75.34
Class 7:	7.00	to	7.99	75.34	to	86.10
Class 8:	8.00	to	8.99	86.11	to	96.76
Class 9:	9.00	to	9.99	96.77	to	107.63
Class 10:	10.00	to	10.99	107.64	to	118.39
Class 11:	11.00	to	11.99	118.40	to	129.06

When this system was first proposed by Roti and Bolden[7], it was found to provide a realistic model for the definition of small and large cars, as well as to provide appropriate detail regarding the change in vehicle sizes over time. The three smallest Classes, 5, 6 and 7, are considered small cars and the four largest, 8 through 11, are considered large cars. The selection of the dividing line between Class 7 and 8 as the boundary between "small" and "large" was consistent with the generally accepted definition of small cars for parking design at the time they adopted this approach. For the most part, cars in Classes 5 through 7 have a length of less than 15'-4" and a width less than 5'-8". Figure 3-14 presents the sales of cars (not including LTVUs) classified as small cars since 1970.

After rising from less than 10% small cars in 1970 to 27% in 1978, sales of small cars soared to over 50% in just two years. Many in the industry predicted that sales would continue to rise, albeit more slowly, and would reach 80% small cars by 1990. Rather than continuing to rise, however, sales hovered in the low to mid-fifties for a decade, before declining back to 34.0% in 1999.

Meanwhile, LTVUs began to be used for everyday personal transportation in increasing numbers. As seen in Figure 3-15, LTVUs represented roughly 10% of the combined market for cars and LTVUs in the 1950's. However, beginning as early as 1960, LTVUs began a slow, steady climb in market share up to today's 48.4% of sales.

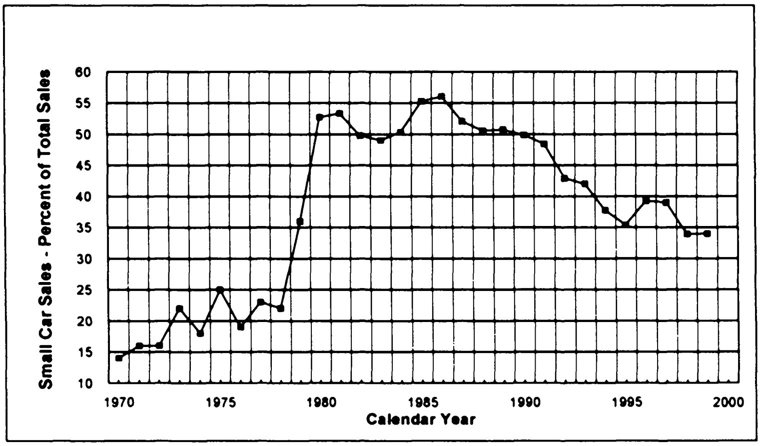


Figure 3-14. Sales of small cars as a percent of total car sales since 1970. Source: Automotive News Market Data Book

Therefore, beginning in 1987, Walker started to track LTVU sales and vehicle sizes, as seen in Figure 3-16. The minivan was making the full- size family station wagon an extinct species, and many families were choosing compact pick-up trucks as economical second, or sometimes third, vehicles.

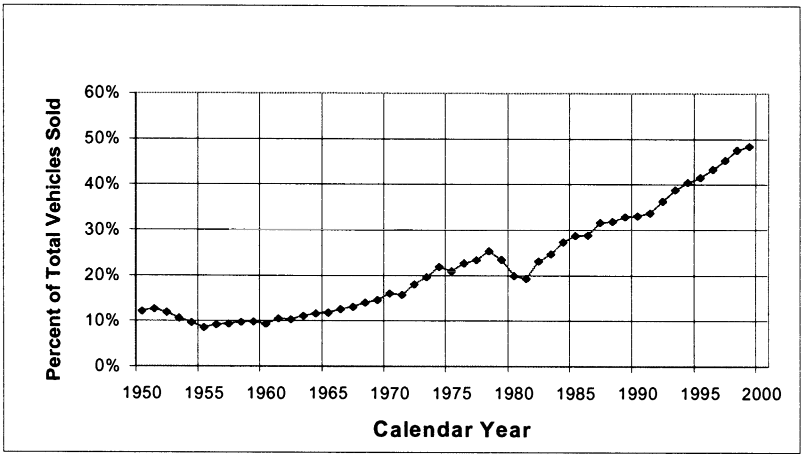


Figure 3-15. LTVU market share since 1950. Source: Automotive News Market Data Books

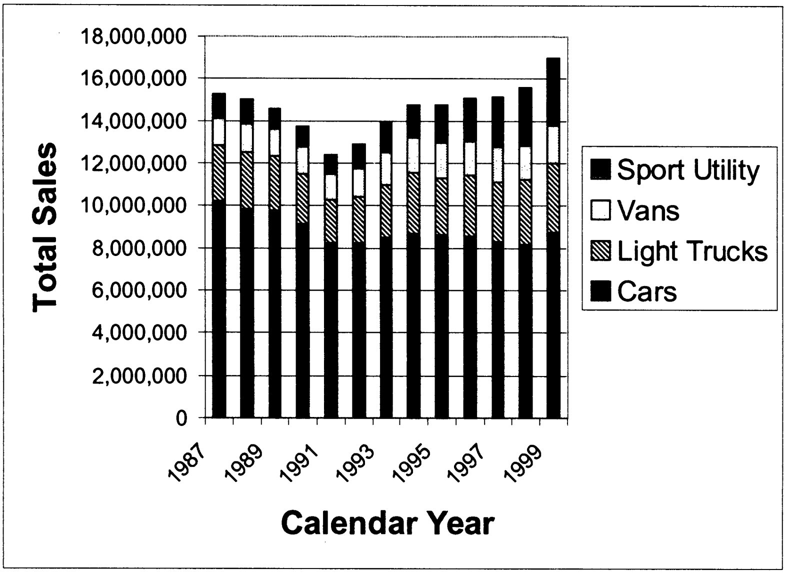


Figure 3-16. Vehicle sales by type. Source: Automotive News Market Data Books

The fastest growing market segment in more recent years is sport utility vehicles, which appear to be taking sales from cars, while pickups and vans hold their own.

The next question, then, is how do LTVU vehicle sizes compare to cars? Figure 3-17 presents the percent of small vehicles sold by vehicle type, as well as overall, since 1987. Over this period, there has never been a significant percentage of vans which fall into the "small" classification, although most minivans are barely over the boundary into Class 8. From 1987 to about 1995, pick-up trucks followed about the same pattern as cars—a slow decline in size—but with 10 to 15% less classified as small. Meanwhile, around 80% of sport utility vehicles were classified as small, compensating to some extent for the negligible percentage of vans that were small. Therefore, the percentage of all "personal transportation vehicles" (cars and LTVUs) which qualify as small tracked closely to the pattern for cars, but was pulled down a few percentage points.

Big changes, however, started to occur in 1995, with the upsizing of pick-up trucks and the even more significant growth in sales of larger SUVs. The "hottest" vehicle at the turn of the millennium, however, is the sport-utility wagon (SUW) a four wheel drive vehicle built on a car chassis with more car-like handling and gas mileage.

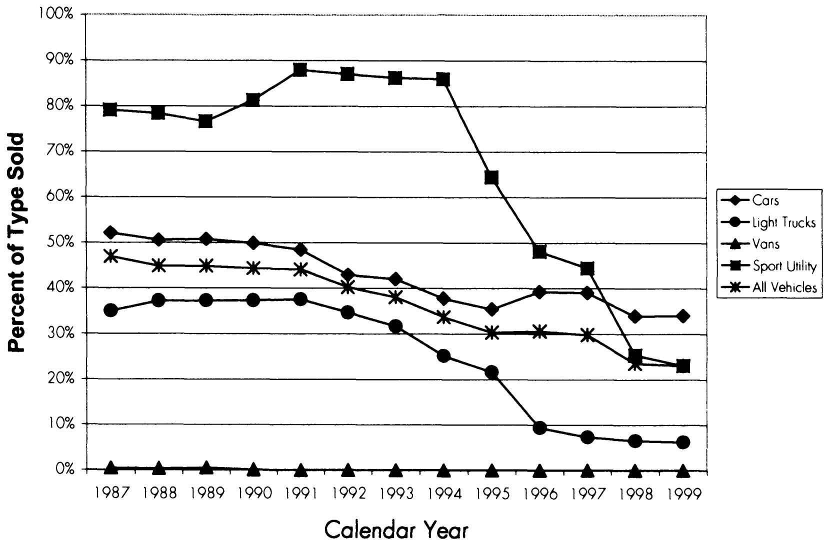


Figure 3-17. Small vehicle sales by type since 1987. Source: Automotive News Market Data Books

While the percentage of vehicles that qualify as small on the road today lags behind the figures for new vehicle sales, within five years the percent of small vehicles on the road across the US should be around 25%. Based on the prognostication of various auto industry forecasters, as of the turn of the millennium, it appeared that the size of the design vehicle would be relatively stable for the next few years. It did not appear that the percentage of small vehicles sold will decline much further, and the surge in SUW sales is in the middle of the market from a size standpoint. If the sales of the largest SUVs and pickups are flat in calendar year 2000 or only slightly higher as predicted, the design vehicle would not change much over the foreseeable future which in the auto industry is no more than five years.

All those prognostications were made prior to the marked increase in gasoline prices in the US that occurred in the first quarter of calendar year 2000. As of this writing, there does not appear to be any immediate impact on the sales of larger SUVs. However, it is possible that those who own the biggest gas-guzzlers will decide to go to a smaller, more efficient vehicle, such as an SUW, for the next purchase. This change could begin to affect sales later in 2000, which in turn would begin to have noticeable impact on the overall mix of vehicles two to three years thereafter. Conversely, gas prices could drop again and/or users could ignore the gas price in their decision making.

3.4.1.2 US Design Vehicles

Following on other traffic engineering practices, we have selected the design vehicle as the 85th percentile vehicle in the range from smallest (0 percentile) to largest (100th percentile.) Table 3-5 traces design vehicles since the beginning of our research in 1983. The design vehicle among cars on the road was determined by evaluating data on all cars registered in the United States in 1983, in a data base purchased from RR Donnelly & Sons. Although new cars at that time were already downsized, there still remained enough very large cars from the early 1970s on the road to have a relatively large design vehicle. Since that time, we have been evaluating the design vehicles among vehicles sold using the *Automotive News Annual Market Data Book,* as previously discussed.

Several elements are interesting to note. The design vehicle among small cars (classes 5 to 7) did not change significantly from 1983 through 1993, but has increased 1 in. in width and 5 in. in length in the last few years. The design vehicle among large cars (classes 8 to 11) decreased dramatically from 1983 to 1993, but has started to creep back up. However, as of 1999, it

Table 3-5: Design Vehicles

	On the Road, 1983			1987 Sales				1993 Sales			1998 Sales			
Small Cars	5'-7"	X	14'-8"	5'-8"	X	14'-8"		5'-8"	X	14'-9"	5'-8	X	15'-2"	Subaru Legacy
Large Cars	6'-7"	X	18'-4"	6'-6"	X	18'-0"		6'-2"	X	17'-0"	6'-3"	X	16'-9"	Dodge Intrepid
All Cars	6'-3"	X	17'-2"	6'-2"	X	17'-0"		6'-1"	X	16'-8"	6'-1"	X	16'-8"	Mercury Sable
% Small Cars			36.0%			52.1%				42.0%			33.9%	
Trucks				6'-7"	X	17'-6"	Ford F250				6'-8"	X	18'-9"	Dodge Ram (long bed)
Vans				6'-8"	X	17'-8"	Ford Econoline				6'-8"	X	18'-3"	Chevy Express
Sport Utility				6'-7"	X	15'-4"	Ford Bronco				6'-7"	X	17'-1"	Ford Expedition
% Small						41.9%							12.1%	
Composite (cars + LTVU)				6'-4"	X	17'-0"					6'-7"	X	17'-1"	Ford Expedition
% Small						48.8%							23.5%	

is still 4 in. narrower and 7 in. shorter than the large design vehicle on the road in 1983 and significantly smaller than the dinosaurs on the road in 1970. Overall, then, the design vehicle for cars is 2 in. narrower and 6 in. shorter than in 1983.

If parking stalls were only designed for cars, the same dimensions employed in 1983 would still be appropriate, if not generous. At the same time, it should be noted that using dimensions unchanged from the early 1980s means that a higher level of comfort has come to be expected by parking stalls users as compared to what was accepted in the 1970s.

LTVUs in general are wider than cars; the design vehicle in each segment was about 4 in. wider than that for cars in 1987. At that time, the design truck and design van were 6 in. to 8 in. longer than cars, but the design SUV was quite short. Therefore the "composite" design vehicle in 1987 was 6'-4" by 17'-0". This was 1 in. wider but a couple inches shorter than the design car on the road in 1983.

Therefore the impact of LTVUs on parking dimensions was negligible in 1987, and there was no real need to modify parking dimensions for standard stalls. In 1999, however, things are startlingly different. The design pick-up is longer, and the design SUV has taken a 1'-7" leap in length from the Ford Bronco in 1987 to the Ford Expedition in 1999. Indeed, the Ford Expedition, a SUV, is now the design vehicle overall among ALL personal transportation vehicles sold in the US in 1998, at 6'-7" wide by 17'-1" long. Thus, while modules may not be impacted by the length of the parked car or the turning radii into the stall (the Expedition's turning diameter is almost identical to that of the design vehicle on the road in 1983), stall widths are being pinched by a 3 in. growth in the design vehicle width.

Presuming that the sales of larger SUVs are relatively flat over the next five years, the design vehicle among those on the road should be creeping up to the Expedition. However, as previously discussed, the increase of gasoline prices could moderate that trend.

This statistical data is supported by the fact that most retailers who accepted 8'-6" wide stalls as an appropriate stall width just a few years ago are asking for 8'-9" if not 9'-0" today. For the first time, we are hearing reports of parking facility owner/operators restriping their lots to increase stall widths, even though they may lose parking spaces. Some aggressive designs of the mid-80s are also developing problems with inadequate turning radii, according to at least one of the larger owner/operators of parking facilities in the US, who wishes to remain anonymous.

3.4.1.3 Recommended US Parking Dimensions

With the surge in vehicle width through 1999, we have recently added 3 in. to our recommended stall widths while adjusting the modules for the turning impact and the vehicle projection of a wider, slightly longer car. See Table 3-6 for our recommended dimensions for stall widths and modules (the wall- to- wall dimension of two rows of parked vehicles and the aisle between.)

The level-of-service approach provides assistance in tailoring a design for the users of the specific project. In parking design, there are virtually infinite combinations of stall width and module.

Table 3-6. Recommended Stall Width Dimensions

North America	LOS D	LOS C	LOS B	LOS A
Stall Width	8'-3"	8'-6"	8'-9"	9'-0"
Angle of Park	Module (ft.)			
40	46.50	47.50	48.50	49.50
50	48.25	49.25	50.25	51.25
55	49.50	50.50	51.50	52.50
60	51.00	52.00	53.00	54.00
65	52.25	53.25	54.25	55.25
70	53.50	54.50	55.50	56.50
75	54.50	55.50	56.50	57.50
90	58.50	59.50	60.50	61.50

LOS A dimensions are the most generous and are often employed in high turnover situations, including shopping centers, airport short-term lots and hospital visitor and patient parking. LOS B might be employed for the same uses in very urban settings where tighter dimensions are accepted; LOS B is also employed for other visitor situations with less turnover, such as longer term parking at airports and visitor parking at office buildings. LOS C parking is often employed for employee parking and/or student parking at universities, although we sometimes move up to LOS B for these uses if a higher level of comfort is desired. LOS D is only employed in the most urban of settings such as downtown New York City, where people are happy just to find a parking space.

As before, no recommendations are provided for LOS E and F designs, because they simply are not recommended. For reference purposes, LOS F designs result in extremely tight conditions where some parkers have to make several attempts to get into the stall. Encroachment into adjacent stalls may leave them unusable.

The user today would rather have the more comfortable stall width than a generous module. Unfortunately there aren't any easy solutions for properties that have 90 degree parking, a lot of small car only (SCO) stalls, or aggressive dimensions from the 1980s (similar to LOS D in the above table.) The usual result in restriping to a larger stall is a loss in capacity that can exceed 10% where a high proportion of the stalls provided was SCO.

Designers may reduce aisle (and consequently module) width 3 in. for each additional inch of stall width and maintain the same level of service. For example, an 8'-6" stall and 51-ft module for 60-degree parking would be LOS C. Increasing aisle width and reducing stall width is not recommended. Additional dimensions for details involved in laying out parking stalls are shown in Figure 3-18 and Table 3-7.

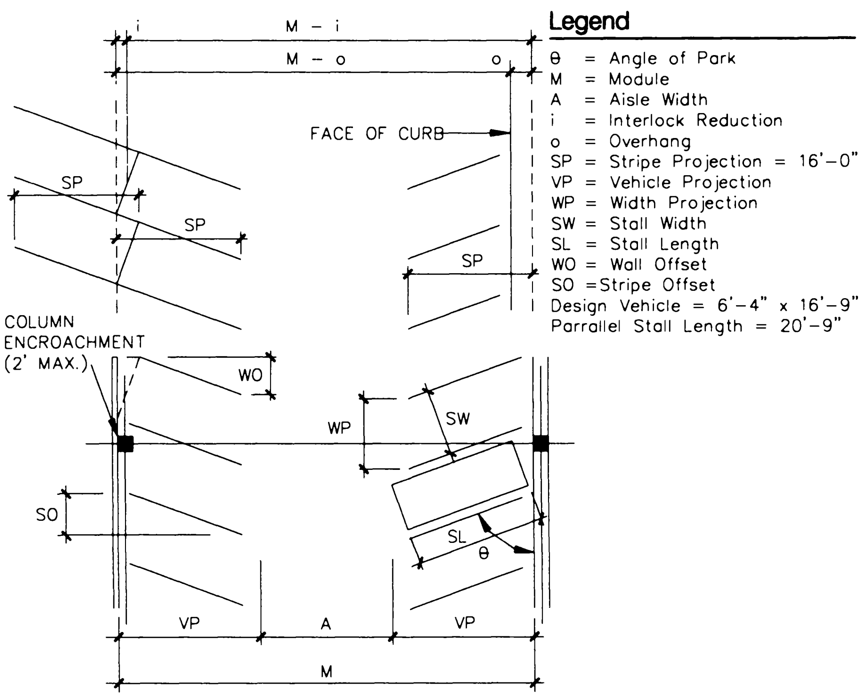


Figure 3-18. Critical parking stall layout parameters.

Table 3-7. Parking Layout Dimensions (North America)

All Levels of Service

θ	VP	WO	O	SO
45	17'-5"	10'-8"	1'-9"	16'-6"
50	18'-0"	9'-4"	1'-11"	13'-10"
55	18'-5"	8'-3"	2'-1"	11'-7"
60	18'-9"	7'-2"	2'-2"	9'-6"
65	18'-11"	6'-1"	2'-3"	7'-8"
70	19'-0	5'-0"	2'-4"	6'-0"
75	18'-10"	3'-10"	2'-5"	4'-5"
90	17'-9	1'-0"	2'-6"	0'-0"

Design Vehicle = 6'-7" x 17'-1"
Stripe Projection = 16'-6"
Parallel Stall Length = 21'-6"

θ	WP	M	A	I	θ	WP	M	A	I
Level of Service A					**Level of Service B**				
45	12'-9"	49'-6"	14'-8"	3'-2"	45	12'-4"	48'-6"	13'-8"	3'-10"
50	11'-9"	51'-3"	15'-3"	2'-11"	50	11'-5"	50'-3"	14'-3"	2'-10"
55	11-0"	52'-6"	15'-8	2'-7"	55	10'-8"	51'-6"	14'-8	2'-6"
60	10'-5"	54'-0"	16'-6"	2'-3"	60	10'-1"	53'-0"	15'-6"	2'-2"
65	9'-11"	55'-3"	17-5"	1'-11"	65	9'-8"	54'-3"	16-5"	1'-10"
70	9'-7"	56'-6"	18'-6"	1'-6"	70	9'-4"	55'-6"	17'-6"	1'-6"
75	9'-4"	57'-6"	19'-10"	1'-2"	75	9'-1"	56'-6"	18'-10"	1'-2"
90	9'-0"	61-6"	26'-0"	0'-0"	90	8'-9"	60-6"	25'-0"	0'-0"
Level of Service C					**Level of Service D**				
45	12'-0"	47'-6"	12'-8"	3'-0"	45	11'-8"	46'-6"	11'-8"	2'-11"
50	11'-1"	49'-3"	13'-3"	2'-9"	50	10'-9"	48'-3"	12'-3"	2'-8"
55	10-5"	50'-6"	13'-8	2'-5"	55	10'-1"	49'-6"	12'-8	2'-4"
60	9'-10"	52'-0"	14'-6"	2'-2"	60	9'-6"	51'-0"	13-6"	2'-1"
65	9'-5"	53'-3"	16-5"	1'-10"	65	9'-1"	52'-3"	14-5"	1'-9"
70	9'-1"	54'-6"	16'-6"	1'-5"	70	8'-9"	53'-6"	15'-6"	1'-5"
75	8'-10"	55'-6"	17'-10"	1'-1"	75	8'-6"	54'-6"	16'-10"	1'-1"
90	8'6"	59-6"	24'-0"	0'-0"	90	8'-3"	58-6"	23'-0"	0'-0"

Notes:

1. All dimensions rounded to nearest inch.
2. Add 1 ft. to module for surface parking bays without curbs or other parking guides (frequent poles, columns or walls) in areas with frequent snow cover.
3. Angles between 76 degrees and 89 degrees not recommended because these angles permit drivers of smaller cars to back out an exit the wrong way.
4. To maintain the same level of service with wider stalls, reduce the module (M) by 3 in. for each 1 in. additional stall width.
5. Columns and light poles may protrude into the parking module a combined maximum of 2 ft as long as they do not affect more than 25% of the stalls in that bay.
6. Small car only stalls 7'-6" wide by 15'-0" long should only be used at constrained locations or in remnants of space. The number of these stalls should not exceed 15% of the total capacity.

A common mistake in laying out parking stalls in short span designs is to not allow for the impact of the column on the comfort of turn into the stall. To achieve the same level of service as provided in long span structures, approximately 1 ft must be added to each stall adjacent to columns. See Figure 3-19. Adding to the stall widths does increase the level of service for door opening movement at those stalls adjacent to columns.

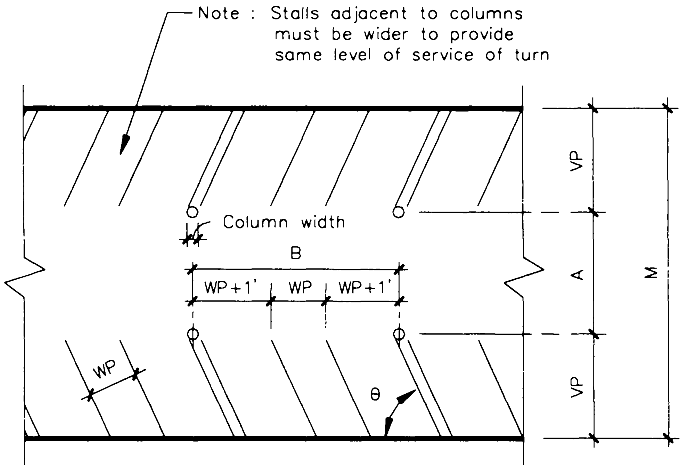


Figure 3-19. Short span parking layout

3.4.1.4 What About Small-Car-Only Stalls?

In 1985, it was recommended that if SCO stalls are provided, the number should not exceed three-quarters of the expected mix, i.e., if 40% small cars are expected in the mix, no more than 30% of the stalls should be small-car-only. This reduction reduced the problem of large cars finding only SCO stalls available when a facility is nearly full.

Not long thereafter, however, most parking consultants began to question the viability of small-car-only stalls, even if the mix remained stable at around 50% small cars. A major contributor to this concern was a phenomenon called clustering in a 1989 study by the Parking Consultants Council[8]. At that time, the manufacturers had downsized intermediate cars and larger cars, but were starting to up-size compact and smaller cars. Two-thirds to three-quarters of cars sold from 1987 through today have been in

Classes 7—largest of the small cars, and Class 8—smallest of the large. Vehicles representative of this trend are the Ford Taurus and Ford Tempo. The result of clustering is twofold:

- confusion among drivers about what vehicles can and should be parked in SCO stalls, and
- SCO stalls no longer being self-enforcing as they were when cars were very polarized in size—either very large or very small.

Therefore, most parking consultants generally stopped recommending small-car-only stalls, except where local parking requirements were heavily weighted towards their use and it was not possible to obtain variances for more reasonable one-size-fits-all designs. Typically, local officials reacted to the downsizing of the 1970s by adding SCO stall provisions, without changing standard size parking requirements. By not allowing a moderated one-size-fits all design that recognized the down-sizing of large cars then occurring, they penalized those who didn't want to use SCO stalls.

Today, with the precipitous decline in the sales of small vehicles to less than 25% of the market (including LTVUs), the appropriate percentage of SCO stalls is such that it renders them useful only in limited situations and remnants of space where a standard car won't fit.

There is evidence of growing pressure to eliminate SCO stalls from the parking design lexicon. In 1999, numerous newspapers, including the *Los Angeles Times*, the *Wall Street Journal* and *USA Today* published articles on the problems of bigger cars and SUVs forced to park in the only available stall, which is often a SCO stall.

The City of Honolulu, once home to one of the most generous ordinances at 50% SCO stalls allowed, went "cold turkey" in 1996—no SCO stalls allowed in new construction. Other cities, facing local complaints, but also recognizing that property owners can't get rid of SCO stalls without a significant loss of capacity, are struggling to find alternate solutions. Palo Alto, CA recently established a $30 fine for vehicles larger than 6 ft wide and 15 ft long parked in SCO stalls. According to enforcement personnel, they are required to carry a tape measure and confirm the vehicle dimensions before ticketing, a cumbersome procedure at best.

The problem with prohibiting and fining vehicles that are really too large for parking in SCO stalls is that there is no easy way to inform users of the restriction in such a way that they can make a rational decision not to park in the stall. Signs stating "small car only" or "compact car only" don't work well enough to prevent the problems. Most owners don't know the exact dimensions of their vehicle. Also, ticketing violations of small car only stalls does nothing to correct the problem of too many small car only stalls for today's vehicle mix.

In sum, cities need to reduce if not remove the provision allowing SCO stalls, and review their ordinances for appropriate parking dimensions for today's vehicles. In many cases, their ordinances still require excessive parking modules for standard stalls, since the design vehicle length is still significantly shorter than it was in the 1970s.

As previously noted, we are also starting to see cases of parking facility owner/operators restriping to eliminate small car only stalls and increase standard stall widths. In some cases where very generous modules were employed, the angle of parking can be adjusted to reduce the loss of stalls. See Figure 3-20. A design based on the widely accepted recommendations in *Parking Principals*[9] would have a 56 ft. module for an 8'-6" stall at 60 degrees. By increasing the stall width to 9'-0" but increasing the angle to 70 degrees, a design that is only marginally below LOS A is achieved and stall width is increased without any loss of stalls. In fact, with long runs, stalls may even be gained!

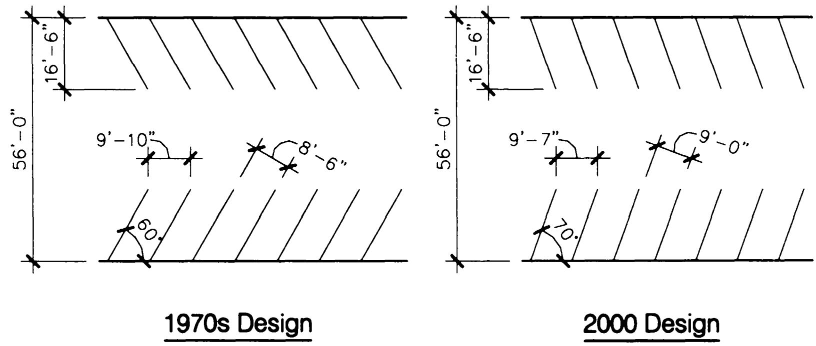


Figure 3-20. Restriping for changing parking dimensions.

3.4.2 European and Asian Parking Design

Although it is impossible to reconstruct the type of research on automobile sizes in other countries that has been conducted for US vehicles annually since 1983, surveys of parking geometric requirements in various major cities and countries have been performed to identify a design vehicle and recommended dimensions for the typically smaller vehicle found in Europe and Asia. A smaller design vehicle is employed in these countries; the average width is 1.75 m and the average length is 4.8 m. This vehicle is approximately 5'-9" by 15'-9", or about 10 in. less in width and 1'-4" less in length. Also, as previously discussed, even if the same design vehicle were present in the US, LOS A dimensions for US conditions would be more generous than LOS A for Europe and Asia. Table 3-8 presents recommended geometrics for European and Asian parking in a format similar to those provided in Table 3-7.

3.4.3 Parking Efficiency

In addition to achieving the correct traffic flow, the selection of the angle of parking will depend on several factors; often the most critical is the efficiency. In most cases, efficiency has a direct impact on the construction cost per parking stall. Obviously if one design requires less floor area per space, it will cost less for the same number of spaces. Because modules with angled parking are narrower than those for 90-degree parking, one can sometimes put more bays of angled parking onto a site.

For example, a site that is 110 ft. wide is too narrow for two double-loaded bays of 90-degree parking, but can comfortably accommodate two double-loaded bays of angled parking. More spaces can be accommodated on that site with angled parking than with 90-degree parking. It is a myth that 90-degree parking is **always** more efficient than angled parking. The case above, in which one bay in a 90-degree scheme would have to be single loaded, is one example. Unfair comparison you say?

Then let's lay out two parking lots on a site 121 ft. wide by 200 ft. long. For simplicity's sake, ignore the need for parking equipment and assume that there are driveways at one end, as seen in Figure 3-21.

Table 3-8. Parking Space Dimensions (Europe and Asia)

All Levels of Service									
θ	VP	WO	O	SO	Design Vehicle = 1.75m by 4.80m				
45	4.83m	3.02m	0.60m	4.65m	Stripe Projection = 4.65m				
50	5.00m	2.66m	0.65m	3.90m	Parallel Stall Length = 6.00m				
55	5.14m	2.33m	0.70m	3.26m					
60	5.23m	2.02m	0.74m	2.68m					
65	5.29m	1.72m	0.77m	2.17m					
70	5.31m	1.41m	0.80m	1.69m					
75	5.29m	1.09m	0.82m	1.25m					
90	5.00m	0.30m	0.85m	0.00m					
θ	WP	M	A	I	θ	WP	M	A	I
Level of Service A					**Level of Service B**				
45	3.68m	13.55m	3.89m	0.92m	45	3.54m	13.25m	3.59m	0.89m
50	3.39m	13.95m	3.95m	0.84m	50	3.26m	13.65m	3.65m	0.81m
55	3.17m	14.40m	4.13m	0.75m	55	3.05m	14.10m	3.83m	0.71m
60	3.00m	14.80m	4.34m	0.65m	60	2.89m	14.50m	4.04m	0.64m
65	2.87m	15.20m	4.62m	0.55m	65	2.76m	14.90m	4.32m	0.53m
70	2.77m	15.50m	4.88m	0.44m	70	2.66m	15.20m	4.58m	0.43m
75	2.69m	15.80m	5.22m	0.34m	75	2.59m	15.50m	4.92m	0.33m
90	2.60m	16.40m	6.40m	0.00m	90	2.60m	16.10m	6.10m	0.00m
Level of Service C					**Level of Service D**				
45	3.39m	12.95m	3.29m	0.85m	45	3.25m	12.65m	2.99m	0.81m
50	3.13m	13.35m	3.35m	0.77m	50	3.00m	13.05m	3.05m	0.74m
55	2.93m	13.80m	3.53m	0.69m	55	2.81m	13.50m	3.23m	0.66m
60	2.77m	14.20m	3.74m	0.60m	60	2.66m	13.90m	3.44m	0.58m
65	2.65m	14.60m	4.02m	0.51m	65	2.54m	14.30m	3.72m	0.49m
70	2.55m	14.90m	4.28m	0.41m	70	2.45m	14.60m	3.98m	0.39m
75	2.48m	15.20m	4.62m	0.31m	75	2.38m	14.90m	4.32m	0.30m
90	2.40m	15.80m	5.80m	0.00m	90	2.30m	15.50m	5.50m	0.00m

Notes:

1. All dimensions rounded to nearest centimeter.
2. Add 0.3 m to module for surface parking bays without curbs or other parking guides (frequent poles, columns or walls) in areas with frequent snow cover.
3. Angles between 76 degrees and 89 degrees not recommended because these angles permit drivers of smaller cars to back out an exit the wrong way.
4. To maintain the same level of service with wider stalls, reduce the module (M) by 3 cm for each 1 cm additional stall width.
5. Columns and light poles may protrude into the parking module a combined maximum of 0.6 m as long as they do not affect more than 25% of the stalls in that bay.

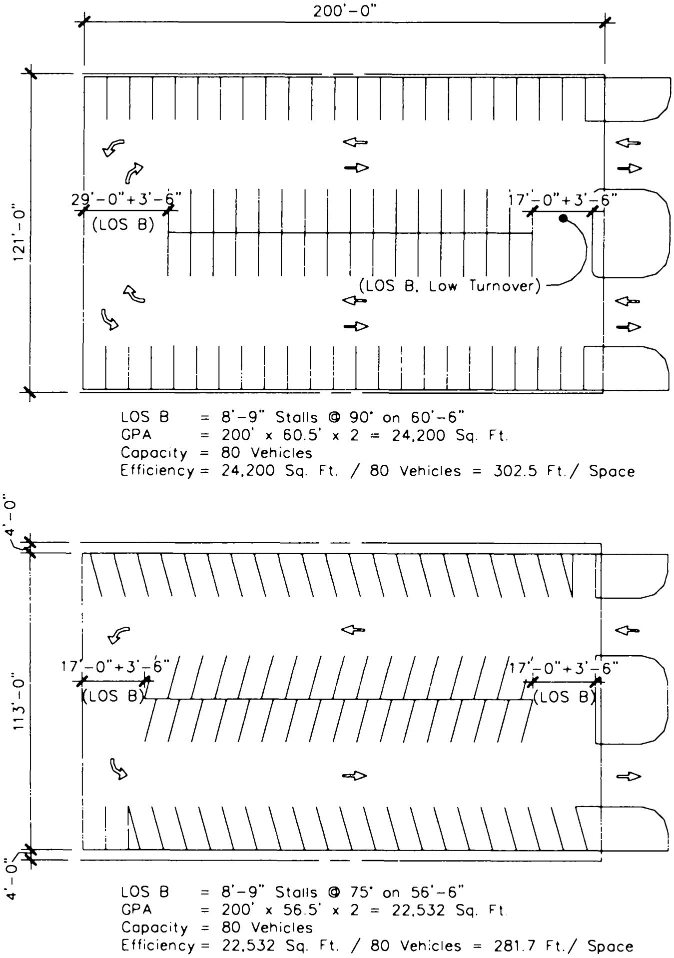


Figure 3- 21. Angled parking can be more efficient than 90-degree parking

One layout has 8'-5" stalls at 90 degrees on a module of 60'-6". This is classified as a level of service B for a vehicle population containing 40% small cars. For 75-degree parking, 8'-5" stalls require a module of 56'-4" for LOS B (40% small cars). Note that for 8'-5" stalls at 75 degrees, the dimension of the stall parallel to the aisle is about 8'-9". The turning bays at both ends are designed to provide LOS B, assuming turnover conditions.

The two lots have the same number of cars, but the 75-degree design uses less floor area. The efficiency of the 75-degree layout is greater than the efficiency of the 90-degree layout. In addition to the money saved on paving, the angled design provides a little more space on the site for landscaping, storm water retention, and other design concerns.

While it is quite true that any 90-degree layout is more efficient in its use of the adjacent aisle, the larger turning bays required for two-way traffic in this particular layout counterbalance the efficiency advantage in the parking bays.

Other design "tricks," such as parking along end bays, affect the efficiency of a design. Therefore, designers, always check several layouts before deciding which is the most efficient. Owners, make sure your designers did it!

The actual efficiency figure depends to some degree on how it is calculated. Some designers make their efficiencies look better by removing interior columns, walls, and any openings between sloping bays to achieve a net floor area, but this approach is specious at best. The best approach is to use the gross parking area (GPA) (outside-to-outside of exterior walls) because it most closely parallels the floor area dedicated to parking, which in turn determines the cost of building the parking space. Stair and elevator towers are removed from the gross parking area even if they are located inboard. The towers are present no matter what the efficiency of the parking area, and the design of the stair/elevator towers (be it Spartan or palatial) should not impact the assessment of parking efficiency. The GPA as defined herein is similar to the gross leasable area used for commercial buildings.

Using the recommended stall and module dimensions, efficiencies of close to 300 sq. ft. per car can often be achieved. Just using these dimensions is no guarantee. A critical factor in the overall efficiency is the length of a row of parking stalls between turning bays or crossovers. A structure 250 ft. long will have better efficiency than one 150 ft. long with the same geometrics. Therefore, it is generally more efficient to lay the parking bays parallel to the long dimensions of the site.

Structures that have fewer turning bays will also be more efficient if other factors are equal. A single-threaded helix either alone or side-by- side (two turning bays per level) will usually be more efficient than a double-threaded helix (two turning bays plus a crossover). The latter is usually more efficient than an end-to-end or a split level (with one-way traffic), each of which has four turning bays. As noted previously, however, it is always best to look at several alternatives before deciding which is most efficient.

3.5 FLOW CAPACITY CONSIDERATIONS

In the past, the relatively small number of parking structures with more than 1500 parking spaces tended to be conservatively designed with multiple circulation paths or high-volume circular helixes. There were no standards for the flow capacity of a circulation route except an old rule of thumb that no more than 750 vehicles an hour should use a sloped parking bay. It becomes apparent to an experienced designer, however, that the type of traffic flow and the design of the system do have an impact on the flow capacity. Several other rules of thumb were developed, such as, it is better to use one-way traffic flow than two-way traffic flow. However, how much better? Where is the division between acceptable and unacceptable?

Parking consultants generally agree that retail facilities with sloping parking bays should have one-way traffic flow because of the high volumes of vehicles arriving and departing at the same time. It is easier to get in and out of one-way stalls; therefore the delay to other users is less. Also, in two-way systems, departing vehicles have to wait for gaps in both departing and arriving traffic streams, often from two directions. Conflicts between two vehicles approaching an empty parking stall from different directions are eliminated. In most one-way systems, arriving and departing traffic are separated, and there is better visibility to watch for approaching vehicles when the car is parked at an angle. The more one direction of flow (either in or out) predominates, the muddier the waters become. Many consultants argue that 90-degree parking and two-way traffic flow are perfectly acceptable for office parking, where most vehicles arrive in the morning and depart in the evening. In fact, a double-threaded helix with two-way traffic flow has twice the circulation routes (two up and two down) of a double-threaded helix with one-way flow. Under the old rule of thumb of 750 vehicles per hour per route, the flow capacity has been doubled. The two-way design eliminates the need for a crossover in a two-bay configuration, improving efficiency. End of argument, right? No. Other consultants argue that one-way traffic flow is still better.

In 1986, Walker initiated a study to find a better way to assess the flow capacity of parking circulation systems. The British equivalent of the Transportation Research Board (TRB), the Transport and Road Research Laboratory (TRRL) did extensive research in 1969[10] and again in 1984[11] on this issue. Unfortunately, it was never widely published in the United States. Also, the test parameters employed were appropriate for British driving conditions, including a much higher ratio (virtually 100%) of small cars. Therefore, the TRRL equations are not directly applicable to American conditions.

The TRRL equations were reviewed, and modifications were made for American conditions. It should be noted that the results have not been field-tested in the same way that the TRRL equations were. However, the results seem reasonable and provide a good basis for an "apples-to-apples" comparison of two circulation systems.The intent of this book is to acquaint the reader with important information regarding the design of parking facilities; in this case, the point is that there **is** an analytical approach to determining the flow capacity of a parking facility. The equations and guidelines for assumptions are provided herein; however, the methodology and research used to develop the methodology are not.

3.5.1 Peak-Hour Volumes

The most critical variable in determining the adequacy of any circulation system is the volume, V, of vehicles expected to arrive and/or depart in the peak hour. The rates shown in Table 3-9 are based on standard trip generation procedures and variations found in various traffic studies.

Table 3-9. Typical Peak-Hour Volumes

	Volume in 1 hr[1] as % of static capacity			
	Peak A.M. Hour		Peak P.M. Hour	
Land Use	In	Out	In	Out
Residential	5-10	30-50	30-50	10-30%
Hotel/motel	30-50	50-80	30-60	10-30
Office	40-70	5-15	5-20	40-70
General retail/restaurant	20-50	30-60	30-60	30-60
Convenience retail/banking	80-150	80-150	80-150	80-150
Central business district[2]	20-60	10-60	10-50	20-60
Medical office	40-60	50-80	60-80	60-90
Hospital				
Visitor spaces	30-40	40-50	40-60	50-75
Employee spaces	60-75	5-10	10-15	60-75
Airport				
Short-term (0-3 hr)	50-75	80-100	90-100	90-100
Mid-term (3-24 hr)	10-30	5-10	10-30	10-30
Long-term (24+ hr)	5-10	5-10	5-10	5-10
Special event	80-100	85-100		

[1] As a general rule, the larger the facility and/or the more diverse the tenants of the generated land uses, the lower the peak-hour volume as a percentage of the static capacity.

[2] It is generally more accurate to determine what portion of the spaces are allocated to retail, office, and other uses.

Some references have recommended that a parking structure should be able to fill or discharge completely in 1 hr, with an even faster fill/discharge rate of 30 min for special events.[12] This standard is, however, substantially higher than that employed for designing streets. Only in a very few cases do land uses generate peak-hour volumes equal to or in excess of the static parking capacity (denoted N) required for that use. One exception is the special-event facility, which in most cases should be designed to fully "dump" in one hour or less. Convenience retail and consumer banking facilities also tend to turn over more than once an hour; however, the spaces associated with these uses are not normally a major component of demand for a multi-story parking facility.

For those unfamiliar with standard traffic engineering practice, "trips" are generated for peak hours based on the square footage of the generating land use, such as office, retail, etc.[13] When these figures are combined with the ratio of parking spaces required per 1000 sq. ft., which have also been published,[14] a ratio of peak-hour volume as a percent of parking spaces can be determined for these land uses. It must be noted that there is substantial variance from the ITE standards based on the specific characteristics of the land use served by the parking facility and/or the community in which it is located. In general, it is wise to estimate the peak-hour volume conservatively high. In addition to the peak hour of the generator as shown in the table, it is sometimes necessary to check volumes during the peak hour of street traffic, because the two may occur at different times. Also, the larger the facility, the more justification there is for doing a detailed study to more accurately determine the peak-hour volume for a particular case.

3.5.2 Peak-Hour Factor

In most real conditions there are peaks and valleys in the flow during the course of the peak hour. To ensure that the flow is not unacceptably constrained in shorter periods, the flow capacity (in vehicles per hour) of a system should be somewhat more than the expected volume in the hour. Traffic engineers use peak-hour factors to upwardly adjust the volume of traffic. The peak-hour factor (PHF) is usually determined by measuring volumes in 15-min intervals within the hour (V_{15}), selecting the highest 15 min volume, and converting to an equivalent hourly rate of flow, v. Therefore, $v = 4 * V_{15}$ and PHF = V/v. A PHF of 0.85 has been found to be reasonable for most traffic situations in the absence of complete data.

However, if a special-event facility were to "dump" in 30 minutes, the PHF would be quite different. One half of V would have to depart in 15 min, so $v = 4 * .5V = 2V$ and PHF = $V/2V = 0.5$. Also, a parking facility that serves a single employer with uniform starting and ending times can have a PHF as low as 0.5.

The ratio of flow rate to the maximum flow capacity, v/c, provides a good measure for assessing level of service for flow capacity considerations. Table 3-10 provides guidelines for v/c at each LOS. It is not recommended that a LOS D flow capacity be permitted in a parking facility, and therefore no value is provided.

3.5.3 Non-parking Circulation Components

Table 3-10 summarizes the capacities, c, of various non-parking circulation components as calculated using the TRRL equations[10] and the dimensions per Table 3-4. The typical flow capacity of straight express ramps and non-parking bays ranges from 1850 to 1860 vph. The difference in flow capacity between one-way and two-way roadways is negligible.

Capacity is decreased when vehicles flow through a turn or bend. In a parking facility, the most common bends are 90 degrees, 180 degrees, and 360 degrees (in a circular helix).

Table 3-10. Flow Capacity of Circulation Elements

	Theoretical Maximum Flow Capacity, c[1] (vehicles per hours)			
Design Standard For:	LOS D	LOS C	LOS B	LOS A
Straight lane or drive ramp[2]				
One-way	1850	1853	1855	1858
Two-way	1845	1848	1850	1853
Circular Helix				
Single-Threaded	1169	1473	1631	1715
Double-Threaded	1589	1704	1761	1793
Turning bays[3]	936	1097	1233	1345
Design flow capacity[4]	NR	0.8	0.7	0.6

[1] Dimensions for each LOS per Table 3-4, capacity equation per TRRL 1969.
[2] Roadways and express ramps without parking.
[3] Turning radii per Table 3-3; no parking on end bay; no merging traffic.
[4] Ratio of expected flow rate to theoretical capacity, v/c.
NR, Not recommended

The flow capacity of a single-threaded circular helix with LOS D geometry is 1169 vph. Because larger radii are recommended for double-threaded circular helixes to reduce floor slope, the LOS D double-threaded helix has a flow capacity of 1589 vph. It should be noted that a circular helix at the geometry for LOS D is acceptable for one turn and/or slow speeds, but for greater heights, or speeds, LOS C or better should be provided. Note also that the flow capacity LOS still must be determined by calculating *v/c*. The capacity, *c*, will be increased with increasing radius; a single-threaded helix with LOS C geometry has 26% more capacity than one with LOS D geometry. One note regarding circular helixes—they reduce travel distance and eliminate delays for the individual driver along the path of travel. Circular helixes therefore deliver the peak surges in activity to the exit area without the moderating effects of differing travel lengths. Systems with circular helixes thus require more careful design of the control lanes, stacking. and reservoir areas.

Also shown in Table 3-10 are *c* values for U-turns in turning bays based on TRRL[11] equations. It should be noted that the TRRL equation does not include any component for width of lane; given the negligible differences in capacity for straight aisles of varying widths, it seems reasonable to neglect width of lane for curve capacity. The flow capacities at turning bays generally exceed those of adjacent parking bays during outbound flows, as will be presented in Section 3.5.4, and thus do not create bottlenecks. The turning bay capacities are, quite reasonably, much lower than the capacities of straight aisles or roadways without parking and thus control the flow of vehicles in systems that combine straight non-parking ramps with 90- or 180-degree turns at the ends.

3.5.4 Capacity of Parking Bays

The TRRL procedures for determining capacity of parking bays are substantially more complicated. As noted previously the TRRL equations and procedures are not reproduced herein; it is felt that a user must have the complete study in order to properly modify the TRRL equations for North American situations. The procedures have been adapted for North American conditions, and modified for use by personnel not trained in traffic engineering. To make this adaptation, a number of assumptions have been made based on our recommendations for such variables as stall width and aisle width. The reader is cautioned that the values presented are thus predicated on certain specific assumptions that may not match those used in a particular project. Further, it is recommended that the Level of Service of flow capacity be kept at LOS C or better. Therefore, the ratio of v/c should not exceed 0.8.

The TRRL[11] equations for capacity of aisle/stall systems are based on field observations and measurements of situations where all the vehicles attempted to arrive or depart simultaneously. The term *tidal flow capacity* has been adopted for these conditions because, while waves of activity may occur, the volume is all inbound (or outbound) in the peak hour; c_{in} is the tidal flow capacity inbound, and c_{out} is the tidal flow capacity outbound.

The TRRL research found a clear relationship between stall and aisle dimensions and flow capacity. Quite logically, vehicles can arrive and depart in a very comfortable stall/aisle system more quickly than in a system with tighter dimensions. A minor variation in capacity is due to the angle of parking; with approximately equal comfort of turning movement into the stall, the capacity decreases as the angle increases from 70 degrees to 90 degrees. The percentage of vehicles backed into stalls also affects capacity, reducing c_{in} and increasing c_{out}. TRRL also found in the later[11] research that short-span column designs reduce capacity compared to long-span designs. With a typical 30 ft x 30 ft short-span grid system, inbound capacity is reduced by at least 30%, and outbound capacity by at least 15%. Standard statistical theory was used to develop equations reflecting these variables.

The TRRL found that the number of stalls in the system (or subsystem when there are multiple circulation routes) does not materially affect the flow capacity, except as it induces peak-hour volumes. That is, the flow capacity at a particular point in two facilities with the same stall and aisle dimensions and similar traffic flow is the same when one facility has 100 spaces and the other 1000 spaces. Of course, the facility with 1000 spaces is more likely to produce a volume of vehicles that exceeds the flow capacity.

Table 3-11. Tidal-Flow Capacity of Parking Bays

Geometric LOS Angle	Tidal-Flow Capacity[1] (vehicles per hour) D C_{in}	D C_{out}	C C_{in}	C C_{out}	B C_{in}	B C_{out}	A C_{in}	A C_{out}
60° one-way	1349	1011	1500	1037	1500	1065	1500	1095
70° one-way	1189	994	1421	1018	1500	1043	1500	1071
80° one way	886	941	979	961	1130	983	1343	1006
90° one way	693	704	764	716	853	725	970	741

Tidal flow capacity has been calculated, both inbound and outbound, for a variety of angles, and the LOS of the geometrics is provided (Table 3-11). These figures do not include a peak-hour factor. There is obviously an upper limit as to how much the degree of comfort in a turning radius impacts the tidal flow capacity, but the TRRL apparently did not test dimensions generous enough to reach this upper limit. We have therefore arbitrarily set an upper limit on tidal flow capacity at 1500 vph.

The 1984 TRRL research was aimed at covering conditions during which spaces are turning over. The turnover capacity, c_t, was observed by dispatching vehicles at predetermined, pseudorandom intervals to enter the stall/aisle system and park; the driver was instructed to unpark and depart after one vehicle had passed. The TRRL then developed a procedure to calculate what maximum rate of turnover a facility with a certain number of spaces and a specific circulation system can handle in an hour. We have chosen a second approach to the capacity problem, that being whether the expected peak-hour volumes will approach the facility's flow capacity, thus allowing classification of flow conditions by LOS.

There is an obvious relationship between c_{in} and c_{out} under turnover conditions; the higher the inflow, the lower the capacity for outflow, and vice versa. The TRRL found that it is important to look at the mean inhibiting period of each vehicle passing the point at which capacity is critical. In a constant stream of vehicles coming as close together as they possibly can, there is an average headway or spacing that can be expressed in either length (such as feet) or time (such as seconds.) In laymen's terms, each vehicle "uses" a certain amount of the available time. If c_{in} is 1000

[1] One hundred percent of static capacity arrives in 1 hr or departs in 1 hr. See Table 3-5, compact only, for stall and aisle dimensions. Percent reversed: 0% for angle less than 90 degrees, 5% for 90 degrees, c_{max} = 1500 vph.

Source: TTRL 1984.

vph, the average time used per vehicle at capacity flow is 60 min/1000 = 0.06 min = 3.6 sec. If the mean inhibiting period, t, is expressed in hours, it is the inverse of capacity, that is, t (hours)= $1/c$ (vph); t is the average spacing (in time units) at capacity flow.

In a typical parking facility, some vehicles driving a primary circulation route may be searching for a stall, some vehicles may be unparking and exiting, and others may be passing through to or from an area off the circulation route. The TRRL found that the t components would be different for each of these four types of movements.

To check flow capacity in a particular situation, one adds up the mean inhibiting period (expressed in hours) of each vehicle in the stream passing by the critical point in a peak hour. The equation for Σt by the vehicles passing through at capacity flow is as follows:

$$\Sigma t = p{*}x\, t_p + u{*}x\, t_u + s{*}x\, t_s + e{*}\, t_e$$

where

p is the number of vehicles parking on the circulation route, and t_p is the mean inhibiting period of those vehicles, which is $1/c_{\text{in}}$,
u is the number of vehicles unparking and departing from the route, and t_u is the mean inhibiting period for those vehicles, or $1/c_{\text{out}}$,
s is the number of vehicles seeking a stall, but parking off the circulation route being studied, with a mean inhibiting period of t_s, and
e is the number of vehicles that pass through from another area on the way to an exit, with a *mean inhibiting period* of t_e.

Note that the t components must be expressed in hours. Based on our field observations of vehicle spacing at peak hours, a value of 1800 vehicles per hour is recommended for the flow rate of vehicles passing through on the way to an exit; therefore, t_e = 1/1800 or 0.00056 hr. Those searching for a stall but parking off the route are assumed to have t_e = 1/1500 or 0.00067 hr.

In a one-way system, there may be all or only one of these activities impacting the capacity at peak hours. In a two-way system, each of the two streams on the route will have its own Σt; however, the parking and unparking movements affect both streams. Another important consideration in applying this methodology is that the "subsystem" through which the vehicles pass may not be just one ramp or leaf of a series in a typical sloping ramp parking facility. If there is basically continuous flow from parking bay to parking bay, the subsystem for the outbound flow would be the entire series of parking bays along the outbound route followed by the vehicle that must drive the farthest from parking space to exit. When bays act in parallel rather than series, they would be separate subsystems. At most points at which traffic merges, the traffic from the minor leg is reflected in the *e* and *s* components. At points where traffic crosses, Σt for each stream is added to determine if the expected flows can be accommodated.

In the Appendix to this chapter is an example problem to facilitate use of this procedure.

3.5.5 Flow Capacity Level of Service

If Σt is less than 1, there is theoretically some time available for more vehicles to join the stream. Remember, however, that at capacity, one has presumed conditions of absolutely constant flow rather than the peaks and valleys that occur in real conditions. Although a more complicated formula is used now, the 1965 Highway Capacity Manual [15] employed the volume to capacity ratio, *v/c*, to determine the LOS. The *t* components represent *V* in time units; further, because we are looking at how much of the hour is used $V/c = \Sigma t/1 = \Sigma t$. The peak-hour factor and flow rate must also be considered before classifying the LOS. Since $v/c = V/(\text{PHF x } c)$, then Σt/PHF is equivalent to *v/c*. Σt for two of the most common PHFs is as follows:

LOS	v/c	Σt PHF = 0.85	Σt PHF =0.5
C	0.8	0.68	0.40
B	0.7	0.60	0.35
A	0.6	0.51	0.30

3.5.6 Benefits of Flow Capacity Analysis

The type of circulation therefore does affect the flow capacity. In using this methodology, we have found it to be of substantial value in several ways:

- Demonstrating that the LOS is quite good. Congestion for the user should be minimal and need not influence functional design.
- Identifying "borderline" situations. This border cannot be treated as a "Berlin Wall" between acceptable and unacceptable conditions. Rather, as Σt approaches 0.8, further study should be made in an attempt to improve circulation.
- Demonstrating that the system will clearly be overstressed and that additional circulation capacity is required.

- Comparing two alternatives to determine which is the best from a circulation capacity standpoint. The analysis can provide an order of magnitude for the differences, answering the frequently asked question: "How much better is alternative X?" Using this analysis, one can say that alternative X will have 25%, 50% or 100% more capacity, with a corresponding decrease in congestion compared to alternative Y.

3.5.7 Functional System Capacities

When all components are included, virtually every different parking facility will have a different peak-hour flow capacity on its circulation routes. There is, however, some benefit to comparing circulation systems on an "apples-to-apples" basis; the general pattern of flow capacity can be observed and factors that influence flow capacity can be determined. To do this, the static capacity, $N_{\text{LOS C}}$, which produces a v/c ratio at LOS C has been calculated for many common functional systems under four scenarios:

- Special events where the volume of vehicles arriving before the event and the volume departing after the event are each equal to 85% of the static capacity. There is, further, no departing flow during peak arrival periods, and vice versa (PHF = 0.5).
- Retail use with both arriving and departing volumes equal to 60% of the total number of parking spaces; these volumes occur simultaneously (PHF = 0.85).
- Office use where the volumes arriving in the morning or departing in the evening are each equal to 60% of the static capacity. The opposing flows (departing in the morning and arriving in the evening) are equal to 5% of the number of parking spaces (PHF = 0.85).
- Airport parking conditions where both the volumes arriving and departing in a peak hour are equal to 30% of the total number of parking spaces; these volumes occur simultaneously (PHF = 0.85).

These percentages were selected to represent relatively high traffic volumes for those uses and thus would tend to be conservative. The results are shown in Table 3-12. Isometric views of most of the circulation systems have been previously presented. These table values work only for designs with flow patterns exactly as shown in the isometrics.

The tables all assume geometrics at LOS C, and adjustment for other conditions may be made by adding approximately 50 spaces in static capacity per step. That is, an LOS D design would have a capacity of the table value minus 50, and LOS A would be the value plus 100. Long-span conditions are also assumed; if a short-span design is used, capacity will be reduced substantially. Designers can use this table as a guide to selecting a design that will provide LOS C or better in terms of flow capacity. Because of the range of the scenarios, the tables may be interpolated for different arrival and departure rates. For example, if a single-threaded helix is expected to have simultaneous-peak hour arrival and departures equalling 40% of capacity, one can interpolate between values in the retail and airport columns. ($N_{LOS\ C}$ = 420 + (840 - 420) x (0.4 - 0.3)/(0.6 - 0.3) = 560 spaces). It is important of course to check for the "weakest link in the chain," be it the parking aisles, a circular helix, or an express ramp.

When the size of the facility exceeds the static capacity that would produce a LOS C *v/c* ratio, alternatives or secondary routes should be developed. For example, if *N* is 800 compared with a table value that shows that a 700-space facility will be at LOS C, a different circulation system should be provided. The numbers are not so precise that exceeding the recommended static capacity by five to ten spaces will cause a major problem. The designer's judgement must always resolve "close calls."

Table 3-12. Functional System Capacities

		$N_{LOS\ C}$							
	Use:	Sp. Event		Retail		Office		Airport	
	PHF:	0.5		0.85		0.85		0.85	
Arrival/Departure	Rate:	85% - 0%		60%-60%		60%-5%		30%-30%	
	Angle	70	90	70	90	70	90	70	90
Two-bay systems									
Single-threaded helix		N.A.	335	N.A.	420	N.A.	750	N.A.	840
Double-threaded helix		585	675	980	840	1360	1505	1960	1675
End-to end helix		585	675	980	840	1360	1505	1960	1675
Split level		480	335	670	420	1090	750	1345	840
Three-bay systems									
Interlocking helix		545	505	850	625	1255	1125	1695	1250
Double-threaded helix		635	830	1160	1135	1490	1880	2325	2275
Side-by-side helix		480	410	710	560	1100	930	1425	1125
Four-bay systems									
Side-by-side helix		585	675	980	840	1360	1505	1960	1675
Single-threaded helix		585	465	980	680	1360	1065	1960	1360
Double-threaded helix		655	930	1275	1360	1555	2125	2545	2720
Larger systems									
5 Bays, Single-threaded helix		615	505	1080	775	1430	1160	2160	1555
5 Bays, Double-threaded helix		675	1010	1335	1550	1600	2320	2710	3110
6 Bays, Single-threaded helix		635	535	1160	865	1485	1270	2325	1730
6 Bays, Double-threaded helix		690	1070	1415	1730	1635	2540	2835	3460

3.5.8 General Implications

There are certain key considerations that maximize the ability to accommodate traffic. TRRL's research confirms in theory a number of rules for good design that many professional parking consultants have learned in practice. It is generally advantageous to provide separate, one-way, inbound and outbound routes even when there is little or no opposing flow. This result is related directly to the fact that fewer spaces are located along the circulation route. For example, under office use, $N_{\text{LOS C}}$ for 90-degree parking in a two-bay, single-threaded helix (in which the in route is retraced outbound) is 750 spaces compared to the 1360 space $N_{\text{LOS C}}$ of a 70-degree, one-way double-threaded helix, which has separate in and out routes. The outbound vehicle encounters proportionately fewer delays from vehicles unparking along the outbound route in a double-threaded helix and thus the total static capacity can be greater.

Similarly, the flow capacity of a one-way, angled parking layout is greater than a 90-degree, two-way design on the same system, if there are the same number of circulation routes. A one-way split level, for example, has 60% more capacity with retail use, and 45% more capacity with office use, than a two-way design. Therefore, although both designs may have adequate capacity, there will be less congestion and delay to users in the one-way system. When 90-degree parking and two-way circulation on the same ramping system increase the number of circulation routes (such as when two-way traffic is employed on a double-threaded helix), there is some increase in the capacity of the system when there is substantially one directional flow, and/or there are many spaces off the circulation routes. However, when there is opposing flow, one one-way system may have more capacity than two two-way systems. For example, when two-way flow with 90-degree parking is used instead of one-way 70-degree parking on a double-threaded helix, capacity with retail use reduces almost 15% ($N_{\text{LOS C}}$ is 840 versus 980). However, with office use, the two-way system increases flow capacity about 10% (1505 versus 1360). As spaces are added in bays off the circulation routes, the capacity benefit of one-way traffic flow is diminished. When a four-bay facility with a double-threaded helix plus two non-circulation bays is provided, the two-way system has 7% more flow capacity with retail use and 37% more capacity with office use than the one-way system.

The rule of thumb that says "angled for retail, 90 degree for office" works well for some situations, but not for others. In terms of flow capacity:

- Angled parking is "better" when there are equal numbers of circulation routes.
- Two, two-way outbound paths are "better" than one, one-way outbound path for office use.
- One, one-way outbound path is "better" than two, two-way outbound paths for retail use, if most spaces are on the paths of travel.
- Adding non-circulation bays increases flow capacity, especially under high-turnover conditions such as retail.

In summary, the TRRL analysis method permits the capacity and congestion issues to be reviewed objectively rather than subjectively. Statements like "one-way traffic is better," or "two-way traffic providing more routes is better," can now be based on analysis rather than intuition. While the analysis procedure is still somewhat theoretical, it can be used to compare two circulation systems on an "apples-to-apples" basis.

3.6 PEDESTRIAN FLOW CAPACITY

Prior to about 1990, parking facilities were primarily viewed as vehicle storage facilities, and were designed predominantly with the needs of drivers and vehicles in mind. As parking facilities have grown larger, pedestrian considerations have begun to be recognized as important to good parking design. The second edition of this text devoted significantly more attention to wayfinding for pedestrians, and included a chapter dedicated to signage and graphics, much of which is oriented to pedestrian considerations. The litigious nature of our society causes many to try to recover "damages" for what was once considered a simple "accident." An entirely new chapter of this text is now devoted to safety, with significant emphasis on pedestrian safety.

Another concern of pedestrian planning is flow capacity, which is ever more important as the increasing emphasis on entertainment uses has increased the volume of pedestrians moving through parking facilities in a peak hour. There are now a number of parking facilities in the US with more than 10,000 parking spaces, at least three of which have been designed for pedestrian volumes in excess of 10,000 persons per hour.

Therefore, more and more facilities are being designed for complex pedestrian movement requirements. See Figure 3-22.

Figure 3-22. As parking structures become larger, more facilities require careful design of pedestrian collectors. Courtesy of Walker Parking Consultants

The ground-breaking work on pedestrian design by Fruin remains the most widely used standard of design for pedestrian concerns. Without repeating all of the research and bases of his recommended design criteria, the following sections address certain design issues that are important to successful design of pedestrian activities in parking facilities. Pedestrian flow capacity issues in parking facilities typically center on elevator and pedestrian bridge design considerations, with escalators and stairs being less common. Table 3-13 summarizes flow capacity criteria for these components.

Table 3-10 recommending peak hour volumes of vehicles entering and exiting parking facilities can be easily converted to estimated pedestrian volumes with assumptions for persons per car. For uses serving predominantly commuting employees and/or students, an assumption of 1.2 to 1.7 persons per car is generally reasonable. For "customer" parking at shopping centers and other short term parking situations, 2 persons per car is a typical assumption, while entertainment uses typically range from 2.5 to 3.0 persons per car.

Table 3-13. Flow capacity of pedestrian elements

Level of Service	D	C	B	A
Walkways, Corridors and Pedestrian Bridges[1]				
Persons per effective foot width, per minute	20	15	10	7
Persons per hour	1200	900	600	420
Stairways [1]				
Persons per effective foot width, per minute	13	10	7	5
Persons per hour	780	600	420	300
Queuing[1]				
Average Pedestrian Area Occupancy sq. ft./person	3	7	10	13
Elevators[2]				
Nominal loading, persons				
2000#	8			
2500#	10			
3000#	12			
3500#	16			
Escalators (Persons Per Hour)[2]				
24" step width, 90 feet per minute	2025			
24" step width, 120 feet per minute	2700			
40" step width, 90 feet per minute	4051			
40" step width, 120 feet per minute	5401			
Moving Sidewalks (Persons Per Hour) No Incline				
24" Treadway Width	2400			
36" Treadway Width	4800			
40" Treadway Width	7200			

One important note is that Fruin employs an "effective width" approach for stairs, corridors and the like, based on the propensity to maintain this separation from stationary objects and walls. Therefore the clear width is reduced by about 18 in. on each side before determining the level of service.

Queuing in waiting areas can become an issue in elevator lobbies and, more recently, in pay-on-foot payment lobbies. Determination of elevator

[1] Fruin, J. J., 1987. *Pedestrian Planning and Design,* revised edition. Mobile, Alabama: Elevator World Inc.

[2] Stakosch, G.R. 1998. *The Vertical Transportation Handbook,* Third Edition. New York: John Wiley and Sons, Inc.

requirements is considerably more complex, and includes such variables as the size of the cab, the speed of the elevator, the total number of stops, on what floor the primary lobbies are (at grade or pedestrian connections to the destination), etc. These issues are best addressed by a vertical transportation consultant, but for preliminary design purposes, a recommended "preliminary" number of elevators are given for various height structures and use types, similar to those in Table 3-12.

Table 3-14. Elevator Capacities

		Maximum number of parking spaces above grade per elevator			
	Use:	Sp. Event	Retail	Office	Airport
	PHF:	0.5	0.85	0.85	0.85
Arrival/Departure	Rate:	85% - 0%	60%-60%	60%-5%	30%-30%
Tiers above Grade					
2 tiers, per elevator		236	358	697	955
4 tiers, per elevator		191	286	565	764
6 tiers, per elevator		158	246	468	657
8 tiers, per elevator		138	216	387	849

3500 lb, 150 fpm elevators assumed.

When elevators are split into banks, an additional inefficiency factor should be employed. For example, if a parking garage serving retail has 6 tiers above grade, and a total of 1500 parking spaces on those six levels, it should be planned to have 1500/246 =6 elevators. However, if the elevators are provided in two different locations, with 60% going to one bank, the preliminary number of elevators is 1500*0.6*1.1/246 = 4 elevators at the larger bank, and 1500*0.4*1.1/246 = 2.7 or three elevators.

It should also be noted that the acceptable waiting time for an elevator for most uses is assumed to be 30 seconds. However, a waiting time of 60 seconds is assumed for the elevators served under a special event condition. Moreover, if alternative methods of pedestrian vertical circulation are provided, i.e., stadium ramps or escalators, the number of spaces served by an elevator should be adjusted accordingly. For example, if a structure with six supported levels serving a special event facility will have 1500 spaces, and it is assumed that half of the people will use the stairs, it should have 1500/2/158 = 4.75 or five elevators.

The above table is based on "conservative assumptions" regarding peak hour volumes, persons per car, etc. and is intended to be used in the early phases of design. During design development, consultation with a vertical transportation consultant, using more realistic peak hour volumes and factors, may result in a reduction in either the size of elevator required, or in the overall number.

3.7 PUTTING IT ALL TOGETHER

There are many subjective considerations in the selection of a circulation system, such as wayfinding, flow capacity, type of user, dimensions of the site, efficiency, spaces passed, and number of turns. For example, it may be desirable to route unfamiliar users past most of the spaces in a small to moderate-size facility, contrary to its effect on capacity. Side-by-side (with four bays), end-to-end, and double-threaded helixes with one-way traffic flow all route drivers past half the spaces on the way up and the other half on the way down. These systems are therefore good designs for retail with a capacity of up to almost 1000 spaces. The number of turns to the top, geometrics, and the size of the site would be other considerations in selecting among these circulation patterns. These systems are also excellent for airport and hospital uses. It should be noted, however, that while capacity restraints under airport peak-hour flow might permit these facilities to have as many as 2000 spaces, the search time for the available space is probably too long. While adding bays off the circulation route might increase capacity, the ability to find the available space is reduced.

In larger systems, flow capacity and wayfinding both point to the use of flat floors with express ramps (see Figure 3-23). The parker then need only search a compartment with a reasonable number of spaces. Today's sophisticated occupancy counting systems allow automatic direction of parkers to the floor with the most spaces available. The compartments can have either angled or 90-degree parking as appropriate to the design. Two-way systems tend to have more accidents (it is harder to see all approaching vehicles) and to have conflicts when two drivers coming from opposite directions want the same stall. One-way traffic patterns are thus "better" for turnover.

In general, if parkers can see across several bays to available spaces, two-way end bays should be provided whether or not the parking bays are two-way. Drivers then can get to the available spaces quickly and without frustration. If, however, parkers must be routed through an area a certain way, angled parking should be provided throughout the system. A second, internal ramping system may be desirable to allow circulation between floors, and may be critical if the express system must be closed for maintenance. The secondary system may have parking along the path of travel, and parking should be angled unless traffic flow on it will be minimal.

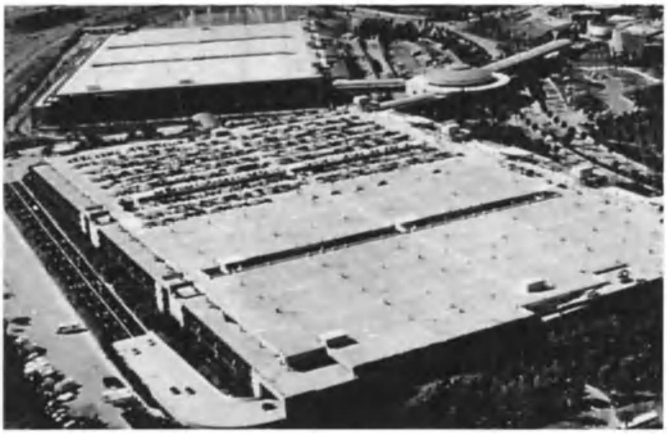


Figure 3-23. With an express ramp and flat floors, a mega-structure becomes a series of parking lots stacked vertically. Courtesy of Walker Parking Consultants

Such two-bay designs as a single-threaded helix or a split-level are very limited in application owing to restrictive flow capacity ($N_{\mathrm{LOS\ C}}$ is about 420 spaces with retail use and 750 spaces with office use with 90-degree parking). These systems are also considered less desirable by drivers than most other systems when the height exceeds three or four levels, owing to the number of turns and the frustration of knowing that one is passing the same spaces on the way down as on the way up. Therefore, a design that has fewer turns, passes fewer spaces, and has less congestion (by virtue of having a greater flow capacity) will be "better" whether or not the capacity is exceeded.

For regular users, a double-threaded helix as the principal traffic route (whether one- or two-way) is almost always considered preferable with four or more tiers because the exit path is substantially shorter. If the site permits, additional level bays of parking off the circulation routes are acceptable as they further reduce travel distance and congestion. Because most users are present every day, they will know where to find an available space at a particular time of day. It should be noted that a one-way system on a double-threaded helix is still preferable unless capacity problems require more than one up and one down route. Some additional capacity may be achieved by using two-way traffic on each of the routes in the double-threaded helix. Again, however, two one-way routes down will still be "better" than two two-way routes.

3.8 SUMMARY

The level of service approach to parking design provides a valuable tool for tailoring a design to the specific needs of the expected users. Guidelines using LOS have been provided for many design parameters in parking facilities wayfinding, turning radii, ramp slopes, travel distance, geometrics, and flow capacity. Using these guidelines, a comfortable, well-functioning internal circulation system can be developed for each and every parking facility. The next chapter – Access Design – deals with an equally important element in design: getting the vehicles you want into the facility, keeping those out that you don't want, and collecting the established parking fee from each and every user.

3.9 REFERENCES

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Chapter 4

ACCESS DESIGN

Mary S. Smith

4.1 INTRODUCTION

The design of the entry/exit areas is critical to the ultimate acceptance and profitability of a parking facility. These areas provide the patron's first and last impressions of the facility. A positive or negative experience will be a very influential factor in decisions regarding future patronage.

To ensure good access design, a number of things must be considered:

- What type of parking access and revenue control (PARC) system, if any, is to be provided?
- How many lanes are required to handle peak loads?
- Are there any special design requirements such as evening event parking?
- What configuration of each lane is required to ensure that the PARC system works as intended?
- How much space is required to accommodate the lanes required, as compared to the space available?
- What are the requirements for auxiliary spaces such as parking management offices?

Before we proceed, however, we must dispense with the first and most obvious decision: Is a PARC system needed at all? A PARC system has one or both of two fundamental purposes–keeping unauthorized users out, and keeping revenues in. If neither of these purposes is an issue, a PARC system is not required. This situation sometimes occurs at a self-contained development that will provide free parking. The access points will be "free flow," at least to the extent the surrounding street traffic system and the internal circulation design permit. If you know you aren't going to have a PARC system, you can skip this chapter altogether. Otherwise we'll proceed with determining what PARC system is right for the project at hand.

A. P. Chrest et al., *Parking Structures*

4.2 PARC SYSTEMS

4.2.1 Levels of Revenue Control

Before discussing specific systems, it is helpful to differentiate between the various levels of revenue control. Following on classifications originally developed by Donohue and Lathan,[1] we have defined "levels of revenue control"[2] as seen in Table 4-1. It should be noted that the Parking Consultants Council has more recently adopted its own levels of control that differ slightly from those published herein.[3]

The first level of control is virtually all by hand and provides, in fact, very little "control"; hence the designation level "0." These controls are rarely used today except in special-event facilities where speed of transaction is critical, as well as in older facilities that provide all-day parking at fairly low fees.

Level 1 controls include electromechanical devices, but have little to no audit trail; for example the first generation of true PARC was a ticket-issuing machine with a cash drawer and out clock. These systems essentially have been replaced by the next generation of equipment and are little marketed if they are still even in production.

Level 2 devices add the first level of electronics, with an audit trail at each device but no centralized reporting. Some memory for data storage and automatic control of devices such as gates is provided.

Level 3 controls use microprocessors in individual devices. From the user perspective, Level 3 controls generally are "bells and whistles" added to level 2, including machine-readable tickets, online card controllers, and pay-on-foot machines. However, there is still no centralized reporting of revenues at this level. To determine total revenue, the reports from the fee computers, card controller, and monthly payment ledger must be either hand copied and tabulated or entered into a separate computer program for reconciliation.

At level 4, most if not all devices are online to a central computer that monitors activity in "real time"— i.e., as it happens. Note that in most of the available systems today, the central computer polls the devices in sequence every few seconds so it is not true real time but is close enough for management purposes. A manager can observe all transactions by one cashier, determine overall occupancy in the facility, or monitor the activity at any or all lanes. Customized reports are developed and then issued automatically, with exception transactions (any occurrence that could be an indicator of theft/fraud) tabulated and highlighted.

Table 4-1. Levels of Control in PARC Systems

Level	Examples	Typical Applications
Zero	Cigar box	Special-events
hand	Hand-issued tickets	Very low fee or
	Slot boxes	Turnover
	Paper permits	Very small lots (<50 spaces)
	Hang tags	
	Decals	
One	Meter (mechanical)	Small lots
mechanical	Coin/token collector	(<100 spaces)
	Zero + mech counters	Low fees/turnover
	Cash register/out clock	
	Non-programmable card reader	
Two	Fee computer	50-500 spaces
electronic	Programmable card reader	
	Electronic meter	
	Electronic multi-space meters	
Three	Two +	300 spaces and up
time and revenue savers		Machine-read tickets
	Licensed plate inventories	
	Debit cards	
	Credit cards	
	Central cashiering	

The argument for on-line parking equipment is the same as in any other industry: the information made available to management increases greatly while the time required of personnel at all levels is reduced. One of the primary audit tasks in any PARC system is to correlate tickets issued, vehicles present, and time parked with revenue generated. Computers can do this in seconds, not hours. On the other hand, far more information is generated by a state-of-the-art system than many users want or need. To determine the right PARC system for each situation, it is critical to assess what is expected from the controls. Some or all of the following may be concerns and priorities of a client:

- controlling cash revenues
- detecting employee theft
- monitoring by on-site managers/supervisors
- detecting customer fraud
- totalling and auditing cash revenues from several cashier stations or several facilities
- maintaining an accurate count of spaces available
- providing activity counts for auditing purposes
- minimizing error
- controlling regular all-day parkers
- minimizing waiting time and/or delays
- providing passive or active security by cashier presence
- minimizing labor cost
- maximizing turnover, utilization, and revenues

As more Level 3 features are added, the "tighter" the controls become. The need for Level 4 controls generally increases as the fees and revenues increase; the incentive for patron cheating and/or fraud, of course, is directly proportional to the fees. Likewise, the more money a cashier handles, the more he or she is tempted to try to divert funds for personal use. Employee theft is generally an even bigger problem than patron fraud and if uncontrolled, can severely impact revenues. An additional, less predictable variable in the equation is the "computer hacker" who tries to beat the system merely for the challenge of doing it. The worst cases of theft often involve a few employees and/or a supervisor working with a hacker who modifies the programming to hide individual, small thefts occurring day in, day out, over a long period.

It is, in sum, critical for the owner to determine the priorities of the PARC system. Once the needs and expectations are known, the most cost-effective control system can be determined.

4.2.2 Nongated Systems

The parking meter was invented over 50 years ago to provide a means of keeping employees out of prime spaces intended for visitors and customers. The basic theory is that short-term users are willing to pay a nominal amount for convenient parking; employees are theoretically not able to keep the meter current by leaving work every two hours to "feed" it. The hourly rate of the meter is intended to cover the cost of collecting the fees and maintaining the meter; in some cases a much lower rate is charged at spaces intended for long-term parkers. When used as intended, meters are quite effective, especially with widely scattered spaces on streets and in small lots.

In practice, however, the meter is frequently misused. Local governments may trim enforcement and maintenance expenditures to lower than acceptable levels, while diverting meter revenues to bolster the general fund. Hourly rates have generally not kept pace with inflation. Area employees find that they can get away to feed the meter a couple times a day and are willing to pay the meter fee and an occasional ticket.

Cheating meters is a "folk crime": everyone does it if they think they can get away with it. If the municipality does not pursue enforcement vigorously, "scofflaws" ignore tickets and may eventually accumulate hundreds of dollars in unpaid ticket fines. Owing to vandalism, poor maintenance, and time-consuming court appearances by enforcement personnel, a substantial number of tickets are thrown out of court. Thefts of the collected funds by both vandals and collection personnel are frequent problems. Under these conditions, the meter is an inefficient means of controlling parking.

Several variations on the meter have been developed. Second-generation electronic meters appear quite similar to the old standard; however, the electronic workings require less maintenance and provide audit information to detect and document theft. The cost of these meters is only 25% more than conventional meters, which should be paid back in relatively a short period. Optional features include solar power and acceptance of prepaid "frequent parker" cards. Enforcement and ticket collection problems, however, remain largely the same.

Another alternative to the conventional meter is the slot box. This device usually consists of a box with numbered slots corresponding to each parking stall in the facility. It is non-electrical, and has no moving parts. The patron inserts the posted fee in the slot. Collection personnel then check that the appropriate fee is present for each occupied space and issue violation tickets to those who have not paid the correct fee. Payment of these tickets is generally on an honor system. These boxes are most effective in perimeter all-day parking lots, where a flat rate is charged and revenues can be checked and collected just once a day.

Electronic meter boxes have likewise been developed in recent years. There are two basic types. Electronic "pay and display" units operate as follows: The patron parks the vehicle in a space, goes to the meter, pays a variable fee for a certain amount of time, and returns to the vehicle to place the voucher on the dashboard. The voucher is checked during enforcement procedures. Somewhat less convenient for the patron than individual meters, these units have been more widely employed in Europe, but are becoming more common in the US for on-street parking. (See Figure 4-1)

Figure 4-1. Pay and display systems are becoming more common for on-street parking in the United States. Photo courtesy of Dambach

The other type of electronic meter box, the multi-space meter (MSM), represents a third- generation solution. The parker is not required to return to the car with a voucher. Instead the spaces are numbered; the parker enters the space number before paying. The device has a microprocessor, which prints a list of currently paid spaces for enforcement officer use during ticket writing. While this system is more user-friendly, users who paid the device after the officer pulled the list—but before the officer's route brought him to the space—can get ticketed. Therefore, the officer usually has to return to the device frequently for updated lists; in parking structures, this requirement may require placing one device on each parking level.

With either type, a wider and more complex range of fee schedules is available, making electronic meter boxes applicable for short-term as well as long-term parking. Dollar bill acceptors and/or changers are provided to reduce coin storage requirements. The machine can accept monthly parkers' cards with nearly all the features discussed for "online" card systems later in this chapter.

Both types also have audit information to provide accountability for the revenue collected. One primary benefit to such a unit is that one enforcement officer can check several facilities frequently, eliminating full-time cashiering at each facility. The ability to accommodate large volumes of vehicles in peak hours is also greatly improved by the lack of gates and cashiering. When combined with card capability, the MSM finds its best application in facilities that predominantly serve monthly parkers and are most frequently seen in commuter parking facilities at intermodal facilities. Converting an underused cashier into a roving enforcement officer improves security as well.

There are also some interesting possibilities in locating several pay units throughout a mall, downtown area, or airport with the units interconnected to each parking facility. The patron who has exceeded a time limit has only to go to the nearest station, enter the space and facility numbers, and purchase more time.

The chief disadvantage to any form of meter is that all are essentially "honor" systems and introduce a punitive aspect to the parking experience. When the multispace meters at an airport short-term lot were replaced by gated controls, one disappointed patron reported to the local paper that he had parked regularly for years without **ever** paying. Scofflaws may ignore tickets if enforcement is insufficient, and private owners may lack a legal remedy for collection. Patrons may also complain that they didn't stay as long as estimated and overpaid their parking fee. Indeed in at least one location where multi-space meters replaced a conventional parking system for downtown short-term parking, there were many complaints that it was merely an attempt by the city to "make more money" off violation penalties and overpaid parking fees.

It was chiefly for this reason that the parking gate was invented (see Figure 4-2). The gate keeps unauthorized users out and authorized users in until they have paid the appropriate fee. Parkers can be charged based on the actual length of stay, rather than an estimate made at the time of arrival. Patrons thus do not have to worry about whether or not a meter has expired.

The public views the system as more fair and user-friendly. In general, a gated system will yield more patron revenue than an ungated system, which in most cases more than pays for the higher operational cost of the gated system. Therefore, most parking structures today with a fee for parking are gated.

4.2.3 Gated Systems

The typical gated PARC system consists of a cashier system for daily fee parkers and a system for regular parkers who prepay on a monthly basis. With the increasing availability of systems allowing other forms of payment by regular users, we now call these parkers frequent parkers. Alternate payment options for frequent parkers are discussed later in this chapter.

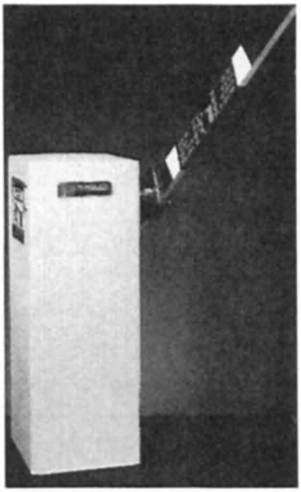

Figure 4-2. The parking gate was invented to keep unauthorized users out and revenues in. Photo courtesy of Federal APD.

In the most primitive gated systems, cash is kept in a "cigar box," with no audit trail whatsoever. The frequent parkers are issued permits in paper or decal format. Gates, if provided, are opened manually or by command of the cashier. These systems provide almost no revenue control, and are really not "parking access and revenue control systems" at all.

In the first generation of true PARC systems, the gates are automatically opened by electrical signals sent by other devices in the lane such as ticket dispensers and card readers. In most cases, the gate is closed by a signal from a vehicle detector, which monitors a loop in the pavement. For parkers who pay a daily fee, tickets are issued at the entry lanes. At the exit, an out clock stamps the ticket with the exit time. The cashier enters the fee in a standard commercial cash register and collects the fee due.

Card readers are usually provided at both entry and exit for monthly parkers because the speed of the transaction is two to three times faster than if the cashier processes the monthly parker. Note that level 1 systems typically can only handle monthly parking and not other frequent parker payment options. Card systems reduce the number of lanes and staffing requirements and are very cost-effective. Reversing a magnetic field in the card with each use at entry and exit provides Antipassback controls. Once a card has been used at an entrance gate, it must be used at an exit gate before it will be accepted at an entrance again. If passback problems are not expected, the system may be designed as "card in, free out."

The negative aspect to first-generation gated systems is that control is not very sophisticated and substantial management time is required to achieve most of the usual goals of PARC systems discussed previously. With a cash register, the only record of transactions is the journal tape. Substantial auditing time is required to find errors, theft, and fraud, which can occur in either the daily fee or monthly parking systems. Virtually every ticket must be hand-audited. To lock out one card user who is no longer authorized to use the facility, all cards must be collected, recoded, and reissued. If the coding is not changed, cards can remain in circulation for months or even years after the cardholder loses authorization to use the facility.

The next generation of PARC system reduces or eliminates all of these problems, at relatively low additional cost. In fact, second-generation systems are almost always cost-effective and should be used in virtually all cases. Today's fee computer systems automatically print summaries of activity each day, report transactions by type, reconcile cash that should be in the drawer, and raise red flags for exception transactions.

Tracking exception transactions permits the manager to note, for example, that there are a lot of "lost tickets" when one particular cashier is on duty. The fee computer thus provides a better audit trail for auditing cash revenues than a standard cash register, primarily because the system software is specially designed for parking. The fee computer also allows the transaction to be completed more quickly since only the "in" time and any validations are entered and the fee computer calculates the fee. Errors and some types of cashier and patron fraud are reduced. The fee computer has a fee indicator specially designed for visibility by the exiting driver. Presumably, the driver will notify management if the fee quoted by the cashier is different from the fee displayed by the fee computer.

A common misconception is that fee computers eliminate the need to audit activity daily. The tickets turned in at the end of each shift must still be checked to be sure that a cashier is not entering a false time or falsely recording validations. This check is more easily done if each ticket is printed with the transaction information processed by the fee computer. Daily, monthly, and annual reports for a facility, much less for a group of facilities, must also be prepared by manually totalling the paper reports from each lane.

The second generation of card systems allows owners to invalidate the cards of those that are no longer employed or haven't paid, even if the card has not been recovered from the individual. These systems also prevent employees from "losing" a card while actually giving it to someone else. The card reader is "smart" in that it is microprocessor controlled. Periodically, management personnel can go to each card reader and, using a device similar to a hand-held calculator, program the reader not to accept specific cards (such as 113, 283, 139) and/or all cards in a certain block (such as 203—249). These card systems also have antipassback capability.

Another important component of the second-generation PARC system is a vehicle counting system. A differential counter maintains a count of the number of vehicles in the facility at all times. When occupancy reaches the preset "full" level, the unit automatically illuminates the full sign until occupancy drops off again. When card systems are used, it is generally desirable to set the "full" level a few spaces below actual capacity. The ticket dispenser is interconnected so that a ticket won't be issued until the occupancy drops below "full." However, the card readers continue to let card holders in, with the cushion of extra spaces between "full" and the actual capacity ensuring that the authorized frequent parkers will find a space. The vehicle counting system also should have nonresettable counters, two for each lane, that automatically record gate uses and card uses. By comparing the total of card uses and cash uses (the latter as reported by the fee computer) with the total of gate uses for each cashier's shift, the manager can determine if cash transactions are being performed by hand, with the revenue going into the cashier's pocket.

4.2.4 Upgrades to the Basic Card System

In situations with numerous gates and especially when there are several lots and facilities (such as at a campus or hospital), a centralized computer system should be used for cards. All the readers are hard-wired to a central microprocessing unit; therefore the generic name is an on-line card system. The central computer may be either a standard microcomputer, such as a PC, or a unit with a CPU, operating system, and memory designed specifically for this application. There are two variations of the online card system: the "dummy" reader and the "smart" reader. In the former case, whenever a card is used at any gate in the system, the number of the card is transmitted to the central unit, which checks to see if it is valid. Authorization for every transaction is sent from the central unit. In the smart reader case, the wiring from reader to central computer is used to "download" changes in authorization, eliminating the need to go from reader to reader with the hand-held device. The authorization decision is made at the reader itself. The smart systems tend to be more expensive (because, of course, each reader is more expensive) and may require more maintenance. However, all readers are not shut down when the master unit goes down, as is the case with the dummy reader.

There is some disagreement in the industry over how tightly the antipassback controls should be applied. "Misreads" of card number are occasionally a cause of problems, often creating a chain reaction with other users. For example, if card number 301 is read at an entry lane as card number 311, the computer will not let card 301 out in the evening as it hasn't been considered "in." Meanwhile, card number 311 can't get in, because the computer thinks it already is "in." In some cases, the misread problem becomes progressively worse owing to degradation of the cards over their usable life.

Almost all major manufacturers have reacted to this problem by designing the antipassback software to be used in either a soft or firm mode, as selected in the field by the owner/operator of the facility. The soft control accepts a card that is properly paid but is out-of-sync with respect to antipassback mode, printing an error message at the central controller for follow-up by the management. Follow-up and/or disciplinary action may only be taken for repeated offenders. The argument for soft control is that it eliminates backups, delays, and complaints at lanes when a "good" card is rejected. The proponents of firm-only controls, which reject the out-of-sync card, argue that the correction to misreads is to eliminate the misread problem rather than to accommodate it. Furthermore, soft systems tend to encourage "lazy" users, who pull a ticket on the way in when the card is not immediately at hand. The ticket is then discarded, and the card is used to exit, avoiding the usually longer line at the cashier. The discarded ticket throws off the daily cash revenue audit. When challenged about the antipassback violation, the lazy user plays dumb and blames "the computer" or shrugs and confesses to being unable to find the card when entering. A similar problem occurs when gates are lifted in off hours and the card holder doesn't stop to card out. The next morning the computer thinks the user is still "in."

The firm mode proponents say the delay that occurs at the lane when a card is rejected is enough to ensure that the lazy and/or fraudulent user tries it only once. However, with today's emphasis on service to the user, the soft system has its advantages. We believe soft and firm antipassback should be provided with any system and the owner/operator should be able to select which to use based on the circumstances at hand. The need for firm antipassback increases as the incentive to cheat the system — which is usually the price of parking — increases. If an owner isn't yet sure how tight the controls should be, buying a system with selectable soft and firm antipassback provides flexibility to determine through experience what is the "best" system.

There are, of course, times when many vehicles legitimately depart without carding out, such as if the computer is down or if a special situation occurs. The resynchronization feature was invented to correct this problem. When resync is activated, all cards are given one authorization in or out before firm antipassback is restored. This feature can be misused; if done too frequently, the firm antipassback control is essentially voided. The on-site personnel can also use both soft anti-passback and resync features for theft or kickbacks, and thus passback violation reports need to be monitored.

A good online card system has the capability to allow any individual card access at certain points and at specific times while denying access at others. Take, for example, a hospital with a number of different parking facilities. An employee card would not work at a certain lot until after 2:00 P.M., reserving those spaces for the evening shift. Doctors' cards might work anywhere or at only one location. When the status of a particular card is to be changed (for example, Jane Smith has been promoted to a position that allows her to park in a different area), the information is entered at the central console. Ms. Smith never has to turn in her card to be reassigned to the new lot.

Some of the systems on the market do far more. For example, in a commercial facility, the ledger for monthly payments is part of the system. If someone has not paid on time, the computer can automatically lock out that person at either the entrance or exit point. The cashier can honestly sate he has no control, but can certainly accept the individual's payment! If the individual does not pay the monthly bill, he or she can be charged for parking at the transient rate.

Another possible feature is the so-called per diem option. One major tenant in a building leases a block of spaces for its employees, but argues that many of its employees are outside salesman who will not be present most of the time. Therefore, 500 cards are to be issued at the fee for 400. The computer keeps track of occupancy by these users and when the 401st patron enters, it begins charging hourly rates for that and all subsequent patrons from this group until the number drops below 400. At the end of the month a statement is issued to the tenant for the hourly charges. This option can also be used for those who regularly come to a facility but stay for shorter periods, such as doctors and part-time employees. The system keeps track of the usage, and bills are issued for parking charges accumulated over the previous month.

There is also a nesting feature available. If a user pays to park in a certain area on a monthly basis, he or she must pass a second card reader to the area within a set period of time after entering. If the user fails to park in the assigned area, he or she can be refused exit that day, or refused entrance to the facility the next day.

4.2.5 Other Upgrades/Options

One of the most desirable and common upgrades to the cash control system is the use of machine-readable tickets. Machine-read systems substantially reduce keying error and the potential for employee theft. Audit requirements are reduced as tickets do not need to be checked daily unless damaged or mutilated. Auditing and tracking of exception transactions become random, rather than regular. The speed of the transaction is also somewhat faster, sometimes allowing a reduction in personnel and/or equipment needs.

As previously mentioned, frequent parker programs are becoming more popular. This program allows regular users who can't justify paying for parking on a monthly basis to enter and exit via the card system. Declinating systems involve the prepurchase of a ticket or card for certain sums—say, $100 worth of parking. With each use, the fee is deducted from the balance until the prepaid amount is used up. It is usually desirable to have a reader process these users at both entry and exit, bypassing the cashier. A light on the reader warns when the fee remaining is low. Cashiering needs can thus be reduced, and customer service to regular users is greatly enhanced. This option is quite similar to the technology employed for commuter rail systems like the Washington DC Metro. Some in the industry call these debit cards, but that is technically incorrect. In the financial services industry, a debit card is one that results in an immediate draw on a user's checking account. Parking systems may accept bank debit cards as well as credit cards and thus a potential source of confusion is eliminated when the term declinating is used for prepayment of parking fees.

Declinating cards are highly desirable in situations where a large number of commuters now pay daily fees to park. These cards can also be highly desirable when an employer wants to encourage use of mass transit and other alternate modes as part of an employee trip reduction program. On most days, the commuter will use mass transit and thus won't want/need to pay for monthly access. However, on days when the employee needs the personal vehicle, he or she can receive a special parking fee through the declinating cards. The system is thus a "win-win" for all parties.

A decrementing card or ticket allows a predetermined number of visits to a parking facility, regardless of length of stay or the charge that would otherwise accrue. Decrementing systems are valuable for visitors who will arrive and depart over several days or even months such as at a hospital, hotel, or seminar. Prepaid parking tickets can be issued months in advance for use on a specific day and time such as a special event. Advance ticketing substantially reduces the number of lanes and cashiers required for major events.

Another frequent parker payment option program becoming more popular is automatic billing of parking charges. This program is most commonly seen at airports, where some users are frequent but monthly parking is not appropriate. The regular traveler enters and exits with a card system, and the charges for parking are either automatically billed to a credit card kept "on file" or direct-billed to the employer at the end of the month.

Valet parking has traditionally been controlled with level 0 or 1 technology: the two- or three-part ticket. With the advent of on-line revenue controls and machine-readable tickets, valet parking controls can now be multi-part tickets issued at entry to stay with the patron, the car, and the keys. ID cards for the valets can be used to monitor and record who had possession of the vehicle at any point in the stay.

Another desirable option is the remote lane monitor (RLM.) This unit, located in a central location such as the parking management office, monitors activity in each lane, such as the fact that the gate remains up too long or the ticket dispenser is running out of tickets. The RLM is especially beneficial for remote lanes where the cashier cannot see problems directly. The oldest systems were electromechanical, but now electronic and online systems are available. Remote lane monitors are now usually buried in facility management systems, but individual units may be provided where an FMS is not provided.

One of the latest options is automated parking availability displays (APAD.) When an FMS is provided, its occupancy counting capabilities can be used to direct patrons to the areas with the most vacant spaces. This is especially desirable in larger facilities with express ramps. Rather than have a patron get off the express ramp and search through a floor with only a few spaces available, sign(s) indicate the number of spaces available on floor to assist in making reasoned decisions. Most systems rely on loop counting systems that are not 100% accurate and thus the "full" sign usually is illuminated when there are a few spaces still available.

Similar technology is employed to provide automated parking guidance systems for a downtown or campus. Signs on the street with changeable messages automatically direct less-familiar users to the nearest parking facility with available spaces. Although more common in Europe, several

US cities either already have them or are in the process of installing them. (See Figure 4-3)

Figure 4-3. Automated parking guidance systems are effective tools to reduce congestion in central cities. Photo courtesy Dambach

Intercoms to remote lanes can be installed directly into, or attached to, ticket dispensers or card readers. The ability to communicate with management greatly reduces patron frustration and gate arm breakage. CCTV monitoring of entry/exit lanes is also valuable in systems with high revenues. Such a system would not have to be continuously monitored. Rather, alarms triggered by exception transactions would summon management, turn on the appropriate camera, and start up a videotape recorder.

License plate inventory (LPI) systems were developed for airports to thwart the parker who has "lost" the ticket and claims to have come in "just an hour ago." In facilities where parkers don't stay for more than one day, the patron with a lost ticket is charged the maximum daily rate. At an airport, however, cars can be parked for days or even weeks. If the parking rate is $10 per day or more, there obviously is substantial incentive to pull the lost-ticket trick. Cashiers also may try to charge the patron the correct fee for the full stay, but enter the transaction into the fee computer as a lost ticket and pocket a substantial amount of money. To prevent this, the license plate of vehicles at cashiered exits are compared against a list of license plates of parked vehicles in the "overnight inventory." In both cases, the license plate data is collected by personnel circulating the parking facility with hand-held devices during the wee hours of the night. Some systems use the LPI only for exception transactions such as a lost ticket; others require that the license plate be entered for every transaction.

Both pay-at exit (even with mandatory LPI) and pay-on-foot systems are still vulnerable to those determined to attempt fraud and/or theft, and therefore, the potential of fully automated matching of license plate/vehicle on entry with license plate/vehicle on exit is eagerly sought by those in the airport parking sector. Moreover, the processing rate of a lane is reduced by as much as one third with every transaction LPI check.

License plate recognition (LPR) technology is now replacing either type of LPI processing. With this technology, a photo of the vehicle's rear end, concentrating on the license plate, is taken at entry and stored with a link to the ticket number. At exit, the photo is recalled and the computer checks to make sure that the vehicle that pulled that ticket on entry is the same one present in the exit lane. This feature will be extremely beneficial in reducing ticket-swapping and lost ticket schemes, without slowing down processing rates as occurs with mandatory LPI. Another benefit of this technology is that it can be implemented with pay-on-foot systems; while the parker pays on-foot, the system still checks that the car at the exit verifier is the same one that entered on that ticket and will refuse exit and alert management to someone who attempted a ticket swap.

LPR is now "up and running" at several airports. Accuracy has reached acceptable rates (up to 99% in some cases) and procedures have been developed for dealing with that last 1% that are acceptable to the operators. Other airports are preparing to install it in the next couple years. Before it is even widely available, LPR thus is rendering moot any decision on whether or not to implement mandatory or exception only LPI for facilities now being designed.

4.2.6 What Reading Technology Is Right for You?

As systems for automatic card and ticket reading have been developed, different manufacturers have used different technologies. As with other control considerations, the choice of technology for a specific project depends largely on how "tight" a system is desired.

4.2.6.1 Card Technologies

First-generation, offline card systems usually have metallic slugs buried in the card in a certain pattern for reading by a magnetic device. All cards are permanently coded with a single code for each facility.

The dominant technology for individually coding cards is the magnetic stripe developed by IBM and often used on credit cards. The major problem with "mag stripes" is that the information can be changed, copied, or recoded. While it takes a pretty sophisticated user to purposely recode a card, an electronic skimmer can copy a card. Firm antipassback, of course, reduces the benefit of a copied card, since two users with the same ID number can't be in the facility at the same time. More critically, the information on a mag stripe can be scrambled by rubbing against a number of magnetic devices, including, on occasion, a card with magnetic spots. The latter cards are formed by a center core of a magnetic material such as barium ferrite, sandwiched between layers of plastic. Security x-rays at airports and other exposures also tend to degrade the coding on mag stripe card over time.

Infrared cards were developed by Citibank to reduce fraud and theft with their credit and ATM cards. Infrared systems tend to be more reliable and more difficult to copy or tamper with, but may be more expensive because cards and reading devices can only be purchased through licensees of Citibank.

Bar-coded cards have become common because of the lower cost of the technology. Conversely, bar-coded cards are the easiest to copy. Again, however, antipassback controls limit the ability to use copied cards. However, in a multi-facility system, such as at a university, copied cards could be used to gain access to different facilities at the same time unless there is some system for cross-checking card use between facilities. This shortcoming is avoided with a facility management system, as discussed later in this chapter.

Wiegand effect cards employ a magnetic reaction to read a unique code created by the placement of individual wires in each card. No power is needed at the card reader to read the code, but power is required to check the validity of the number. Even when Wiegand cards are not used, the protocol developed for communications in this system has become fairly standard to the security industry. Using Wiegand protocol, manufacturers of card controllers have the flexibility to use many different types of cards, even within the same system. This feature is quite beneficial, for example, when an institution already has an ID badge/security system. Designing the card system to read the same badge will eliminate the need to carry multiple cards. In some cases the badge can be dual technology, with one type of read system for parking (mag stripe, for example) and another for ID (bar code, for example.)

All of the preceding systems require the insertion of the card into the reader. Other systems read a card from a distance, in some cases without the driver removing the card from a wallet or other carrier. The distance at which the card can be read varies between systems. Proximity systems require the card to be held up within a few inches of the reader; the technology of this type usually involves scanning by very low power radio frequency signals. Automatic vehicle identification (AVI) (See figure 4-4) systems can be read at a distance of 10, 20, or even 30 feet. Most of the longer-distance systems can read while a vehicle is in motion, at speeds of 20 mph or more, and were developed for regular users of toll highways and bridges. The speed of transaction for proximity/AVI readers is faster, especially with the longer-distance systems where the vehicle does not need to come to a full stop, which can reduce the number of lanes required. Proximity readers also eliminate many weather problems that can occur with insertion readers. They are considered substantially more user-friendly. However, proximity card systems are more expensive, with AVI yet more expensive, as compared to insertion card readers.

Figure 4- 4. AVI is becoming increasingly common for frequent parker entry/exit control. Photo courtesy Amtech.

When a local agency has already developed an AVI system for toll collection, it is possible for the parking system to "tag along." An airport parking system, for example, could read the declinating AVI card of a local toll authority. It could collect parking fees directly or receive payment for parking charges from the toll authority. Cashiering would be eliminated from the transaction. At present, this system requires coordination among agencies and is more feasible with public entities. While the toll authority may charge fees to join its system, it would probably be no more than what credit card companies charge to collect fees for merchants. One of the leading vendors of toll tags has developed its own clearing house, in which participating facilities are polled via the Internet in the wee hours. Payment for the previous days' transactions is then wired to the facility's bank account before the start of the business day.

With more and more users going to online access control, new opportunities for control open up. For example, a card reading system in the associated parking facility can also read hotel room keys; the parking control system then reports parking charges to the hotel's computer system for inclusion in the guest's bill.

4.2.6.2 Machine-Readable Ticket Technologies

Today, machine-read systems for tickets use one of two technologies: mag stripe or bar code. The primary advantage of mag stripes is that all of the data relating to the transaction is stored on the ticket. As the user progresses through the system, additional information is added. For example, in pay-on-foot systems, the ticket is recoded at the central payment station and used as the exit ticket. Validations for free parking can also be added by merchants and read at the exit lane.

In most bar code systems, either a serial number or a series of random numbers is preprinted on each ticket. The ticket dispenser "reads" the bar code and tells a central computer when that ticket was issued. When the bar code is read again at the exit, the computer searches its memory for the data on that ticket. The relevant information is all kept in the computer, not on the ticket. The chief drawback is that if the central computer goes down, the entry time and date must be entered manually from the ticket. Bar code systems are therefore considered "communications dependent;" however, they are also generally less expensive and more reliable due to having fewer moving and electronic parts than mag stripe systems.

Recently, a number of manufacturers have begun to use bar code technology tickets in which the bar code is written “on the fly”, making it feasible for data relating to the transaction to be carried on the ticket. Those systems then eliminate any communication dependency.

4.2.7 Facility Management Systems

The "ultimate" in gated systems now available is a system fully online to a central computer. The primary reason for going totally online is to allow management of the parking system, be it one facility or a dozen, from a central station. As more complex logic and sophistication are added to any system, it is capable of greater control and management with less human input. The information available increases greatly while personnel time decreases. One of the generic names for these systems is thus a facility management system (FMS). Using data management software, the FMS can generate just about any type of report imaginable. While this information has always been available to parking managers, the amount of time required to track trends in use and revenues was cost-prohibitive. Now, computers can do the searching and compiling, allowing management to improve performance. Some specific management functions that can be performed by FMS are:

Revenue Maximization. This term refers to a step-by-step refinement of management procedures with the goal of increasing revenues through improvements in facility performance and reduction of fraud and theft. An integral component of revenue control is the feedback provided to local facility supervisors and employees from a series of timely reports. Information in such reports is derived from the transaction data received from "intelligent" peripherals, which include the card reader controller, the ticket dispensers, the fee computers, and the gates.

Facility Use. Analysis of peripheral transaction data can also reveal patterns of usage that are vital in the preparation of overbooking plans for the facility. Such information is also valuable for setting empirically based rate structures and in formulating expansion plans.

Equipment Maintenance Control. By tracking malfunction data returned from peripherals, objective judgements can be made regarding which devices are failing, the nature of the failure, and environmental factors related to the failure. This information is useful for scheduling preventive maintenance and for deciding which pieces of equipment are due for replacement.

Revenue Forecasting. Information obtained from statistical analysis of peripheral transaction data can be extrapolated for revenue forecasting and management planning. By monitoring specific data, "trends" may be identified early to optimize management response. In addition, hypothetical situations can be analyzed and should provide management insight for business planning.

Alarm Reporting. Communication lines can provide status information, exception transactions, or failure conditions for the various peripherals (e.g., gate arm stuck).

Perhaps the most fundamental technological improvement resulting from online, real-time computers in PARC is ticket tracking. As previously discussed, auditing primarily involves correlating tickets issued with other activity. With machine-readable ticket dispensers online to a computer, the system can trace the path of the ticket through the system, eliminating this cumbersome task. This feature allows the system to report how many tickets are outstanding at any given time and how much revenue those tickets represent. It can be used to process mutilated tickets, since the cashier can enter the ticket number and the computer will retrieve the entry time. This attribute is among the most beneficial features available today for detecting revenue and fraud.

One significant feature of these on-line systems is that they are designed to control a number of different lanes and/or different facilities from one central computer. Several parking structures can operate independently, even with different commercial operators, but all transaction data are "off-loaded" to a central computer for analysis and management action by the owner. The owner can program the system to poll each parking facility overnight, tabulate and summarize the activity, and print out reports before management arrives in the morning. Substantial clerical time can thus be saved in tabulating activity at several facilities, while management can spot a new trend in minutes. Fee schedules and other programming changes can be downloaded to any individual facility or to all facilities in the system. The online system is thus most effective for an owner with multiple parking structures (such as a parking authority or an operator) or one with many lanes and high revenues (such as an airport).

The number of facilities connected to an FMS has a bearing on the design of the system. When multiple facilities are connected to a single FMS, each individual facility may have a local facility computer (LFC), which collects and tabulates the data for that facility before sending it on to the master parking computer (MPC). The LFC provides the facility's on-site manager with the data necessary for day-to-day operations while allowing central management to track data and monitor the full system.

In other cases, one MPC is connected to peripherals at several facilities. While saving on hardware costs, there are far more ramifications if—or should we say when—the central computer goes down.

In a third case, peripherals at each facility are connected to a local controller that makes decisions, receives and/or stores data, but which has no workstation. Data are uploaded and programming is downloaded from the MPC.

The size of the system and the features desired definitely have a bearing on the computer hardware required. Most systems today involve networked computers. The server tabulates data, and the work stations are used to perform functions. Each work station has its own computing capability which allows it to be used to perform individual functions. One handles the LPI; another, the occupancy and lane monitoring. With the relatively low cost of fast, powerful personal computers, we find the network option to be highly cost-effective as compared to using a minicomputer to run the whole system.

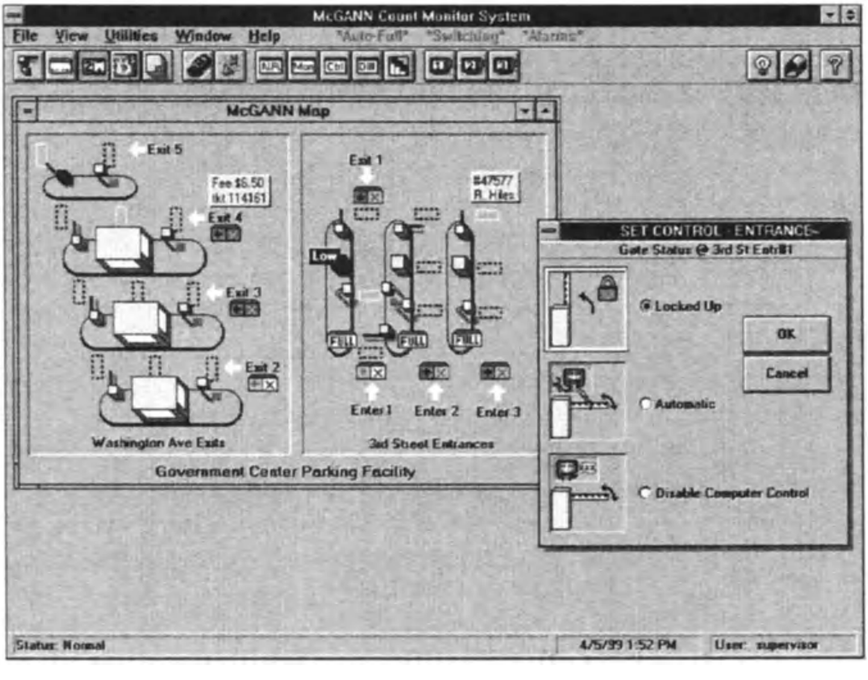

Figure 4-5. Facility management systems allow managers to monitor and project performance. Screen photo courtesy of McGann Software Systems.

4.2.7.1 Coordinating Peripherals with an FMS

Owners often want to have the flexibility to choose from many vendors for their PARC peripherals. When an FMS system is designed to run on a standard computer, one is not, in theory, married to a particular brand of peripherals. If the peripherals are microprocessor controlled and have the capability to communicate to a central computer, one needs only the protocol of the peripherals to integrate the system. The use of Wiegand protocol, for example, has made it possible to use different card reading technologies within one card system.

In practice, however, most FMS systems now on the market are tied to certain PARC devices, because of the intricacy of communication between devices. Customizing the FMS package for a different set of peripherals might not be cost-competitive with the peripherals that already work with the FMS. The larger parking vendors make all the necessary peripherals **and** FMS systems and may not be particularly interested in sharing protocol.

In the absence of standards, one must either purchase a package that has already been developed or pay for integration of components that individually have the features desired. The more detailed the specifications, the smaller the pool of qualified bidders. All of these factors make it difficult to specify and competitively bid PARC/FMS systems. Designers are forced to use performance specifications rather than specify how that performance is to be achieved. It also makes it more difficult to compare bids on an "apples-to-apples" basis. Whereas in the past, an owner could call a distributor and outline requirements in a telephone call, today that owner must do extensive research or retain a consultant to negotiate the "high tech" maze of PARC systems.

4.2.8 Pay-on-Foot PARC

Before discussing pay-on-foot PARC, there is one issue of terminology to clarify. As with any "new " technology, there is a lag between the development of the systems and the adoption of terminology industrywide. Often, the terms used by the first or leading manufacturer become the standard of the industry. In the case of pay-on-foot, there is yet much confusion over terminology. Some in the industry use the term "pay-on-foot" broadly; others use the term only for cashierless, automated pay stations (see Figure 4-6). It can be confusing when a term is defined more narrowly than the sum of its parts indicates. Logically, pay-on-foot should be defined as any revenue control system in which payment for parking is rendered "on-foot" rather than from a car. Under this definition, pay-on-foot systems range from the traditional parking meter serving one stall to sophisticated automatic pay stations. Pay and Display and Multi-Space Meters are the higher-technology versions of ungated pay-on-foot.

For gated systems, the microchip allows the cash transaction to be performed at a location other than the exit lane, while maintaining the integrity of the gated system. Any cash transaction is faster when performed on foot rather than from a vehicle; the cashier and/or equipment is not idled while the vehicle pulls into and out of the lane.

The entry to the parking facility with a gated pay-on-foot system is controlled with ticket dispensers and barrier gates. Frequent parkers are processed by card readers at both entry and exit lanes. The cash patron pays the parking fee at a central pay location after visiting the destination but before retrieving the car. The central payment station can be cashiered or equipped with an automated pay station or both. Following payment, the patron receives the receipt (if requested) and an "exit ticket." In some systems, the exit ticket is actually the original parking ticket reissued for reading at the exit. This feature allows each ticket to be printed with the appropriate data at every step along the way, which eases auditing. The parking patron then has a preset time period, usually 10 to 15 minutes, to retrieve the car and reach the exit lane. The exit lane is equipped with an exit reader instead of a cashier

Figure 4-6. Automated pay-on-foot machines eliminate human cashiers. Photo courtesy of Federal APD, Inc.

booth. The patron inserts the ticket into the exit reader, which determines if the ticket is still valid. If so, the gate rises and the patron is free to leave. If the elapsed time is greater than allowed or the ticket has not been validated, the exit reader rejects the ticket and the gate will not open. The patron holding the invalid ticket must then return to a cashier or pay station to pay the additional fee. Some exit readers, however, accept payment for small overtime charges at the exit lane.

Several variations of pay-on-foot solutions are available for gated settings. With central cashiers, the traditional cashiers and fee computers are merely relocated to a central location to perform the cash transactions. Automated pay stations are machines similar to ATMs that process the transaction, replacing the cashier and fee computer. "Hybrid" systems also exist, in which two different types of equipment are combined to form a system. Hybrid pay station/exit cashiers have centrally located automated pay stations **and** exit lane cashiers. The intent of this combination is to reduce the number of exit lane transactions while providing a means of processing the patron who forgot or chose not to pay at the machine. With hybrid pay station/central cashiers, both cashiers and automated pay stations are located at the central location. The cashiers are on duty during the busy times, whereas the automated machines can be operational 24 hours per day. Customers can choose between the human cashiers or the machines. Only one cashier may be required in facilities that would otherwise require multiple cashier lanes.

4.2.8.1 Why Pay-on-Foot?

Pay-on-foot revenue control has been touted for a number of years as the future of PARC. Cashierless parking facilities with automated payment machines were expected to become as common as ATMs. Fully automated, cashierless pay-on-foot systems are widely used and accepted in Europe. However, in the U.S. there have been a number of "disasters" but fewer success stories. One of the biggest concerns regarding the acceptance of pay-on-foot in the U.S. has been the perception that the American customer, in general, tends to expect a higher level of customer service than the European parker does. In Europe—as well as in much of Asia—parking is at such a premium that the parker is happy just to get a parking spot. A tour of parking facilities in Europe reveals that significantly less attention is paid to user comfort in all aspects of parking design and operation than in the U.S. Lighting, parking geometry, and other functional issues are all designed to a lower standard of user friendliness than in the U.S.

Another issue impeding the acceptance of pay-on-foot has been the dollar bill. In Europe, there are widely circulated coins for dollar-equivalent denominations. In the U.S., however, the lack of acceptance of the Susan B. Anthony dollar has made it imperative to include dollar bill acceptor/changers in most installations. Only recently has the reliability of those units been improved to a level minimally acceptable to the U.S. parking operator. At the same time, the cost of dollar bill readers/acceptors keeps the cost of APS machines high. The introduction of the new US dollar coin in year 2000 is anxiously awaited by the industry. If it is widely accepted, there should be a marked acceleration of the acceptance of pay-on-foot solutions across the US.

In 1993, we conducted a survey of all American users of pay-on-foot systems that we could identify, primarily from lists of installations of pay-on-foot provided by manufacturers.[4] We included multispace meter units in the survey, as well as gated systems.

The general advantages of pay-on-foot applicable to all such systems cited by the respondents are as follows:

- Lower operating costs—primarily owing to savings in labor costs.
- Reduced exit lane queuing—because of the improved speed of the exit lane transaction.
- Increased revenue control/security—because the revenue is collected at a single central location. In the case of central cashiers, the cash is collected in an office setting with other personnel nearby and where management can more easily monitor the performance of the cashier. In cashier-less systems, the number of people who handle cash is sharply reduced.
- Reduced staffing problems. Again, the reduced labor in a cashier-less system will reduce the headaches of hiring, supervising, and scheduling staff. When the system is cashiered, the work setting is improved and turnover is reduced; also other office staff can more easily "pinch-hit" when a queue develops for a few minutes without scheduling additional cashiers.
- Improved customer service—primarily due to the elimination of delay at the exit lane; also in the case of central cashiers, because the transaction is performed in an office-like setting rather than in a vehicular exit lane.
- Improved speed of transaction—which not only reduces congestion at the exits, but also may result in a reduced number of cashiers and lower labor costs.
- Reduced auto emissions by queuing autos. While some may scoff at the notion that cashier lane queuing is a major cause of pollution, improving air quality will require a lot of individual little steps to reduce auto emissions. Further, removing the cashier from the exit lane is a significant improvement in quality of the workstation as well as eliminating exposure to vehicle fumes.

Certainly, there are also disadvantages, the most predominant being the need to change American "habits" to accept pay-on-foot systems. The most common reasons cited in the industry for **not** doing pay-on-foot are accommodating the parker who routinely leaves the ticket in the parked vehicle and the individual with "machine phobia." ATMs are widely accepted and used, but there does remain a small segment of the population that refuses to use them. Like the banking industry, the parking facility owners who have tried pay-on-foot in recent years have found that those two problems can be reduced to a very acceptable level, while garnering the benefits listed above.

The survey also found differences in the application of various pay-on-foot systems.

4.2.8.2 Multispace Meters

The most significant advantages of the electronic multispace meter are the elimination of queuing at the entry and exit, and generally lower capital and operating costs. In many of the successful installations, overpayment of fees apparently compensates for underpayment/scofflaws. However, there are several negatives, chief among which is that writing tickets is a negative approach to providing service to the customer. As previously noted, customers in systems converted from pay-at-exit (gated) systems complained about overpayment of fees and the lack of customer service. There may also be a net loss of revenue due to non- or underpayment of fees, especially if the enforcement is lax or the owner has no means of collecting ticket fines.

4.2.8.3 Central Cashiers

Gated installations with central cashiers have been very well received. The cashier puts a human face on the parking operation that is important to many American parking operations. Remember that maxim of the parking industry—parking is the first and last experience that the customer has at the ultimate destination, be it business district, shopping center, airport, hospital, or other use. Where competition for patronage exists, customer service will be a key aspect of marketing. Indeed, one manufacturer of pay-on-foot systems has noted that some European facilities are starting to add central cashiers to formerly cashier-less systems to improve customer service and increase market share.

Customers of central cashier systems are enthusiastic. Several parking facility owners noted that customers comment on how much nicer it is to pay at the central location than from the vehicle. Comments like "Why didn't someone think of this before?" are common. (See figure 4-7) Overall, operators of systems with central cashiers felt they provided the best overall service to their customers; the number of patrons forgetting to pay before exiting was far lower than expected, and nearly all patrons were provided a better level of service than would have been afforded by exit-lane cashiering.

Figure 4-7. Central cashiers provide a high level of customer service. Photo courtesy WPS North America.

4.2.8.4 Automated Pay Stations

A PARC system relying totally on automated pay stations can be cost-effective in certain situations. However, the owner must accept that a certain percentage of the patrons will have problems with the equipment and require assistance. The bank customer who is turned away from an ATM owing to problems with the bill receiver/changer simply won't get any money out of the account. The parking patron who can't pay for parking can't get out of the parking facility without either breaking the gate or calling for assistance. Adding the problems with machine phobia to bill rejections and change problems, as many as 10% of the customers will have problems with the system and will leave the facility frustrated and/or dissatisfied. As a result, more and more people are installing credit card acceptance units to reduce the use of cash at automated payment stations.

Several owners surveyed who had systems relying totally on central pay stations were satisfied, feeling the benefits outweighed the problems in their particular circumstances. One satisfied user is a university with a high number of regular, cash parkers. The parking office was located in the structure, within sight of the automated machines. When a user has a problem with the machines, assistance is close at hand. At the same time, the staffing problems associated with cashiers have been eliminated.

Another example of an appropriate installation is a commuter train or transit station. There may be an hour or more between trains in the off-hours; stationing a cashier in the lot to collect parking fees from off-hour commuters is not very cost-effective. In situations where commuters are already familiar with automated pay stations for train fares, and an attendant is already present inside the station, using 100% automated pay stations for parking is an ideal solution. Using the same declinating ticket as the rail system for frequent parkers is a further, viable option.

We continue to believe the technology—and the ability of the American public to use that technology—is not yet ready for a parking facility that is totally automated and operated without any staff, but where someone is available to assist parkers, a system with only APS units is feasible. However, should the new dollar coin succeed, the acceptance of APS should skyrocket, while the cost per unit plummets.

4.2.8.5 Hybrid Central Pay Station/Exit Cashiers

As previously noted, hybrid systems with central pay stations and exit cashiers are designed to process those who forgot to take the ticket and/or pay-on-foot at the exit lane. Another benefit is derived from using machines for off-hours when it is not cost-effective to staff a cashier station, while maintaining exit-lane cashiering in normal hours.

In a more recent installation at an airport, it has been found that initial use of the machines may be high (75% on opening day) with good signage and visibility of the machines, but patronage may decline over time (to about 50% in less than a year in this particular case). People just pass by the pay-on-foot machines, knowing they can pay at the exit. However, they cannot see that there is a backup until they get to the exit area. Credit card customers or frequent travelers seem to be the most comfortable with the APS units.

This difficulty of predicting use makes it very difficult to design hybrid systems. If it is assumed that a certain percentage of the patrons will use the pay-on-foot option, the number of cashiered exit lanes is reduced accordingly. However, if the actual use of the pay-on-foot option is lower, there may not enough exit lanes. If there is then no way of adding any more cashiered exits, there can be large backups at peak hours.

A 50% reduction in cashiering requirements is nothing to sneeze at. The key is to project with reasonable accuracy the number of cashier exit lanes that will be required, and to provide flexibility for future changes in use in design.

4.2.8.6 Hybrid Pay Station/Central Cashiers

The hybrid system with central pay stations and central cashiers proves to be the overall best solution for pay-on-foot revenue controls. It has all the advantages of both automated pay stations and central cashiers. Giving the choice of paying on-foot to cashiers or machines provides the overall best customer service, balancing speed of transaction with ability to accommodate persons with machine phobia. It is interesting to note that this hybrid approach combining the best of both pay-on-foot systems – central cashiers for those who prefer it and automated machines for faster service at lower operating cost – is analogous to what the banking industry did. ATMs are placed at bank branches with a reduced number of cashiers. Over time a significant segment of the population becomes familiar with the machines and now, many people prefer to use the machines.

This approach still provides an ability to tighten staffing requirements. Even in a very busy facility there will be peaks and valleys in the flow of traffic. Queues tend to build and then dissipate over a period of a few minutes. The automated pay-on-foot machine allows a balancing of staffing without a decline of service to the patron. When a queue occurs at the cashier, the individual patron can choose to bypass the line by using the machines.

One owner who has used the hybrid system in a number of facilities has found that a split of 60 percent cashiered, 40 percent machine transaction in peak periods is an appropriate balance. We frequently reverse this ratio and plan for 40 percent cashiered and 60 percent machine. We do strongly recommend that an owner not over-staff the facility; the formation of small queues at the cashiers is an important factor in achieving a successful system.

Overall, the hybrid system combining central cashiers and automated pay stations achieved the goals/benefits of pay-on-foot to the highest degree with the fewest disadvantages/problems.

4.2.8.7 Designing Pay-on-Foot Revenue Controls

Several problems require close attention during the planning and design of pay-on-foot systems. One of the biggest problems is the propensity of the American parker to leave parking tickets in the car. It should first be noted that changing this habit is a desirable goal for the parking industry for other reasons. Leaving the parking ticket in the car makes it much easier for someone to steal the car, since the thief can use the ticket to exit the facility without attracting undue attention.

The first action is to place signage in prominent locations in both the parking and pedestrian areas. The messages on the signs can be reinforced with audio messages. Some equipment manufacturers offer ticket dispensers that deliver an audio message when a ticket is issued. A customized message in LCD or LED technology can also be developed to remind the parking patron to "take the ticket with you." See Figure 4-8. Care, however, must be taken; patrons may not hear the entire message.

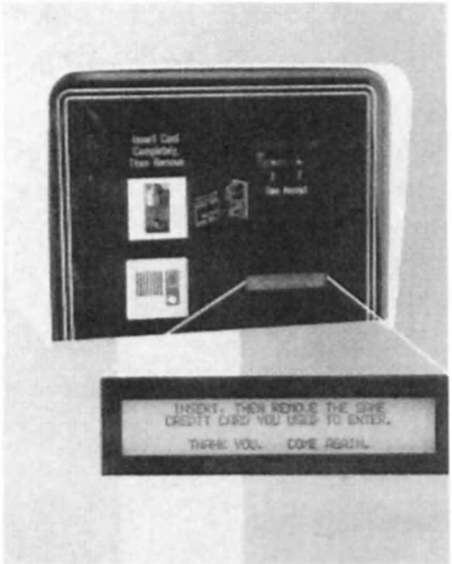

Figure 4-8. LED and LCD technology allows customized messages to be provided at PARC devices. Photo courtesy of Standard Parking Systems

It should be noted that even facilities that are highly transient, such as shopping centers, have a high degree of repeat customers. After a first period of familiarization, the problem is likely to diminish, as patrons will remember to take the ticket after once having a problem at the exit lane.

The design of the pedestrian traffic flow through a parking facility also influences the success of a pay-on-foot system. Pay-on-foot systems work best when patrons must pass through one pedestrian access point to return to a parking area. Too many expensive machines and/or cashier locations may be required with a large number of pedestrian portals. Similarly, pay-on-foot systems work best when the payment stations are prominently located. The parking patrons should not have to search for the pay station.

For the first few months after opening a pay-on-foot operation, the operator should station personnel in a prominent location such as the main elevator lobby to greet patrons, inform them in a positive way of the new system, and remind them to take their tickets with them and to pay for parking before retrieving the vehicle. Operators of well-designed pay-on-foot systems have found that, with this extra assistance, the number of patrons who get to the exit lane without having paid is extremely low. One operator with 1800 spaces said that no more than four or five patrons a day forget to pay, even after just a few months of operation.

It is not recommended that the owner place fee computers and cashiers in booths at the exit lanes for an introductory period in an attempt to mitigate the inconvenience to the patron who forgets to pay. It merely encourages a bad habit that must be broken to achieve a successful installation of pay-on-foot revenue control. That money is much better spent on "greeters" who inform patrons of the need to take the ticket on the way to the destination and to pay before returning to their car. In this case that old saying, "Begin as you mean to go on" is quite applicable.

When the exit lanes are near the parking office, the supervisor can go to the lane and process an exception transaction for the patron who hasn't paid. If the exit lane is distant from the office, it is important that the physical design of the parking facility allow sufficient room for the patron who arrives at the lane without having paid to pull off to the side. A second option is to provide at least two exit lanes and/or excess capacity in the peak hour at each exit location so that other patrons can get to an open lane. A third option is to provide a system allowing the patron to re-enter the parking facility and park before going to a machine and paying.

This procedure can even be automated. The gates at the street are normally up, while the re-entry gate is normally down. When an exception transaction occurs, the system holds that patron at the exit lane until entry transactions in progress at the other lanes are completed and those patrons have passed the street gate. The gates lower and hold the patron as required, the re-entry gate raises and the exception transaction patron is released to re-enter. After he/she passes the re-entry gate, the entire system resets to normal operation.

4.2.8.8 Conclusions

For most users, a hybrid system of central cashiers with pay machines will:

- lower operating costs and staffing headaches
- increase net operating income

- reduce queuing and pollution
- improve the work environment for employees
- provide the overall best service to customers

A system that is 100% automated pay station may be cost-effective in certain situations, but 5% to 10% of the customers will resist and/or have problems using the stations.

Hybrid systems with automated pay stations and exit-lane cashiering have not worked as well because of the difficulty in projecting the use of the machines.

To make pay-on-foot work, the facility must have with a limited number of pedestrian portals, so that all patrons pass by a central payment location on the path of travel to/from the ultimate destination. Signage must be placed both in the parking areas and along the path of travel to remind patrons to take their ticket with them after parking the car, and to pay on foot before returning to the vehicle. A method for processing the patron who has not paid or whose grace period has expired before arriving at the exit lane must be provided.

4.2.9 The Future Is Already Here...

Technology is changing quite rapidly, with changing requirements for space needed at entry and exits to parking facilities. The only thing one can be certain of is that the "state of the art" revenue control system in five or ten years won't be the same technology as today. We have a pretty good idea of where things will be in say five years, but we don't know how fast we will actually get there. Therefore, the number of lanes for entry and exit needed today is different from how many we think we will need in two years, which in turn is different from how many may be needed in five or ten years.

There are those who believe that LPR (license plate recognition, as previously discussed) will result in ticketless parking (car recognized on entry and matched at exit.) This system would then also eliminate the entire pay-on-foot approach; however, it would still require **more** exit lanes for payment of parking fees than POF, so that POF with LPR may still be the more economical approach over "ticketless" systems.

At the same time, others are going to credit card in/out systems, and automatic vehicle identification (AVI) technologies for frequent parkers. Credit card in/out systems allow a user to "dip" the credit card on the way in and the way out, without taking a ticket. (See Figure 4-9) One key to success of this system is the user remembering which credit card he/she used on the way in!

Figure 4-9. Credit card in/out at entry and exit lanes is becoming more common. Photo courtesy Federal APD.

Another variation is credit card only exit lanes. The patron takes a ticket on entry, but at exit inserts the ticket into the reader and then inserts the credit card. As the public has become more comfortable with not signing the receipt for small charges, as when they “pay at the pump” for gasoline, credit card only systems or lanes without any cashier involvement are gaining favor.

We believe that at some not too distant future date, LPR will also become passe' because the federal government plans to require manufacturers to install AVI chips in all new vehicles for its "intelligent transportation systems" initiatives. Once a standard payment methodology for automated billing of charges through the AVI device is developed (the chief stumbling block is not technical but privacy concerns), **all** of today's systems will be rendered obsolete by a ticketless, cashless payment technology.

Another technology that appears to be just around the corner is the use of video and/or radar cameras for activity counting. Loops and detectors are notoriously inaccurate, due to variations in vehicle height and size. If you tune the loop to accurately count sport utility vehicles, it will have more tailgating problems. According to manufacturer's claims, a single radar unit can provide presence, volume, speed and occupancy of vehicle activity separately for up to eight lanes on highways and intersections, with less maintenance and higher accuracy than loops and detectors. While not yet common in parking applications due to either cost or lack of familiarity by parking equipment vendors, more accurate vehicle counting is a technology advance eagerly awaited by many operators.

We frequently receive questions about individual space occupancy monitoring. There is at least one system on the market that monitors the use of each specific parking space. The primary purpose of this information is to provide automated guidance for arriving parkers to the nearest available parking space in an individual floor. This system has red and green lights mounted on the ceiling over the major circulation routes that illuminate to indicate the path of travel to the nearest empty space; obviously there is significant data processing capacity required to make all of the individual decisions regarding control of lights. This approach is particularly useful with "dead end" parking bays. Also, it can eliminate the need to consider a facility "full" when some spaces are still available, increasing revenue/space. Some of the cost of installing the system (on the order of $500/parking stall) can thus be recovered by increased parking capacity within a particular footprint.

In sum, most of the new technologies on the five to ten year horizon are already "here" and provable to at least some degree; the "unknown" component is that some corollary problem like computer hardware, cost of devices, or privacy concerns is not yet solved.

4.2.10 Summary of Considerations in System Selection

In general, a good fee computer system, and/or a programmable or on-line card system is appropriate for many smaller parking facilities. Owners who are motivated to monitor activity closely and who will use the voluminous reports that can be generated will probably benefit having an FMS in an individual facility. The FMS, however, will be most cost-effective to those who own or operate a number of parking facilities or one with relatively high revenue. The purchaser of PARC system equipment must also address how tight a system must be to meet the facility's needs, and select manufacturers and technology appropriate to those needs.

How much to spend on a PARC system is another consideration. In facilities with relatively low revenues, the PARC system is usually designed to keep unauthorized users out more than to keep revenues in, and thus the expenditure is justified on other things than revenue. When a facility or group of facilities has annual revenues exceeding $1,000,000, an investment in the PARC system equal to 10% of the annual gross revenues has been found to be appropriate. When it is appropriate to investigate the cost-effectiveness of alternative PARC systems or features, the potential revenue and revenue collection efficiency factors must be studied.

4.3 DETERMINING LANE REQUIREMENTS

The traditional method for determining the required number of lanes of PARC equipment involves estimating the number of vehicles expected in a certain peak period and dividing that by the "capacity" of the equipment in the same period. In recent years, however, the average size of parking facilities has dramatically increased. Consultants with extensive experience with larger facilities have found that this methodology can be very inaccurate, resulting in a very over-designed system in one case and a very under-designed system in another. While over-designed systems merely result in wasted capital resources, under-designed systems can result in user frustration sufficient to cause patrons to choose another facility. Crommelin[5] first adapted standard traffic engineering theory for queuing at traffic signals for use in PARC lane design. The author has further developed this approach[6], updating and expanding the procedures for conditions common today.

4.3.1 How Many Lanes?

The number of lanes needed is first estimated by dividing the volume, V, of vehicles expected in the peak hour by a peak utilization factor, PUF, times the service rate, μ, of one lane as follows:

$$n = V/(PUF * \mu)$$

Dividing by the peak utilization factor essentially reduces the capacity to that associated with a minimally acceptable level of service. Loading a lane to virtually 100% of the capacity results in significant queuing in shorter periods within the hour. Normally, the analysis is done hourly; the queuing analysis methodology predicts arrival and departure patterns within the hour and therefore the peak hour factor discussed in Chapter 3 is not employed in the queuing analysis for most situations. However, if a system has an unusually low peak hour factor (less than 75%) the hourly volume should be factored up to adequately design the system. For example if the facility will serve special events, the peak hour factor may be 50%; that is, the design criteria is to allow 100% of the capacity to depart in 30 minutes. If it is to be operated pay-at-exit (unusual for this type of facility, but let's stick with it for explanatory purposes), the volume departing should be multiplied by 2 to represent the equivalent volume that would occur over a full hour.

The queuing model discussed later will provide a better picture of the peak and average activity in the hour, but the PUF assumption allows for the number of lanes to be quickly estimated. In general, the higher the volume and the greater the number of lanes required, the higher the PUF that can be used. This pattern occurs both because the peaks and valleys in activity tend to be moderated as overall activity increases, and because the bursts in traffic can be distributed over several lanes. Table 4-3 presents suggested peak utilization factors that would yield a good level of service (B or better).

Table 4-3. Peak Utilization Factors

	Peak Utilization Factors			
Number of Lanes	1	2	3	4 or more
Daily fee payment	0.5	0.65	0.75	0.8
Quick transactions (FPP cards, ticket dispensers)	0.7	0.8	0.9	0.95
Very quick transactions (FPP with AVI)	0.8	0.9	0.925	0.95

When these PUFs are used, any fraction should be increased to the next highest number— e.g., if 1.2 lanes are calculated, two should be provided. Table 4-4 presents recommended service rates for design purposes based on studies of average seconds per transactions at various facilities.

When the peak-hour volumes are estimated conservatively, fewer lanes can be equipped initially to accommodate a more realistic estimated volume. Then, if worse comes to worst, equipment can be added later for additional lanes if required. It is usually difficult and expensive to add lanes later when no consideration of additional lanes has been made in the initial design.

The service rate is determined by using the inverse of the average time per transaction $\underline{s}$ and converting to hours. Thus, the service rate, $\mu = 1/\underline{s}$. If a cashier can process two vehicles per minute, $\underline{s} = 30$ seconds and $\mu = 120$ vph.

It should be noted that the service rates of equipment also vary from one manufacturer to another depending on the design and technology employed. During the course of collecting data on service rates for today's equipment for this publication, we discovered variances of +/-35% in the processing rates of automated pay-on-foot machines from the value in the table. These variations appear to be almost entirely related to the ergonomics of the machines and the quality of the instructions provided. Also, the type of credit card processing employed has a huge impact on service rate.

Certainly if the manufacturer is known at the time of the design, the actual service rates should be obtained and used. However, when several manufacturers are possible bidders, it is neither practical nor advisable to calculate the required number of lanes for each manufacturer. If service rate is that critical, it would be more desirable to specify that the equipment must achieve the desired service rate. In any event, the determination of an accurate design hour volume will be far more critical and valuable to the analysis than fine-tuning the service rates according to likely manufacturer.

Table 4-4. PARC Service Rates

	Veh/hr	Sec/veh
Prepaid Frequent Parker Entry or Exit		
Insertion Card	435	8.3
Proximity Card	600	6.0
Automatic Veh ID	800	4.5
Pay Per Use Patron Vehicular Entry		
Push Button Ticket	400	9.0
Auto Spit Ticket	450	8.0
Pay on Entry-flat fee, gated, ticketed	200	18.0
Pay on Entry flat-fee, non gated/ticketed	300	12.0
Pay Per Use Patron Vehicular Exits		
Cash to cashier-Variable Rate	135	26.7
Credit card-online check (telephone line) and sign	95	38.0
Credit card online check but no sign	110	32.7
Credit card-batched or high speed line and no sign	175	20.7
Validated for free parking	300	12.0
Flat Rate Transaction (gated)	180	20.0
LPI if front plate	100	36.0
LPI if rear plate only	80	45.0
LPR	120	30.0
Insertion Ticket for POF Validation	360	10.0
POF Central Pay to Cashier		
Cash to POF cashier – Variable Rate	175	20.7
Credit card-online check (telephone line) and sign	115	32.7
Credit card-online check but no sign	135	26.7
Credit card-batched or high speed line and no sign	245	14.7
Validated for free parking	600	6.0
POF Central Pay to Machine		
Cash to APS-Variable Rate	75	48.0
Credit card – online check (telephone line) and sign	NA	NA
Credit card – online check but no sign	66	54.5
Credit card – batched or high speed line and no sign	100	36.0
Validated for free parking	240	15.0

Sharp turns in the approach to equipment lanes have a significant impact on μ. When it is more difficult for a patron to pull into the lane from the first position in the queue, seconds are lost from each transaction. This loss can be accounted for by **adding** seconds to the average transaction time to represent the turning factor. See Figure 4-10 for diagrams showing appropriate turning factors for design. If, for example, the design of a lane equipped with an insertion card reader requires a very difficult turn into the lane, and thus adds five seconds to the average transaction, the adjusted service rate is 3600/(8.3+5 =13.3) seconds per transaction, or 271 vehicles per hour rather than the 435 vehicles per hour of a lane without a turning factor adjustment.

4.3.2 Queuing Analysis

The proper design of access points requires additional information. For example, vehicles may back into the street if there is not enough space between an entrance gate and the street, even though there are enough lanes to process the peak flows comfortably in an hour. Problems may also occur if the queue of vehicles waiting for one lane blocks vehicles trying to get to another lane; in such a case the second lane is not effective. Designing sufficient lanes only to meet peak-hour factors may result in an unacceptable level of service in the field, especially in larger facilities. Therefore, additional traffic engineering theory must be employed to ensure good design. Traffic engineers have developed queuing theory using standard statistical procedures to model flow patterns over the course of an hour.

Queuing equations are available for two types of conditions: single-channel and multi-channel. Single-channel equations are intended for use where one lane is provided at the access point. The multi-channel equations are used when the driver has a choice of two or more similarly equipped lanes at an exit or entry area.

A simple graphical approach avoids the need to use the actual equations. Note that the vehicle at the equipment is in the service position and is not counted in the queue.

In traffic engineering, it is generally accepted to design for an 80% to 90% probability. There is relatively small variation in reservoir size within this zone. Substantially larger reservoir space and/or more lanes would be required to be adequate for essentially all conditions, as depicted by a 99% curve. Therefore, most systems should be designed for q_{90}.

Ninety percent probability does not imply that this queue will be exceeded 10% of the minutes in the peak hour. A better translation is as follows: If one went out and observed many different lanes, each with this flow intensity for a full hour but with random patterns within the hour, and recorded the queue at very frequent intervals (say every ten seconds), 90% of the recordings among thousands and thousands taken would be less than q_{90}. In sum, we are 90% confident, using standard probability theory, that the design queue will not be exceeded. Even if the queue does exceed that indicated by the 90% probability curve, it will probably be quite rare and short-lived.

The average queue, $\underline{q}$ is used to determine the average wait, $\underline{w} = \underline{q} * \underline{s}$. Because the average time per transaction, $\underline{s} = 1/\mu$, $\underline{w} = \underline{q}/\mu$, can also be used. If the service rate, μ is in vph, $\underline{w}$ will be of the order of magnitude of 10^{-3} or smaller; conversion to minutes or seconds will make $\underline{w}$ more readily understood. Use of $\underline{q}$ for determining the levels of service will be discussed later.

The traffic intensity, λ, is V/μ. Thus, when a V = 300 vehicles is expected to arrive at a card reader, with a service rate μ = 435 vph, λ = 0.69. When a mixture of users such as one volume of monthly parkers (V_m) and another volume of transient parkers (V_t) is expected at a lane, the service rate must be blended to reflect the differeing rates, μ_m and μ_t as follows:

$$\mu = \frac{V_m + V_t}{V_m/\underline{\mu}_m + V/\underline{\mu}_t}$$

The designer thus calculates λ, goes to the queuing curves, moves vertically up to the line, and then traces horizontally across to determine the queue, q. Because the queuing equation models the approach of vehicles to the lane, a peak-hour factor is not used in the queuing analysis, unless there is a significant concentration of activity in shorter periods, as previously discussed.

The queues for various combinations of service rates and number of channels have been calculated and plotted with the design queue, q_{90}, in Figure 4-11, and the average queue, q, in Figure 4-12. Both q and λ in the graphs are per lane. For example if a V = 600 cars is expected at two adjacent lanes, each with a μ = 435 vph, λ = 600/(435 * 2) = 0.69, q_{90} at each lane is two vehicles and $\underline{q}$ is 0.63 vehicle per lane.

It can be seen that using the single-channel equation instead of the multi-channel equation becomes more conservative (that is, overestimating the queue) as the number of lanes n increases and also as intensity increases. For example, at λ = 0.6 and n = 2, q_{90} with the multi-channel equation is two vehicles less (3 versus 1) than with the single channel equation. At λ = 0.9

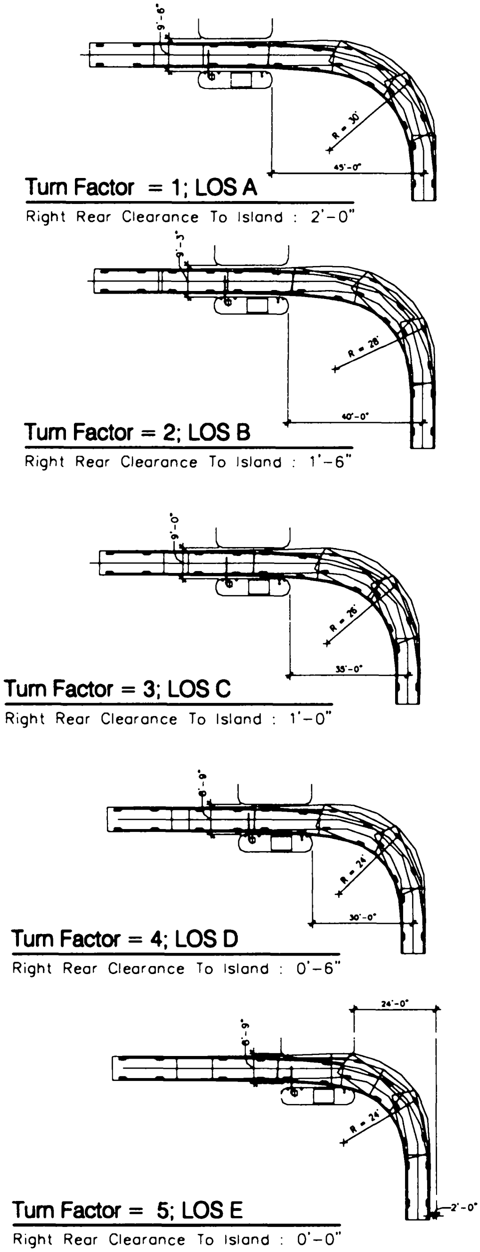

Figure 4-10. Turning factors are employed to adjust service rates for delays caused by sharp turns into equipment lanes.

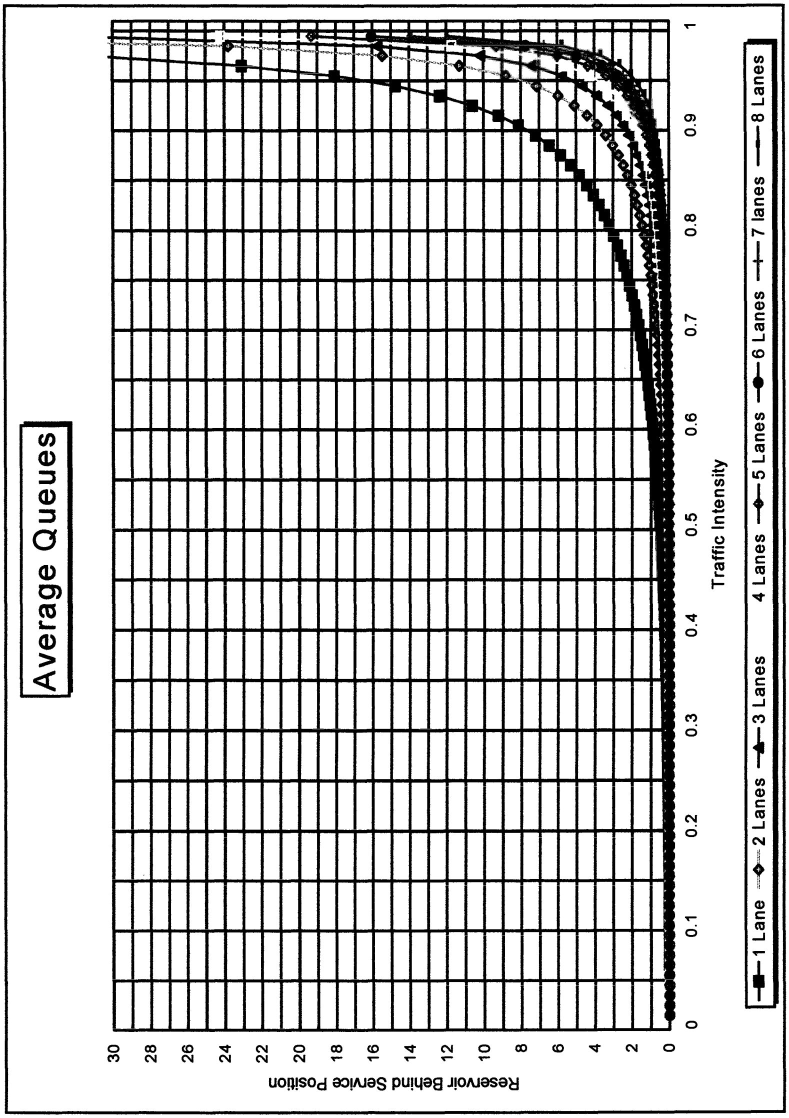

Figure 4-11 Average Queue Curves

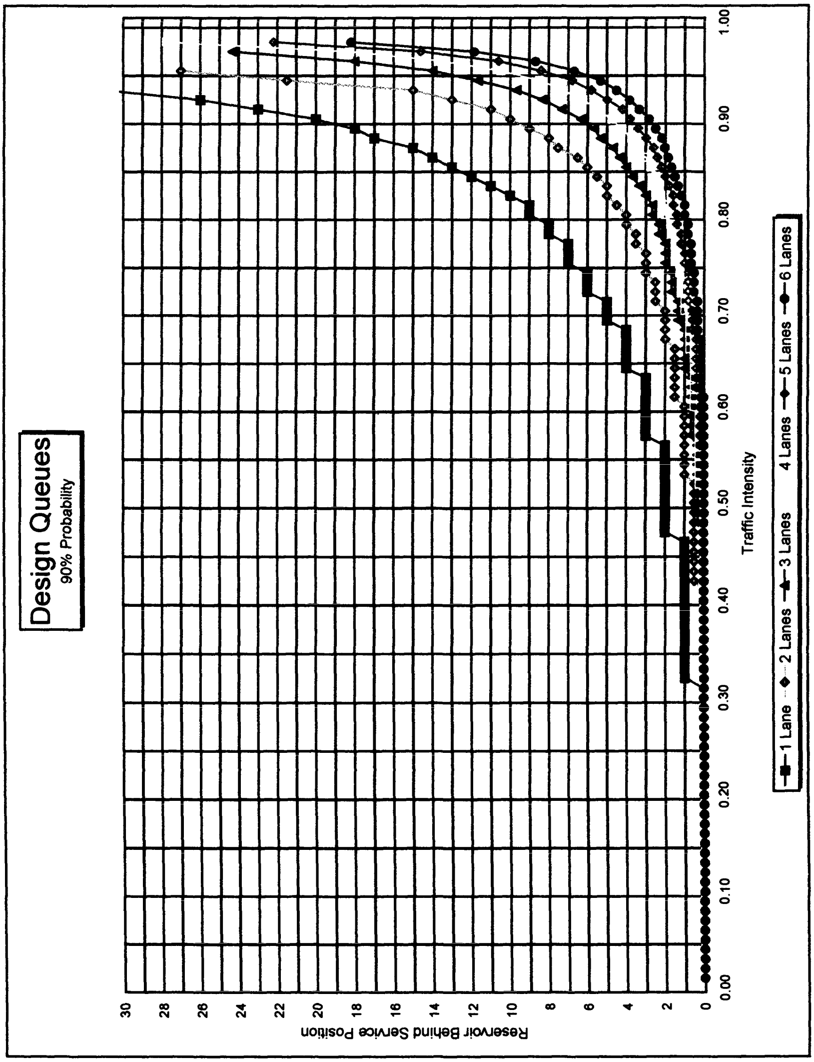

Figure 4-12. Design queue curves

and $n = 2$, the multi-channel design queue is more than 10 vehicles less (20 versus/0) than the single-channel design queue.

The multi-channel equation is, of course, only applicable when multiple lanes are located side by side. If two exit lanes are provided with one at each end of a facility, each lane should be designed using the single-channel equations. Also, if two adjacent lanes serve different users (for example one is both cash and frequent parker but the second is frequent parker only) each should be designed using the single channel equations, because the arriving cash parker doesn't have a choice of lanes.

4.3.3 Level-of-Service Classification

A question often raised is what queue is acceptable to patrons. The level-of-service (LOS) approach is a useful concept in this case. At a traffic signal, the LOS is related to the average delay encountered in the design or peak hour. This concept is easily applied to delay at a parking gate. The acceptable average delay of each LOS at exit/entry lanes is slightly longer than that at traffic signals.[6] This modification is based on the fact that delay at entry/exit lanes is a single occurrence in each trip to or from the facility. The same delay at each of a series of traffic signals would be more frustrating and less acceptable.

Table 4-5 displays the definition of acceptable delay for each LOS, and the associated average queue. The design queue (maximum expected with 90% probability) would be substantially longer. For example, an exit area with two card-controlled gates each having average queues of 7.3 vehicles (LOS D) would have design queues of 21.5 vehicles each. Two cashiered controlled exit gates with LOS D would each have average queues of 2.3 vehicles and design queues of approximately six vehicles.

This approach therefore takes into account the fact that some transactions are considerably slower than others, such as a variable fee paid to a cashier versus a card reader. While the length of the line does have some psychological impact, the critical factor to user acceptability is the delay time. As with other traffic and parking conditions, the acceptable LOS at a facility's entrance/exit depends on the type of user. However, it should be noted that one user type does not require the same LOS at every point in the facility. As discussed in Chapter 3, short-term visitor parking design should have a higher LOS (typically B) than employee parking (typically C), because of the frequency of turnover and the lack of patron familiarity with the design.

Table 4-5. Average Queue for Level of Service

	Average Queue q (vehicles)			
Level of Service	**D**	**C**	**B**	**A**
Delay in Seconds	90	45	20	10
Prepaid Frequent Parker Entry or Exit				
Insertion Card	NR	NR	2.4	1.2
Proximity Card	NR	NR	3.3	1.7
Automatic Veh ID	NR	NR	4.4	2.2
Paper Tag-No Gate	NR	NR	4.4	2.2
Pay Per Use Patron Vehicular Entry				
Push Button Ticket	NR	NR	2.2	1.1
Auto Spit Ticket	NR	NR	2.5	1.3
Pay on Entry-flat fee, gated, ticketed	5.0	2.5	1.1	0.6
Pay on Entry-flat fee, not gated, ticketed	7.5	3.8	1.7	0.8
Pay Per Use Patron Vehicular Exits				
Cash to cashier – variable rate	3.4	1.7	0.8	0.4
Credit card-online check and sign	2.4	1.2	0.5	0.3
Credit card-online check but no sign	2.8	1.4	0.6	0.3
Credit card-batched and no sign	4.4	2.2	1.0	0.5
Validated for free parking	NA	NA	1.7	0.8
Flat Rate Transaction (gated)	4.5	2.3	1.0	0.5
LPI if front plate	2.5	1.3	0.6	0.3
LPI if rear plate only	2.0	1.0	0.4	0.2
LPI if Automatic Vehicle Recognition	3.0	1.5	0.7	0.3
Insertion Ticket for POF Validation	NR	NR	2.0	1.0
POF Central Pay to Cashier				
Cash to POF cashier – variable rate	NR	2.2	1.0	0.5
Credit card-online check and sign	NR	1.4	0.6	0.3
Credit card-online check but no sign	NR	1.7	0.8	0.4
Credit card-batched and no sign	NR	3.1	1.4	0.7
Validated for free parking	NR	7.5	3.3	1.7
POF Central Pay to Machine				
Cash to APS – variable rate	NR	NR	0.4	0.2
Credit card-online check and sign	NR	NA	NA	NA
Credit card-online check but no sign	NR	NR	0.4	0.2
Credit card-batched and no sign	NR	NR	0.6	0.3
Validated for free parking	NR	NR	1.3	0.7

NR = Not recommended
NA = Not Applicable

At entry/exits, frequent parkers demand a higher LOS than less frequent users. Users who encounter the same delay day after day are more likely to complain or choose a facility with a better LOS. Employees or monthly card holders generally want LOS A, but will accept B. Therefore we don't recommend designing frequent parker systems to LOS C or lower. Similarly, those arriving at a facility have less patience with delay at ticketing devices than they would at a cashiered exit. Therefore we almost never design entry controls to operate below LOS B. More irregular users such as shoppers will accept LOS C or B at a cashier on a very busy day.

There are relatively few cases where LOS D is acceptable, unless it occurs on a very infrequent basis such as at a parking facility under special-event conditions. Also, airport toll plazas also may be designed to LOS D in peak periods, particularly if there is substantial hub activity. Three planes may come in very close together, resulting in a significant load at the exit gates say 15 minutes later. The rest of the hour there will be much lower activity. Staffing up to provide LOS A in periods much shorter than an hour is not cost-effective when there are significant variations in activity within an hour.

There also is a perception problem that can occur when a lot of lanes are built, but not staffed. When there are visibly no more lanes that could be opened, there is considerably more patience in the queue and with the staff. Therefore, operators of large toll plazas are just as concerned with not building too many lanes as they are with building too few.

4.3.4 Entry/Exit Layout

When the type of PARC equipment and the number of lanes are known, entry/exit layouts are fairly routine. Typical entry lanes are shown in Figure 4-13. The configuration of "card only" lanes is the same at both entry and exit. At entry lanes, ticket dispensers may be placed just before or after card readers. In this configuration, the patron must press a button on the machine to dispense a ticket. When space is available to separate the dispenser and the card reader, a detector loop in the floor can sense a vehicle approaching the dispenser and "spit" the ticket before the vehicle even comes to a full stop. "Auto-spit" ticket dispensers therefore are faster, as well as less confusing to unfamiliar patrons. The card reader must be placed at least 10 ft in front of the ticket dispenser so that the vehicle stopping at the card reader does not activate the auto-spit function of the ticket dispenser. If the vehicle has used the card reader before reaching the ticket dispenser, the auto-spit function is bypassed. A similar bypass control is used when cash and card customers use the same exit lane, but separation of equipment is not required.

Due to the lack of standardization of AVI reading systems, it is almost impossible to accurately lay out lanes for conduit and device locations without knowing exactly which system is to be installed. Therefore, care has to be taken to keep flexibility in the design of lanes with AVI until a vendor is selected and input on the system requirements can be obtained.

"Reversible" lanes, which serve as entry lanes in the morning and exit lanes in the evening, can be very space efficient when peak hour volumes are predominantly one-way. Reversible lanes are less confusing if they are monthly only, but with proper signage they can be cashier equipped as well.

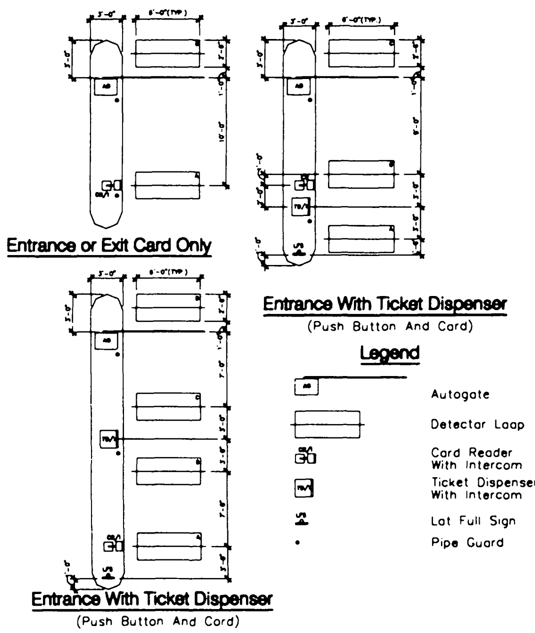

Figure 4-13. Typical entry layout

The Americans with Disabilities Act (ADA) has significantly impacted cashier lane layout. Although the requirements are discussed in more detail in Chapter 7, it is helpful to repeat one critical and most often misunderstood requirement here. Under ADA, **every** cashier booth must be accessible **to and through the door**. This means that the booth must be recessed in the island. It is recommended but **not required** by ADA that at least one of the cashier booths be designed to be fully wheelchair accessible — i.e., have the controls at proper height and the required clear floor space for maneuverability of a wheelchair.

A common error in entry/exit layout is providing inadequate space for the driver to turn into the lane and get aligned with the ticket dispenser or card reader. (See the discussion of turning radius in Chapter 3.) Overhang beyond the wheel track must also be considered. The sharper the turn, the slower the processing of vehicles, as documented previously. However, the issue goes beyond the processing rate to damage of equipment by vehicles unable to make the turn and/or the safety of cashiers working in a booth. Figure 4-14 shows designs of an entry/exit point: one that is too tight, and recommended layouts.

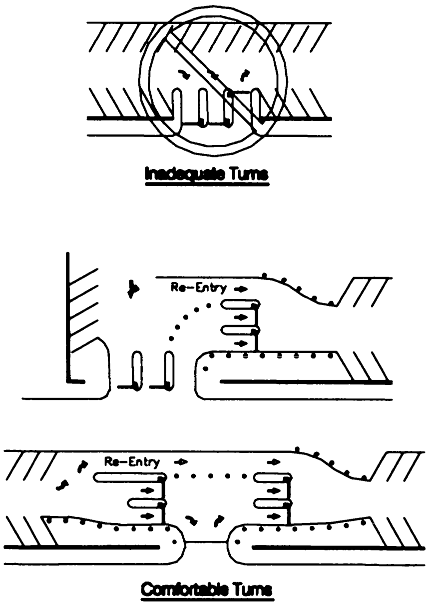

Figure 4-14. Providing inadequate space for turns is a common error in designing access points. Pulling the control equipment inside the facility will provide a much more comfortable arrangement

4.3.5 Auxiliary Spaces

In many parking facilities it is desirable to provide an office for management purposes. In smaller facilities, an enlarged prefabricated booth that combines a cashier station and a counter and/or wall space for various panels (such as the facility intercom, the vehicle counting system, etc.) can meet project requirements. However, the design requirements may also include restrooms, security stations, storage, coat/locker facilities, and management workspace. A custom-built office may then be desirable. Figure 4-15 shows custom designs at two ends of the spectrum: a relatively simple combined cashier/management office and a complex with multiple offices, employee lunchroom, lockers, etc., such as might be required at an airport. Note that all areas in such facilities must be designed to be accessible under ADA.

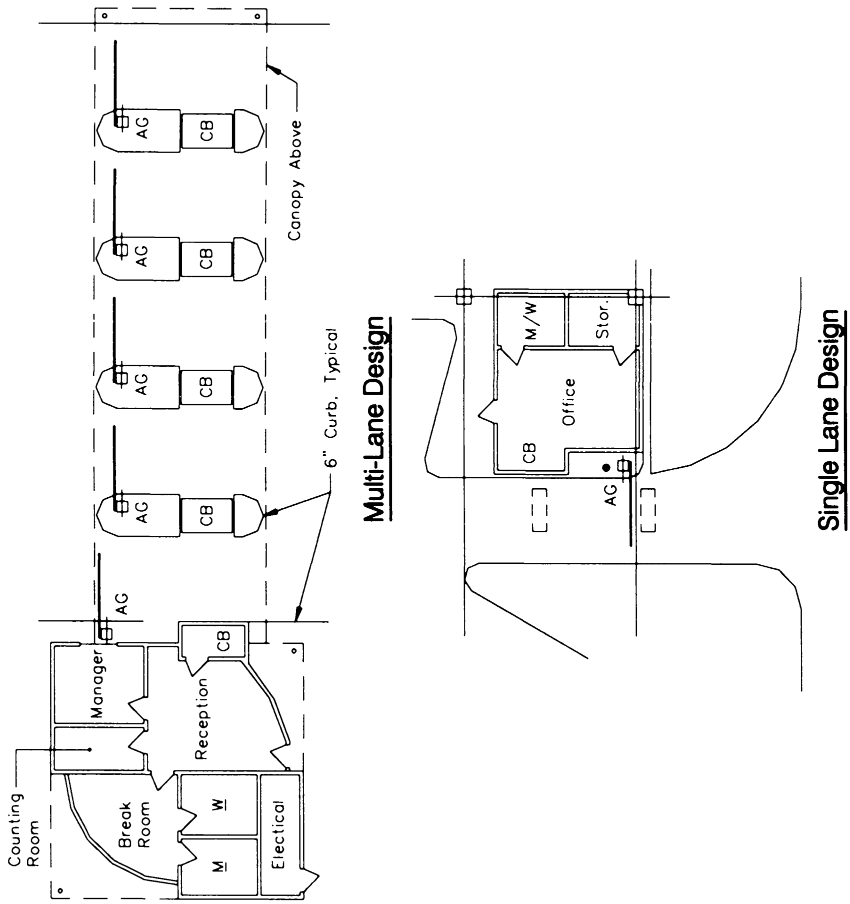

Figure 4-15. Management office layout

4.4 REFERENCES

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[2] Smith, M. S., and W. L. Surna, 1988. "The High Tech Approach to Parking Access and Revenue Control," *Parking* (submitted, July 1988).

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Chapter 5

BUILDING CODES

Mary S. Smith

In the words of the *International Building Code 2000*[1], the purpose of a building code is "to establish the minimum requirements to safeguard the public health, safety and welfare through structural strength, means of egress facilities, stability, sanitation, adequate light and ventilation, energy conservation, and safety to life and property from fire and other hazards attributed to the built environment."

As parking structures have become larger and more complicated, understanding the requirements of building code(s) early in the design process has become far more important. This chapter is dedicated to discussing those elements of building codes that can affect the basic design of a facility. All of the details required by code are not discussed; rather the conceptual issues and common problems that owners and designers encounter are presented. For example, while the need for firewall is discussed, the required details of a firewall are not presented.

As with the chapter on accessibility, where the specific language of a code requirement is critical to its interpretation, the actual code language is quoted herein, rather than being paraphrased.

5.1 WHAT CODES APPLY?

Traditionally, a model building code has been adopted at the state or local level to govern the design and construction of buildings. While the primary purpose of building codes has been life safety, other issues have been addressed over the years to result in a certain minimum quality of

A. P. Chrest et al., *Parking Structures*

construction as deemed appropriate for the best interests of the community. In the US, there are three model code agencies:

- Building Officials and Code Administrators (BOCA), which publishes the *BOCA National Building Code*[2]. The latest edition is dated 1999, and hereinafter denoted BOCA. This code is most frequently seen east of the Mississippi and north of the Mason Dixon line, per Figure 5-1.
- International Conference of Building Officials (ICBO), which publishes the *Uniform Building Code*[3]. The latest edition is dated 1997, and hereinafter denoted UBC. This code is most commonly adopted west of the Mississippi.
- Southern Building Code Congress International (SBCCI), which publishes the *Standard Building Code*[4]. The most recent edition is dated 1999, and hereinafter denoted SBC. This code is typically employed in the southern states.

Following the issuance of a newly updated model code, which has typically occurred on a three-year cycle, states and/or local legislative bodies formally adopt a code for use in their area of jurisdiction. Many states/localities take additional time to study each new issue and adopt significant amendments. As a result, it may take a period of six months to two years for the new model code to come into wide usage. Other states/localities have written their own codes, substantially from scratch, over a period of many years.

The three model codes have many similarities but also unique differences. Traditionally, UBC has focused heavily on earthquake design issues. Some decisions regarding issues that would not at face value involve seismic issues, such as separation of mixed uses, have in fact reflected seismicity concerns. SBC has traditionally been strong in the area of wind and other coastal design issues, and has looked more favorably on certain types of timber construction. BOCA has had more of a generalist point of view.

A fourth code setting group, the National Fire Protection Association, is another wild card in the code lexicon for parking facility design. The NFPA generally publishes fire protection standards, but their life safety code, *NFPA 101*[5], covers much of the same ground as the three model codes.

In the past, the three model building codes referenced portions of NFPA 101 as well as other NFPA documents for specific issues, but NFPA 101 was not usually adopted in total by very many jurisdictions. Many parking designers are relatively unfamiliar with it. More recently, local fire prevention/protection folks have argued for the adoption of NFPA 101.

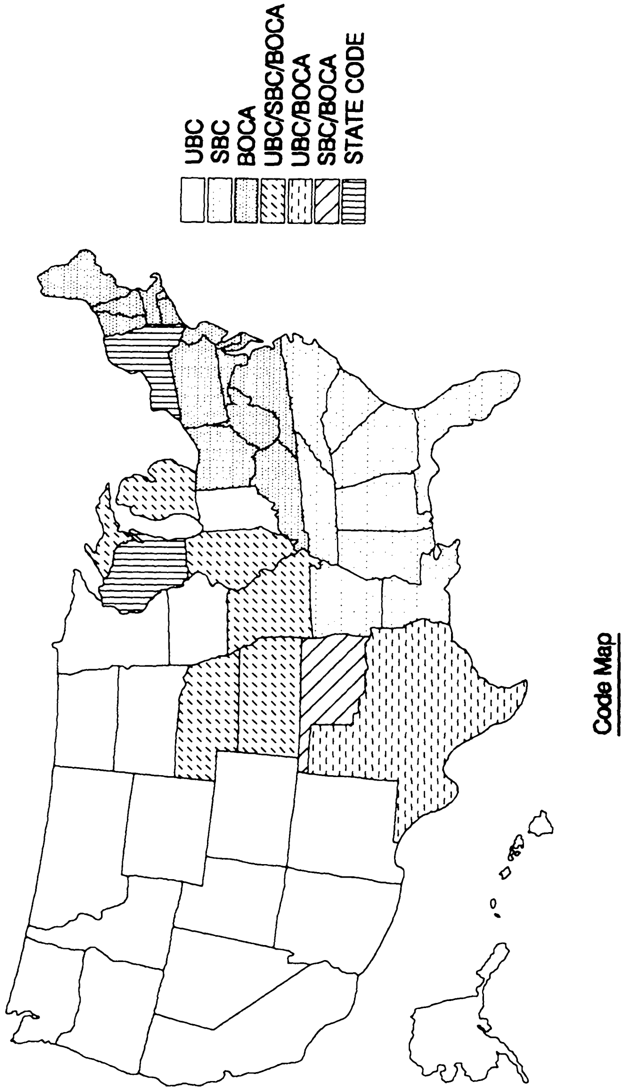


Figure 5-1. Applicability of model building codes in the US. Source: ICBO

Some entities, e.g., the State of Maryland, now adopt both NFPA 101 and a model code; in such cases they enforce the higher or more restrictive standard, issue by issue, from either of the adopted codes.

NFPA 101 is specifically a code focused on life safety during fire events. It doesn't address design elements subject to other risks to life safety; for example, there are no requirements for structural design to withstand seismic, hurricane or wind forces.

Of course, many features that provide for enhanced life safety from fire events are beneficial to other emergency events. Other NFPA codes address specific issues; NFPA has a separate code for parking structures, 88A[6], that fills some of the gaps between NFPA 101 and model building codes. NFPA 88A is less widely adopted than NFPA 101. Unfortunately, some conflicts and inconsistencies in requirements exist between NFPA 101 and 88A. The inconsistencies stem from the fact that independent committees having different scope assignments primarily write NFPA's codes. NFPA uses a committee structure based on the procedures established by American National Standards Institute (ANSI), including full voting membership for those in the building and design industries. The membership does vote on each standard before publication; however there is a certain level of reliance on the committee's judgement because issues are extensively debated and consensus is achieved at the committee level by a cross-section of interests.

Where a code is adopted at state level, localities are usually prohibited from adopting another code instead, or making their own amendments. For example, in the State of Indiana, UBC is officially adopted and local entities are not allowed to adopt NFPA 101 instead of UBC. However, there are ways to adopt and/or force designers to follow certain requirements. For example, the Fire Marshall may successfully argue for a local ordinance that an open parking structure above a certain height must be sprinklered.

Meanwhile, the Americans with Disabilities Act changed the face of building design yet again. Although a separate chapter is devoted to accessible design issues, the adoption of ADA spurred all three model codes to adopt accessibility requirements, especially in the area of means of egress. The federal *Americans with Disabilities Act Accessibility Guidelines*[7] (ADAAG) developed by the Architectural and Transportation Barriers Compliance Board in 1991 relied heavily, but not totally, on the then-current version of ANSI A117.1[8] that dated to 1980. The three model code agencies participated in the development of the next update thereto and all adopted ANSI A117.1-1992 virtually intact. Conflicts exist between ADAAG and 1992 ANSI code, as well as the model codes that follow the latter, resulting in conflicts where either 1992 ANSI was modified from, or the Access Board saw fit to deviate from, the 1980 version of ANSI. It is therefore often necessary to lay the applicable codes side-by-side and determine which clause is likely to apply.

As designers, contractors and building product suppliers have extended distribution of their products and services nation-wide, there occurred an increase in concern regarding the regionalism of building codes. In 1993, BOCA, ICBO and SBCCI announced that by the year 2000, they would publish a single code for the entire country. The International Code Council was formed. A comprehensive model code was developed, now known as the *International Building Code 2000,* (hereinafter referred to as IBC.)

Those concerned with accessibility also responded to the call for uniformity of requirements. A new version of ANSI A117.1[9], now also sponsored and published by the International Code Council was published in 1998. In turn, a completely revised ADAAG[10] has been published for comment in late 1999, which should be adopted by the end of 2000. This version is much more closely coordinated and has fewer conflicts with ICC/ANSI A117.1-1998. Therefore, it has fewer conflicts with the latest versions of each of the three model codes, and with IBC.

All three model code groups continued to publish their own codes through the dates listed above. Part of the reason is that each reorganized their old code into the common code format to facilitate the transition for their own members. Also, many of the adopting entities are moving slowly to adopt IBC and having the old familiar code updated gives the skeptics more time to accept the single code. The revision process for BOCA, SBC and UBC, however, has ceased, and none of the three will be published again. When the adoption process is complete, there will effectively be three national codes that can affect design: ADAAG, NFPA and IBC.

According to the Window and Door Manufacturers Association[11] (WDMA), only four states plan to adopt IBC in 2000, but two of those will not begin to enforce it until 2002. Four more states are likely to adopt it in 2001, with three more in 2002 and five likely to wait until the 2003 edition is published. A number of states leave code adoption to local jurisdictions, while at least two (Pennsylvania and Nebraska) have adopted other codes and will not be considering IBC in the near future. Two of the entities which have long employed self-developed codes, the City of Chicago and the State of New York, are among those that have indicated they will adopt IBC, although probably with various amendments reflecting local concerns.

One of the reasons for the slow adoption rate is conflict with NFPA. In 1998, ICC and NFPA attempted to adopt a joint fire protection code, but the process broke down over code development procedures. ICC accepts code proposals from any interested party and the final decision is rendered by the membership at large; however that voting membership is limited to building officials. Apparently, ICC wouldn't accept ANSI-style committee organization and NFPA wouldn't give it up. Indeed, it has been reported that NFPA and some splinter organizations are planning to develop more comprehensive code(s) to fully compete with IBC.

The final complication is that all of the codes give latitude to the local official. While there are various references regarding interpretation of the codes, ultimately, the local building code official has the right to enforce it as he/she sees fit. As such, he or she may choose not to enforce a provision that in his or her interpretation is not in the best interests of the public health, safety and welfare for that project in that location. In the past, due to the lack of familiarity with parking issues, one would sit down with the code official and explain the "common interpretation" of a code requirement and more often than not, the official would accept it. However, in recent years, local officials have been more likely to ask for an official interpretation from the national code group and then enforce it. The interpretation rendered by the national groups will consider, among other things, the specific intent of and debate on the provision when it was adopted; this documentation is not available to the typical designer reading the code at its face value. For example, one might conclude that NFPA has an exception that excludes vehicle ramps from requirements for landings and handrails on parking ramps that also serve as the path of travel to an exit. However, the exception for "vehicle access ramps" is intended for boarding ramps to airplanes and cruise ships.

The NFPA standards contain various clauses that effectively allow the "authority having jurisdiction" to determine the hazards that might exist in a particular set of circumstances and to determine the adequacy of the design to protect life safety against those hazards. This provision is frequently used by fire marshals to require sprinklers or other features not otherwise required by NFPA. Conversely, the NFPA standards also give the local official somewhat more latitude to consider and accept alternate approaches that provide equivalent protection of life safety. There is thus a need to discuss approaches with local officials, as well as to treat issues and concerns more globally under NFPA, rather than ask for an interpretation, waiver or variance of a single narrow, issue.

The combination of all of the above factors has made it difficult for a designer working in varying jurisdictions to design a building with the confidence that it won't get hung up by building code issues during the permitting process. It has also made it advisable for designers to retain experts in code interpretation, and/or meet with local officials early and often to obtain understanding of local interpretations of code.

This chapter will focus on significant requirements by discussing the requirements of the IBC—which at least represents a recent consensus of the three model building code groups—and NFPA. Where significant, some discussion of the UBC, SBC and BOCA requirements is also provided; these discussions are intended to illuminate the IBC requirements for those primarily familiar with one of the older model codes. However, no attempt has been made to discuss state and local codes and amendments.

5.2 LIFE SAFETY ISSUES

All of the model codes have one provision or another that conflicts with provisions in other codes and/or is generally considered inappropriate by the parking industry. The NFPA openly acknowledges that its life safety code is focused on fire risks: the operative part of its title is "Code for Safety to Life from Fire..." Although NFPA 101 doesn't require sprinklers in open parking structures, it does have some provisions that are more restrictive than the other model codes. For example, stairs in open parking structures must be enclosed. There is a provision to allow the stairs to be open if the walking distance down the stair is included in the path of travel to the exit, but it often requires more stairs. Either way, construction cost is increased. Walking distance to the stairs from any point on a parking structure floor in an enclosed structure is also significantly less than permitted in other codes. Conversely, NFPA has some bonuses, too: an open parking facility that is 50% open on all four sides may have its travel distance increased from 300 ft. to 400 ft. The increase, in turn, can allow open stairs to be used in many structures with three or four supported levels, without penalty under NFPA.

UBC, in turn, has long had a provision that open parking structures cannot be part of mixed-use buildings, except for the specific combination of an open structure over an enclosed one. If any other occupancy classification is included in a building with an open parking structure, the occupancy classification of the parking structure defaults to an enclosed structure. SBC, NFPA and BOCA however, have allowed open parking structures for an equally long period of years to be part of mixed-use buildings, if separated appropriately.

Although building officials in some cities will have at least some experience with parking structure issues, other members of the code organizations have little-to-no experience base regarding the application of requirements to parking facilities. When asked to interpret an issue locally, they naturally make their decisions from their personal knowledge base: the well-established principles of life safety for other building types. While understandable, it therefore often takes some education of local officials regarding the design issues and constraints for parking facilities.

The lack of familiarity of parking issues also results in language slipping into the national codes that cause problems for parking designers. For example, IBC contains a provision that effectively limits parking ramp slopes to 1:20, even though slopes up to about 1:15 have been regularly used in parking structures across the country with no apparent egress problems. It is believed that no one in the code organizations even contemplated the application, much less the impact, of this provision on parking design. The intent is to "mainstream" accessibility into means of egress. However, accessibility laws require that those with mobility impairments be given special parking locations closest to the pedestrian entrances and with the path of travel meeting all requirements for accessible routes. Therefore, designing the path of travel across a parking floor to meet accessibility criteria is not the issue it can and should be in other building types. The code groups did, in fact, make exceptions to the ramp requirements for theatres. There are also special locations for accessible "seating" that make it less critical for theatre aisles to be accessible. Theatres are a use with much higher risk to life safety in fires than parking facilities. Presumably, the code groups would be willing to make appropriate exceptions for parking if the situation is brought to their attention.

In most cases, the parking industry is equally, if not more, at fault for not following the code change process more closely. Often, only after the code is in force has the industry recognized a problematic, albeit un-intentioned, impact on parking structures. The parking industry has had representatives on the NFPA 88A committee for many years, but that document is rarely if ever adopted and enforced. Its primary benefit is in the education of local officials as to what representatives of a cross-section of interested parties agree upon as a consensus standard.

Similarly, because fires are so rare in parking structures, the majority of fire protection officials don't have enough experience fighting fires in parking structures to understand the unique characteristics of such events. Even though the national codes, including NFPA 101, have considered and adopted special considerations for parking structures based on studies of the risk to life safety in actual parking structure fires, officials often have added requirements, such as sprinklers, back at the local level. It therefore may take an effort to educate local officials regarding the documented risks to life safety from fire during the building code approval process for a specific project. Almost uniformly, if presented with the proper, well-documented information, local officials will seriously consider requests and make well-reasoned decisions.

Therefore, the following discussion of life safety issues in parking structure fires is presented so that designers, owners and local officials alike may agree upon appropriate life safety requirements in parking structures.

Certainly, fire safety remains the single largest factor driving all building codes, because the loss of life in fires often could have easily been avoided. The history of parking structure fires proves beyond all reasonable doubt that the risk to life safety from a fire in a parking structure, whether open or enclosed, is very, very low. Indeed it has been asserted, and never disproved, that there has **never** been a loss of life solely resulting from a fire that began in a parked vehicle. The deaths that have been documented were directly the result of an explosion, caused by either an intentional attempt at murder (such as a car bombing or terrorist act) or improper handling of explosive materials (such as welding during construction or repairs to a facility.)

And once a fire starts, it simply doesn't spread very far, at least as compared to other uses. Because vehicle fires are so localized, a sprinkler head that is not directly above a burning vehicle may not activate at all. The buildings are constructed of non-combustible materials that resist fire spread and indeed suffer very little damage in the fires that occur in parking structures. Most importantly, there is generally a very low density of occupants as compared to the volume of space, so that the potential for panic during exiting is considerably reduced.

A 1972 report that was updated in 1977[12] was one of the first analyses of actual parking structure fires. It documented the findings of a survey of 1,686 parking structures of all types, sizes and construction totalling over 775,000 parking spaces. During the history of these structures dating to as far back as 1911, 500 fires were reported. Only nine of those fires caused more than $5000 damage. Seven of the nine started as a result of a fire in an auxiliary space such as an office or storage; a gasoline truck overflow and a car bomb caused the other two.

The Scranton Fire Tests of 1972[13] focused on the potential for damage to structural elements from fires and found that even unprotected steel suffered no permanent damage from a fire that was intentionally allowed to spread to three vehicles. Windows in the three cars were left partially open and the foot wells of the passenger compartments were "stuffed" with crumpled newspapers to encourage fire spread. However, only the plastic tail light assembly on one of the adjacent cars burned when exposed to flaming gasoline after the gas tank on the first car failed. The fire did not spread farther into that vehicle. The fire did spread to the other adjacent car, apparently originating in a fiberglass repair patch on a door. The fire spread through the door into the passenger compartment, but burned so slowly that general involvement of this vehicle had not occurred when the tests were stopped 40 minutes after the fire was started in the first car, which was totally burnt out. Maximum temperatures and deflection of the structural steel remained far below critical levels throughout the test and no damage to the steel occurred.

Additional tests were conducted in Australia in 1985 to address the issues of increased use of plastics in cars, the reduction in parking stall widths due to smaller vehicles, the use of plastic gas tanks and LPG cylinders, and the increasing use of lighter steel structures.[14] The test structure was constructed of steel members representative of the smallest members likely to be used in practice in an open-deck car park. In the first test, only the car in which the fire was started burned. After 25 minutes, the fire spread to the gas tank filler pipe and the gas from the tank continued to burn for another 30 minutes.

In the second test, the car set on fire had a LPG cylinder rather than a gas tank. 14 minutes after the fire was started, the pressure relief valve on the LPG tank vented to relieve the build-up in pressure in the tank. The gas continued to vent intermittently but never ignited. This fire did spread to the cars on each side. The fire finally spread to the filler pipe of one of those two cars (after 50 minutes), and again the gas was consumed by fire.

In both tests, the car park was loaded with vehicles on the floor above and it supported those loads throughout both tests without any noticeable stress or risk of collapse. The measured steel temperatures showed a significant factor of safety as compared to temperatures expected to cause the beams or columns to "shed load."

Another detailed study[15] of all fires reported in parking structures, both open and enclosed, by the National Fire Incident Reporting System from 1986 through 1988, in parking facilities of all types (both open and enclosed), found a total of 404 fire incidents. 80% of the fires were vehicle fires. Most (94%) of the vehicle fires originated in the engine compartment; half of those were electrically related. Approximately 72% of the fires were extinguished by fire-fighters. Of the "serious fires" which were defined to be those that spread to at least one adjacent vehicle, the fire department extinguished 93% of the fires.

No deaths were reported and only three civilians and six fire-fighters were injured; **none** of the injuries were caused directly by either the fire or the smoke thereof. Note again that this study included both enclosed and open structures. The overall conclusions of this study are as follows:

- Parking structure fires are extremely infrequent compared to other building uses;
- they rarely spread from the point of origin;
- they result in very little property damage;
- personal injuries are rare; and
- no one died in a parking structure fire.

The three model codes have long since recognized both the low fire risk and the higher violent crime risk and allow open stairs and other considerations for passive security in open parking structures. As discussed in the chapter on Security, the National Institutes of Justice[16] reported about 1,400 violent crimes **per day** in parking facilities in the United States in 1992. NFPA, however, continues to require enclosed stairs or to place restrictions that generally cause most designers to give up the passive security concern and enclose the stairs. Similarly, each of the other codes enforces at least some requirements that are considered unnecessary and a waste of resources that could be put to better use. But again, a key reason for the lack of recognition of unique issues regarding parking in building codes is the lack of active involvement in the code development process by parking designers.

The bigger problem that frequently occurs is that local officials want open parking structures to be sprinklered even though all of the national codes are very clear that sprinklers are not required. A more comprehensive discussion of the literature regarding sprinklering parking structures therefore follows.

In the above-cited survey of fires, which occurred from 1983 to 1985, fire sprinklers extinguished only 1.4% of the incidents. Seventy-six percent of the parking structure fires were extinguished with hand-laid hoses from fire trucks or with fire extinguishers. Standpipes were used in 11% of the fires. The remainder burned themselves out or were put out by occupants of the building.

It is true that only 37.4% of the structures had sprinklers; however, in those cases, the fire was controlled or extinguished by sprinklers in only 13.6% of the fires. The two primary reasons the sprinklers were not considered effective by the survey respondents was either that the "fire was too small" (54.9%) or the "sprinklers were not in the area" (42.9%.) A second data analysis using only the serious fires in sprinklered buildings found that sprinklers controlled or extinguished only 20% of those fires.

Fire sprinklers are considered a key component in life safety provisions in most buildings to contain, if not prevent, fire spread long enough for the occupants to safely exit and/or for the fire department to arrive and take charge of the situation. Sprinklers may be ineffective in achieving these goals in parking structures when fires start in and are generally confined to the protective metal shell of the automobile, especially if they smoulder for a long period. There will usually be enough smoke from a smouldering fire to alert the occupants to a problem without reaching the levels at which egress is hampered by smoke. In the Scranton fire test, a heavy layer of smoke about three ft. thick rose to the ceiling, but the openness of the structure allowed it to migrate out of the structure so that it never became thicker.

Sprinklers spraying water on the roof of a car will not extinguish a fire inside or beneath the automobile, at least as an early intervention method. In addition, water from sprinklers has been shown in some tests to actually facilitate the spread of fire from one vehicle to the next. [17] Gasoline and water do not naturally mix; the relatively small volume of water from sprinklers tends to carry flaming gasoline down parking floors sloped for drainage or floor-to-floor circulation.

Indeed, sprinklers are **prohibited** in parking occupancies, including enclosed and underground facilities, in some jurisdictions in Europe because, in addition to failing to control or extinguish fires in test vehicles, the extinguishing water caused more smoke, leading to loss of visibility. Tests conducted in Switzerland [18] in 1970 specifically modeled three different types of fires in enclosed parking structures. In the first test, a "smouldering fire" was set inside the vehicle. The fire smouldered inside the car for more than 25 minutes before it flared up inside the car. An automatic fire alarm activated shortly before the flare up, at 23 minutes, 30 seconds. Although smoke was produced before the sprinklers activated, it did not fill the test "room" and visibility was good. At 28 minutes, 30 seconds after the fire was set, the sprinkler system activated whereupon smoke completely filled the room. No fire spread occurred with this fire.

The second Swiss test simulated a "clumsy topping off" with ignition of gas spilled from an open gas tank. An intense fire immediately occurred outside and under the vehicle. The sprinkler system activated at 40 sec after the fire was set and smoke "greatly intensified" immediately thereafter. The extinguishing water then spread the fire to the adjacent vehicle. Even though there was no damage to the inside of the first car, the fire attacked the adjacent car at the front tire, burned through the engine compartment, and ignited the interior, all while the sprinklers were activated and operating. The fire brigade "standing by" then ordered the test facility evacuated and the sprinklers turned off. They extinguished the fire using foam but had to use breathing apparatus due to the quantity of smoke.

The third of the Swiss tests was intended to model an arson event; the interior of the car was loaded with combustible materials, including tires, plastic waste materials and celluloid. For this test, the sprinkler system was deactivated, as one of the goals of this test was to study the smoke produced by the combustible materials. The fire was begun by igniting a gas/oil mixture placed in a pan on the floor under the gas tank. The car was blazing with flames shooting out of the gas tank filler cap within 30 seconds. The gas tank, despite being directly exposed to the fire, did not explode or fail, although the contents burned as they escaped via the filler pipe. However, the tires of the first vehicle exploded and the fire spread to the adjacent car when its tire caught fire. The interior of the second car did not ignite, and the windows remained intact.

The Swiss study concluded that an automatic fire detection system alerting the building occupants and allowing the fire department to be summoned was more effective than sprinklers for underground, enclosed structures.

Additional tests in Australia in 1988 studied the issues of fires in enclosed structures.[19] This study found that sprinklers did control and extinguish fires set in vehicles and reduced the amount of smoke. The difference in results from the Swiss tests may be due primarily to differences in the way the fires were set. In the Australian tests, the fires were started by placing gasoline-soaked rags under the front seat and lighting them through an open window on the driver's side. The fire broke the windshield very quickly (within one minute or less after the fire was ignited) and the sprinklers then extinguished the fire before it spread further; it never engulfed the vehicles. In additional tests, where sprinklers were not automatic, the fires continued until the vehicles were engulfed; in some cases the fires did spread to adjacent vehicles.

The Australian fire tests also included some interesting tests specially constructed to determine problems resulting from plastics used on the exterior of vehicles and in gas tanks. The conclusion of that study was that the vehicles with extensive plastic did produce more smoke than older vehicles with less plastic and steel gas tanks, although the toxicity of the smoke in both cases was not measured. The Australians also raised the concern that the "venting" of LPG cylinders that occurred when fire heated the tanks is more of a concern when the gas doesn't immediately burn than it would be if it burned immediately after release, particularly in enclosed structures.

In sum, sprinklers in parking structures probably are a "mixed bag." They appear to be effective in containing certain types of vehicle fires, but not others. The smouldering fire of the Swiss tests, in which sprinklers clearly made things worse, is believed to be more likely to occur than the very rapidly-built fire of the Australian tests. The data on fire history further seems to indicate that sprinklers, even when provided, are not very effective in actual parking structure fires. The cost-effectiveness of sprinklers in both open and enclosed structures is thus questionable. And if the specific circumstances of the fire are such that sprinklers increase smoke or spread fires from vehicle to vehicle, as has been proven to occur in some circumstances, they may do more harm than good.

In open parking structures, there is enough natural ventilation to allow smoke to dissipate and the documented risks to life safety are low.

Therefore, it makes sense to simply let the fire burn until it either burns itself out or the fire department arrives to put it out.

The issues relating to enclosed structures are more difficult, because the smoke produced in both the Swiss and Australian tests was significant enough to hamper egress by occupants. However, in the smouldering fire of the Swiss tests, there was more than enough time and warning for the occupants to evacuate before the smoke affected egress. Therefore, we believe that it may be more appropriate to employ automatic fire detectors rather than sprinklers in enclosed structures, as required in many jurisdictions in Europe. However, today's codes in the US uniformly require sprinklers in enclosed structures.

5.3 BASIC ISSUES

Building codes recognize two fundamental types of parking structures: the open parking structure and the enclosed parking structure. An open parking structure is one that is sufficiently open to allow natural ventilation as well as dispersion of smoke from any fire, thereby reducing hazards to the occupants. There then devolve distinct differences in the requirements for design that, in turn dramatically affect construction cost and other factors. When a structure does not qualify as open, it must comply with the requirements for enclosed parking structures, which means sprinklers and ventilation, enclosed stairs and so forth. It behooves the parking designer to assure that a facility be able to qualify as open wherever possible.

5.3.1 Open or Enclosed?

An open parking structure is defined by IBC as follows:

> ....with the openings as described in Section 406.3.2.2 on two or more sides and which is used exclusively for the parking or storage of private motor vehicles as described in Section 406.3.4. (IBC 406.3.2.1).

The intent of the word **exclusively** as used in the IBC definition is of concern to the parking industry, because it came from UBC. As previously noted, that code prohibits open parking structures from being part of non-parking mixed-use buildings. UBC has consistently indicated in formal interpretations that the word "exclusively" is intended to generally prohibit the incorporation of open parking structures in mixed-use buildings. IBC also uses UBC language repeating the word "exclusively" specifically as regards to uses.

406.3.4 Uses. Except as allowed under the special provisions of Section 508.3, open parking structures shall be used exclusively for the parking or storage of private motor vehicles.
Exception: The grade-level tier may contain an office, waiting and toilet rooms having a total combined area of not more than 1,000 sq. ft. (93 m^2), Such area need not be separated from the open parking structure.

BOCA and SBC have long allowed open parking structures to be part of mixed-use buildings. According to several sources in the code development community, this issue was one of the many compromises that had to be forged in the IBC development process. The intent of the IBC committee dealing with this issue was that open parking structures **could** be part of mixed uses, if properly separated as discussed later in this Chapter. The retention of the UBC "exclusivity" language is intended in IBC to only restrict the types of vehicles that can be parked in open parking structures.

Each of the codes has some qualifiers about what constitutes a private passenger vehicle; buses and commercial trucks are prohibited from parking in open parking structures under all of the codes except NFPA 101. Under IBC and UBC, motor homes and RVs are considered to be private passenger vehicles and are allowed in open structures even though they may be closer to buses than passenger cars in construction and fire hazard. Conversely, taxis and limos (which are usually converted cars or vans and have the same fire risk as privately-owned cars) cannot be parked in open parking structures under IBC and UBC. If such vehicles are to be parked in a structure, it automatically becomes an enclosed structure under IBC and UBC. This restriction has been an issue at some airports where structures were built for taxi dispatch and waiting areas. Similarly, there is also concern that IBC and UBC definitions would not allow the storage of rental cars in an open parking facility. To date, most local officials have ruled that a rental car structure can be an open parking structure based on the fact that the fire risks are identical to a parking structure serving private vehicles.

BOCA limits parking structures, both open and enclosed, to vehicles that carry nine or fewer passengers. Many larger motor homes and RVs can carry more passengers and would not be permitted in open parking structures, but taxis and limos, as well as rental cars would clearly be permitted. If there are buses and/or larger RVs and motor homes parked in the facility, it must be considered a public structure, type 1, which is also the type used by BOCA when repairing/fueling occurs in the structure.

SBC defines parking structures, both open and enclosed, as serving "automobiles" which, under Federal vehicle regulations at least, are limited to passenger cars and do not include light trucks, vans and sport utility vehicles (LTVU), much less RVs and motor homes. However, this language is more than likely simply a carry-over from the days when trucks, vans and utility vehicles were not normally used for personal, everyday transportation. In fact, the common interpretation is that buses/commercial trucks may be parked in open structures under SBC, but that level must be sprinklered.

Both NFPA 101 and 88A allow "motor vehicles" to be parked in both open and enclosed parking structures. The 1998 edition of NFPA 88A in fact considered the impact of both compressed and liquefied natural gas fuel systems in vehicles and concluded: "A natural gas leak should pose no greater risk than leaks of conventional motor fuels."

All except NFPA 88A prohibit the dispensing of motor fuels or repair of vehicles in either an open or enclosed parking structure. If fueling of motor vehicles occurs in a parking structure, it kicks in a different occupancy under the various codes. Parking areas can be classified as open or enclosed parking structures if separated appropriately from the repair/fueling area and/or the other potential hazards of repair facilities, including explosions, are addressed. Note, however, that due to the UBC prohibition of non-parking mixed uses with open parking structures, the parking above a repair facility would have to be classified as an enclosed structure, even if open.

NFPA 88A allows repairing and fueling in either open or enclosed structures without separation but does impose certain special requirements thereto; another code NFPA 30A, which is referenced by 88A, addresses requirements for fuel dispensing inside buildings. Given the infrequency of designs with fueling and repairing in parking structures, we have not outlined those special requirements herein. The fact that NFPA 101 prohibits fuel dispensing in both open and enclosed structures, by changing the occupancy type to industrial, but 88A allows it, is one example of a conflict between the two.

There also is a distinction between "mechanical-access open parking structures" (which employ parking machines, lifts, elevators, etc) and "ramp-access open parking structures" which have a series of interconnecting ramps permitting the movement of vehicles between floors. UBC and IBC only define and consider mechanical access structures if they qualify as open. That definition may be somewhat confusing because in many cases, the vehicles are not driven through the facilities and therefore natural ventilation is not a concern, and pedestrians are not allowed in the parking areas so smoke dispersion is not a concern. However, the language is believed to be a carry-over from the mechanical structures of the past; they often had an elevator that took the vehicle to the storage floor, but it was then driven and parked by an attendant. As discussed in the chapter on mechanical structures, today's mechanical structures are often designed to be totally automated if not unattended. Essentially, a mechanical access structure can be treated as an open parking structure if it meets openness criteria and an enclosed structure if it is not open.

SBC doesn't discuss mechanical structures at all, while BOCA has a few exceptions for mechanical structures buried here and there in various specific requirements related to either open or enclosed structures, or both. NFPA 101 says that its requirements for open and enclosed structures do not apply to mechanical structures or exclusively attendant-type structures, but does not say if any of its other sections apply to those facilities. This lack of definition of requirements for mechanical structures is an example of an area where the authority having jurisdiction is allowed to determine the hazards and the protections based on a determination of similarities to other uses. NFPA 88A most clearly addresses mechanical structures generally as either open or enclosed, but does not have any special or specific requirements thereafter; they are simply treated as open or enclosed structures. Designers may use NFPA 88A to help negotiate the specific requirements under NFPA 101.

The clear height of a parking tier or level shall not be less than 7 ft., under IBC, BOCA, UBC and SBC. Note that 7'-6" clear height may be required for offices and other occupiable and habitable spaces. The clear height is generally interpreted as the straight vertical clearance. A parking facility with this clearance will typically be signed with 6'-8" to 6'-10" vehicular clearance to allow for vehicle break-over. (See chapter 3.)

NFPA 101, however, requires that 7'-6" clearance is provided throughout a means of egress system, which as discussed later, includes parking areas. It does allow projections into that height, maintaining 6'-8" clear, if the projections do not exceed one-third of the ceiling area of the room or space. Neither post-tensioned beams nor tee stems and beams in a precast concrete structure would exceed one-third of the ceiling area. Therefore, under NFPA 101, structures, both open and enclosed, could have 6'-8" clearance to any projecting element, (such as a sign or light fixture) and somewhat less than 7'-0" clearance to the underside of beams and/or tee stems. Those facilities could be signed with as little as 6'-6" vehicular clearance, as long as the height to the underside of the "slab" elements is 7'-6" or more. Application of the NFPA provision to other structural types, such as waffle and flat slabs, would have to be checked carefully. NFPA 88A does not address clearances.

5.3.2 Required Openings

To qualify as open, the following criteria apply under the IBC:

406.3.3.1 Openings. For natural ventilation purposes, the exterior side of the structure shall have uniformly distributed openings on two or more sides. The area of such openings in exterior walls on a tier must be at least 20 percent of the total perimeter wall area of each tier. The aggregate length of the openings considered to be providing natural ventilation shall constitute a minimum of 40 percent of the perimeter of the tier. Interior walls shall be at least 20 percent open with uniformly distributed openings. **Exception:** Openings are not required to be distributed over 40 percent of the building perimeter where the required openings are uniformly distributed over two opposing sides of the building.

The other codes have similar but slightly different requirements to those in IBC regarding calculation of openness. BOCA's language would **appear** to require the openings to be distributed over 40% of the perimeter, rather than the aggregate lengths of the openings to constitute 40% of it as per IBC and UBC. However, the Commentary[20] published by BOCA as a companion to the Code indicates that the intent is that the sum of the length of the openings be not less than 40% of the perimeter and thus it is fundamentally the same requirement as IBC/UBC. Note that the confusing language in BOCA is carried over into IBC language. The IBC uses UBC's exact language for the base requirement, but BOCA's exception, resulting in the apparent but subtle conflict. Based on the fact that BOCA's Commentary uses the aggregate length criteria, it is reasonably clear that the intent is as seen in Figure 5-2.

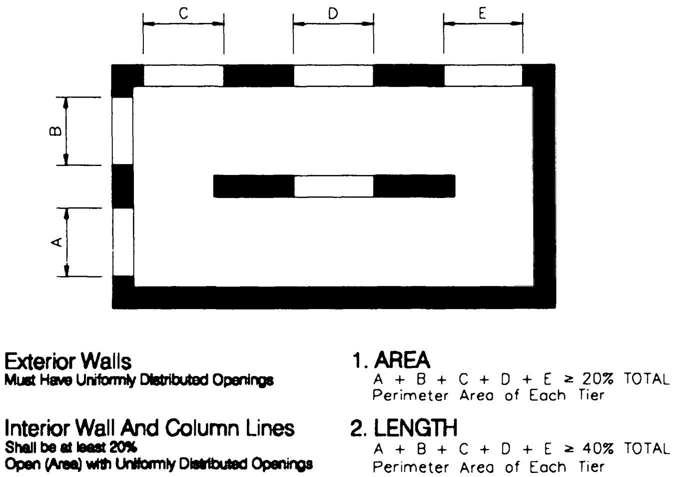


Figure 5-2. Calculation of openness. Source: UBC Handbook.

NFPA 101 has similar requirements as BOCA but does not have the exception allowing openings over less than 40% of the perimeter if the openings are on opposite sides. NFPA 101's language however, clearly allows openings to be distributed uniformly over 40% of the perimeter rather than having the aggregate length of the openings equal to 40% of the perimeter.

NFPA 88A requires that the openings be distributed over 40% of the perimeter. Instead of requiring 20% of the wall area to be open, 88A requires 1.4 sq. ft. of opening for each linear foot of the perimeter, which equates to 14% of the wall area with a 10 ft. floor-to-floor height and less as the height increases. The conflict between NFPA 101 and 88A on openness is another example of the subtle differences in the NFPA standards.

UBC also does not have the exception allowing openings over less than 40% of the perimeter. SBC doesn't have the exception but allows 50% of the clear height between floors to be open for the full length (except for stair and elevator walls and structural columns) on at least two sides, whether or not that constitutes 20% open. The two sides may be either adjacent or opposite. When opposite, the SBC requirement yields a similar result (albeit not mathematically equal) to the IBC/BOCA exception.

A long narrow structure, while still having to have openings totalling 20% of the perimeter wall area, could have them distributed over significantly less than 40% of the perimeter if they are on opposite sides. This exception is clearly intended to allow mid-block structures in urban settings with openness only on the ends to still qualify as open. For example, as shown in Figure 5-3, a two-bay parking structure might have a footprint of 124 ft. by 250 ft. If open only on two ends, less a stair/elevator tower at each, that would constitute only 26% of the perimeter. The openings also have to be larger than normal under this clause; in this case, the height of the openings for a 10 ft. floor-to-floor height would have to be 7.63 ft. high, which doesn't leave much for structural elements or vehicular guards but could be achieved with a little effort. The structure would be classified as open by IBC, SBC and BOCA, but not by UBC or NFPA. The latter two codes allow the openness to occur on opposite sides, but the length of the openings must exceed 40% of the perimeter.

Although columns, handrails, shear walls and walls enclosing stairs and elevators were often neglected from these calculations in the past, local officials today expect a precise calculation of the area of each opening as compared to the total wall area, unless it is obvious that the openness exceeds the requirement. For example, 40% or 50% of the floor-to-floor height open all around the perimeter, except at columns, stairs and elevators, will clearly qualify the facility as an open structure.

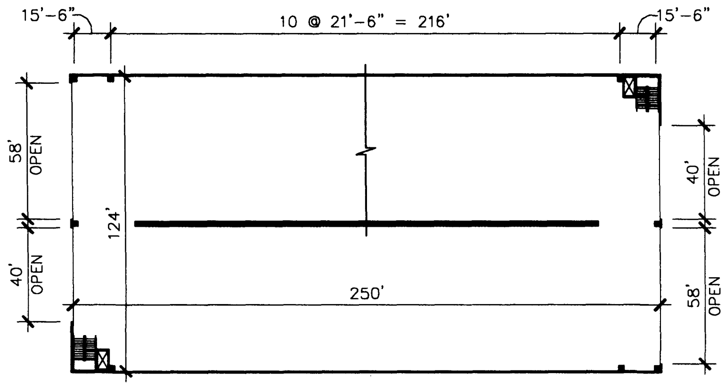


Figure 5-3. Exception for openness on two opposing sides.

Having openings well distributed over two adjacent sides of a rectangular parking facility constructed of post-tensioned concrete will usually constitute more than 40% of the perimeter being open, and the height of the openings will have to be roughly 50% of the floor-to-floor height, unless stair/elevator enclosures are unusually large. With 21'-6" column spacing down the long side of the structure in Figure 5-3, the aggregate length of openings on that wall would be about 208.5 ft. With one end open, the total aggregate length of openings is 306.5 ft. or 41% of the perimeter, and the minimum height of the required openings is 4.88 ft. When all four sides have openings, the required height of openings would be halved, or 2.44 ft. to achieve 20% openness on each side. With precast concrete structures, this requirement may require more attention to design of the guardrail, as discussed later in this section.

Where the architectural theme is to screen the structure, louvers, perforated metal panels, or materials intended form a trellis for climbing plants have occasionally been proposed. This approach is usually of concern to those who routinely deal with open parking structure designs. There may technically be a percentage of openness specified by the manufacturer of the material. However, it is usually recommended that such panels be limited in their overall usage on a particular façade or that the area of openings significantly exceed the minimum required so as to allow for reduced effectiveness of the air flow through the screening material under ambient conditions.

Unfortunately, the code language using the total wall area for that story tends to penalize designs with more floor-to-floor height, which is often provided simply to improve the user-friendliness of the design. A parking structure with 12 ft. floor-to-floor height doesn't have any more noxious fumes or fire hazards than one with 10 ft. floor-to-floor height, but it still must have that much more wall area open. Some local code officials will therefore waive **minor** variances in openness where the floor-to-floor height exceeds the usual minimum of 10'-0". In that respect, NFPA 88A's requirement is a more reasonable approach, albeit a lower overall openness standard. It should also be noted that additional floor-to-floor height can help precast concrete structures, by providing more opening height.

In the early design phases before architectural and structural design has been developed, it is very important to be conscious of the opening requirements. For example, a concept illustration of the building for zoning approval of the project may constitute promises to the community that cause problems regarding openness as the design is fully developed down the road.

As previously noted, there tends to be more difficulty achieving openness in precast concrete structures, because the designer usually wants to extend the precast panels down to hide precast elements and up to the required handrail height. See Figure 5-4. With only a 10 ft. floor-to-floor height and two adjacent sides with openings, a precast panel depth of 6 ft. or more almost certainly won't meet openness when shear walls as commonly required for precast structures are added into the equation. For the structure in Figure 5-3, adding just one shear wall on the long side reduces the length of the aggregate openings by 18 ft. The percentage of perimeter with openings is then reduced to 40.1% and the required height of the openings is increased to 5 ft.

Because we are already at the limit for openings on the perimeter, shear walls as required in the opposite direction would be forced to the interior, which is not very desirable for passive security and visibility. That 5 ft. open height also requires a maximum 5 ft. precast concrete panel. Two to three horizontal railings are then required to meet guardrail height, which in turn can raise "ladder effect" concerns, as discussed in the section on handrails.

The mindset of disguising a parking structure to hide its true function often causes conflicts with openness criteria. See Figure 5-5. This facility meets openness requirements only because there are additional openings on the two sides not visible in the photo. If it appears that the design is anywhere close to the limit, precise calculation of openness may have to be performed regularly throughout the design to be sure that it hasn't slipped below the requirement for an open structure.

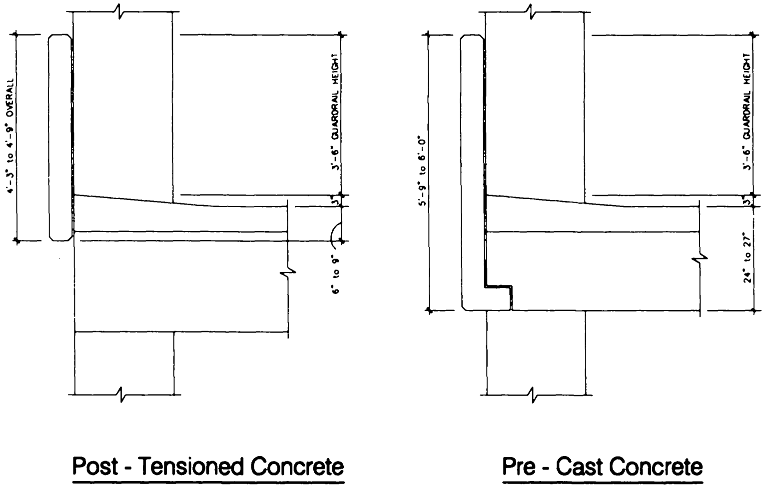


Figure 5-4. Exterior facade panel depths are typically much deeper on precast concrete structures and require special attention to maintaining openness.

Figure 5-5. Trying to disguise a parking structure as another building type often causes problems maintaining openness. Photo courtesy of Walker Parking Consultants.

5.3.3 Incidental and Accessory Uses

Mixed-use provisions as discussed in the next section do not apply to two specific types of uses, incidental and accessory uses. An incidental use under IBC is as follows:

> **302.1.1 Incidental use areas.** Areas which are incidental to the main occupancy shall be separated and protected in accordance with Table 302.1.1 and shall be classified in accordance with the main occupancy of the portion of the building in which the incidental use area is located.

The incidental use classification only applies to those elements specifically tabulated in 302.1.1. Incidental uses include a number of associated functional spaces, such as mechanical spaces (furnace and boiler rooms), kitchens, physical plant shops and maintenance facilities, laundry rooms, etc. Gift shops and coffee shops in hospitals are specifically considered incidental uses. However, retail and coffee shops will not be considered as incidental uses in parking structures because they are not specifically allowed under 302.1.1.

Of particular interest to parking designers, storage rooms exceeding 100 sq. ft. are permitted in open and enclosed structures by IBC table 302.1.1, if there is a separation rated as 1 hour from the main use; sprinklers are not required. Storage rooms less than 100 sq. ft. do not even need to be separated. Such spaces are required for storage of equipment and materials employed in the day-to-day operation of the parking facility, including snow removal and cleaning equipment, light bulbs, etc. As a result, storage rooms in parking structures almost always exceed 100 sq. ft.

There also is a provision in IBC that an automotive parking structure can be an incidental use in other buildings (except R-3 for which there are specific provisions) if separated by a 2-hour fire barrier. Note that there is no limitation on the size of the incidental use before it becomes a separate mixed use. The criterion is that it is listed in the table as an incidental use. However, that is not a license to call a 1,000 space parking structure, which would require at least 300,000 sq. ft. of parking area, an incidental use in a building which also has 10,000 sq. ft. of retail, office or other uses.

Although the approach to incidental uses came from BOCA, its specific requirements are somewhat different. Indeed, BOCA called these uses "specific occupancy areas" but defined them as incidental to the main use. The Commentary to BOCA indicates that these uses constitute "special hazards or risks to life safety". BOCA specifically requires storage rooms over 100 sq. ft. in area to be sprinklered, but IBC does not.

NFPA 101 allows that an occupancy that is incidental to operations in another occupancy can be considered to be part of the **predominant** use, and thus would not need to be separated. The 2000 edition of NFPA 101 modifies its incidental use provisions, limiting them to mercantile, business, industrial and storage uses. UBC does not provide criteria for either incidental or accessory use areas, while SBC only addresses accessory uses.

The second type of non-mixed use is an accessory use, with the IBC requirement as follows:

> **302.2 Accessory use area.** Except for accessory areas of Group H in accordance with Section 302.3.1 or when required for incidental use areas indicated in Section 302.1.1, a fire barrier shall not be required for a use not occupying more than 10% of the floor area of any floor of a building, nor more than the tabular values for either height or area for each use.

The IBC language for accessory uses also appears to come from BOCA. The Commentary to BOCA requires that accessory uses must have a direct relationship and be subordinate and secondary to the use served. One way of thinking of accessory uses is that they are provided as necessary for the operation of the building or for the convenience of the occupants in a building. The most common accessory use in parking structures is the office for management of parking operations. Retail and coffee shops, even if they occupy less than 10% of the floor area, are not accessory uses in parking structures under the various codes if they are oriented to the general public. However, they might be accessory uses if they primarily serve occupants of the building; for example, if a parking facility is an intermodal facility, the retail and coffee shop could be accessory uses.

As noted above, IBC 406.3.4 specifically limits parking management offices in open parking structures to 1,000 sq. ft., but the office in an enclosed structure may equal 10% of the floor area as an accessory use. This is a carry-over of language from UBC, which is intended to restrict non-parking uses in open parking structures. BOCA applies the same 10% limitation to both open and enclosed structures. While being more restrictive for smaller facilities (a structure with 30,000 sq. ft. per floor could only have an office of 300 sq. ft.), BOCA's requirement is much more reasonable for larger structures than the IBC/UBC requirement. A 10,000-space parking structure at an airport can easily have 500,000 sq. ft. per floor and also require 3,000 to 5,000 sq. ft. of office space for management of the facility. Also, where the local planning desire is to have retail at grade in parking structures, local building officials have considered leased retail or commercial space as the permitted office space under UBC, and may even give a variance for more than 1,000 square feet, in order to skirt the UBC prohibition on open parking structures in mixed-use buildings.

SBC allows up to 25% of the story to be an accessory use, and then further excepts storage uses, such as open and enclosed structures, from that limitation. Effectively, there is no limitation on the size of a parking management office space in any parking structure under SBC. A storage room would also be considered an accessory use under SBC.

NFPA 88A specifically allows up to 3,000 sq. ft. of office or other spaces related to the operation in all parking facilities, open or enclosed. The separation between parking area and the office does not have to be fire rated, but it should resist the passage of smoke.

5.3.4 Mixed Uses and Area Separations

IBC discusses mixed occupancies and the separation thereof in Chapter 3. It has been previously discussed that UBC intentionally prohibits open parking structures from being part of buildings with mixed uses other than the specific combination of an open structure above an enclosed one. The intended, net result of the requirement under UBC is that the incorporation of non-parking uses in the building automatically kicks the occupancy type to an enclosed structure, with the associated increased provisions for life safety, including sprinklers and enclosed stairs.

Apparently, the language intending to prohibit mixed uses in open parking structures has been present in the UBC since at least 1973. In many jurisdictions, it was generally thought that the wording meant that the portion of the building classified as an open parking structure had to be exclusively used as described. Mixed-uses were routinely approved. In the few cases where local officials enforced a prohibition on mixed uses, it was viewed as an overly strict interpretation taken by a local official. However, in 1991, UBC added a line to the table for required separations between mixed uses stating that open parking structures are excluded, which certainly clarified the intent.

It then became fairly routine for local code officials operating under UBC to individually waive or accept a variance (as permitted under the local enabling legislation) for each design requirement, one by one, under the enclosed structure category back down to that allowed for an open parking structure. Getting all these variances seems to be a waste of effort, when mixed uses have long been allowed under SBC & BOCA without significant life safety problems. As previously discussed the risk to life safety in a parking structure, whether open or enclosed, is relatively low. Meanwhile, the incorporation of mixed uses is highly desirable to most communities. Retail or other commercial space at grade enlivens the streetscape and is an important component of Crime Prevention through Environmental Design (CPTED.) For example, the zoning ordinance of the City of Albuquerque, NM, which employs UBC for building code purposes, mandates that parking structures built in the downtown have retail or commercial space at grade.

As previously noted, the consensus of the committee and, in turn, the participating organizations involved in the development of IBC is that open parking structures may be included in mixed- use buildings under IBC. The following paragraphs are special conditions that, under both UBC and IBC, exempt or modify the uses from normal requirements regarding allowable heights and areas, as well as provide other provisions for these specific combinations of mixed uses.

> **508.2 Group S-2 Enclosed Parking Structure with Groups A, B, M or R above.** A basement or first story of a building shall be considered a separate and distinct building for the purposes of determining area limitations, limitation of number of stories and type of construction... *(Note: there are a number of specific requirements for the separation between the uses that are not repeated here, but which should be studied whenever this requirement is invoked.)*
>
> **508.3 Group S-2 Enclosed Parking Structure with Group S-2 Open Parking Structure above.** A group S-2 Enclosed Parking Structure located in the basement or first story below a Group S-2 Open Parking Structure shall be classified as a separate and distinct building for the purpose of determining the type of construction when the following conditions are met:
>
> 1. The allowable area of the structure shall be such that the sum of the ratios of the actual area divided by the allowable area of each separate occupancy shall not exceed 1.0;
> 2. The Group S-2 Parking Structure is of Type I or II construction and is at least equal to the fire resistive requirements of the Group S-2 Open Parking Structure;
> 3. The height and the number of floors above the basement shall be limited as specified in Table 406.3.1;
> 4. The floor assembly separating the Group S-2 Enclosed Parking Structure and the Group S-2 Open Parking Structure shall be protected as required for the floor assembly of the Group S-2 Enclosed Parking Structure. Openings between the Group S-2 Enclosed Parking Structure and the Group S-2 Open Parking Structure, except exit openings, shall not be required to be protected, and
> 5. The Group S-2 enclosed Parking Structure is used exclusively for the parking and storage of private motor vehicles but shall be permitted to contain an office, waiting room and toilet rooms having a total area of not more than 1,000 sq. ft. and mechanical equipment rooms incidental to the operation of the building.

Due to the last limitation regarding parking only private motor vehicles in the enclosed portion of the facility, this clause cannot be used to allow the parking tiers above an intermodal or ground transportation center to be classified as an open parking structure under IBC and UBC. That type of facility would have to be classified as an enclosed parking structure throughout under UBC. Under IBC, an open structure can still be provided above an enclosed parking structure used by buses or other vehicles not allowed in 508.3, but it would have to be treated as a fully separated use. Among other things, the joints in the floor slab would have to be fire-rated and the vehicle ramp connecting the floors would have to be enclosed. Theoretically, this enclosure requires a fire-rated door that would either open and close for each vehicle using the ramp, or would be normally open but would close automatically upon detection of a fire in either occupancy. The latter, in turn, requires an automatic fire detection system. Another solution commonly accepted by local officials is a "sprinkler curtain" consisting of sprinklers along the "enclosure" line. This option allows not only the vehicle path of travel to be open but the sides of the ramp as well, which significantly improves passive security. As the enclosed level would more than likely be sprinklered in any event, the sprinkler curtain is not usually a "deal killer."

The ability to have an open parking structure over an enclosed one serving an intermodal or other commercial vehicle facility in IBC is a substantial improvement over UBC's requirements which would kick the entire building (both open and enclosed portions), over into the enclosed category.

The following two provisions are provided in IBC but are **not** present in UBC.

> **508.5 Parking beneath Group R.** Where a one story Group S-2 Typical Parking Structure, Enclosed or Open of Type I construction or Open of Type IV construction, with grade entrance, is provided under a building of Group R, the number of stories to be used in determining the minimum type of construction may be measured from the floor above such parking area. The floor assembly between the parking structure and the Group R above shall comply with the type of construction required for the parking structure and shall also provide a fire resistance rating not less than the mixed occupancy separation required in Section 302.3.3.
>
> **Section 508.8 Open parking structures beneath Groups A, I, B, M and R.** Open parking structures constructed under Groups A, I, B, M and R shall not exceed the height and area limitations permitted under 406.3. The height and area of the portion of the building above the open parking

> structure shall not exceed the limitations in Section 503 for the upper occupancy. The height, in both feet and stories, of the portion of the building above the open parking structure shall be measured from the ground plane and shall include the open parking structure and the portion of the building above the open parking structure. *(Author note: there are specific requirements for the fire separation between the uses in Section 508.8.1 that are not repeated here, but which should be studied whenever this requirement is invoked.)*

Open parking structures are also allowed under IBC to be located over various other uses. Unfortunately, there was apparently an error in the development of the language. Part of the agreement on the issue was that both open and enclosed parking structures would have to be separated from other uses in accordance with Section 302.3.3, Separated Uses. Paragraph 406.2.7, which applies to both open and enclosed sub-types, as published in the final version of the code in 2000 contains a reference to Section 302.3.1, which in turn allows **either** non-separated uses per 302.3.2 **or** separated ones per 302.3.3. While it is likely that a code change will be submitted to correct the error, in the interim, open parking structures can be designed as non-separated uses as discussed in the following paragraphs.

Where a building is occupied by two or more uses not included in the same occupancy, each part of the building is treated as a separate occupancy. Generally, there are three ways to treat the mixed use, with the first two being specified under IBC 302:

> **302.3.2 Non-separated uses.** Each portion of the building shall be individually classified as to use. The required type of construction shall be determined by applying the height and area limitations for each of the applicable occupancies to the entire building. The most restrictive type of construction so determined shall apply to the entire building. The other requirements shall apply to each portion of the building based on the use of that space except that the most restrictive applicable provisions of the high rise building provisions and fire protection system requirements shall apply to these nonseparated uses. Fire separations are not required between the uses except as required by other provisions.

The most common type of use combined with parking is retail or commercial office space at grade. As the code provisions for those uses are significantly more stringent than for parking uses, the non-separated approach is not likely to be used often.

> **302.3.2 Separated uses.** Each portion of the building shall be individually classified as to use and shall be completely separated from adjacent areas by fire barrier walls or horizontal assemblies or both having a fire resistance rating determined in accordance with Table 302.3.3 for the uses

> being separated. Each area shall comply with the code based on the use of that space. Each area shall comply with the height and area limitations based on the use of that space and the type of construction classification. In each story, the building area shall be such that the sum of the ratios of the floor area of each area divided by the allowable area for each use shall be not exceed one.

The third type of treatment is separated buildings as permitted under IBC 503.1:

> ...Each part of a building included within the fire walls shall be considered as a separate building.

Note that while the fire rating of separations may be the same, the details of a wall designed as a "fire wall" are significantly different than one designed as a "fire barrier" for the purposes of separation of uses.

The separation required between an open or enclosed structure and most other uses as shown in Table 302.3.3 is typically 2 hours except for certain higher hazard groups, as well as institutional uses.

BOCA has substantially similar requirements. Of course, under UBC, open structures in mixed-use buildings are sharply limited. The only type of separation that is applicable to open structures under UBC is two completely separated buildings with a fire wall between. The separate building approach can only be used with side-by-side occupancies, because the required fire wall extending to the roof would have to bisect any occupied space above the two spaces, which obviously would have an impact on the function of a parking structure.

A footnote to the table for separations in IBC says that areas used only for private or pleasure vehicles may reduce separation by 1 hour, which is then typically from 2 hours down to one hour. Also, an exception to 302.3.3 allows that if neither of the uses being separated is a Group H (high hazard) and the entire building is sprinklered, then the required separation is reduced by one hour, but to not less than 1 hour or the required floor construction rating according to the type of construction. Obviously, both cannot be applied as the minimum one hour separation of the sprinklered criteria will always kick in.

While the wording is slightly different, the requirements for mixed uses under SBC are effectively the same. Open parking structures may be constructed under or over any other occupancy if:

- area and height of the open parking structure portion of the building are within permissible limits;
- the total height of the building also is not more than that allowed for the use above (i.e., the height of the structure is taken from grade, not from the first floor of the other use);

- any members which are critical to the stability of the building as a whole must meet the fire resistive requirement for the use above;
- occupancy separations are provided and all exits for the upper occupancy are protected to the exterior of the building; and
- separations between parking structures, whether open or enclosed, and other uses adjacent horizontally and/or below the parking structure shall be one hour for business, mercantile, and other parking structures, and two hours for most other uses. Special separation requirements apply to high and moderate hazard uses.

5.3.5 Occupancy Classification and Construction Type

Parking structures, whether open or enclosed, are typically classified as storage uses of low hazard. The specific designations are as follows:

	Open Parking Structures	Enclosed Parking Structures
IBC	S-2, Low Hazard	S-2, Low Hazard
UBC	S-4	S-3
BOCA	S-2, Low Hazard	S-2, Low Hazard
SBC	Special Storage	Special Storage
NFPA 101	Storage, Ordinary Hazard	Storage, Ordinary Hazard
NFPA 88A	Not Defined	Not Defined

IBC does not have separate sections and classifications for open and enclosed parking structures. Indeed, the commentary indicates that it was decided that **all** motor vehicle-related occupancies would be grouped in section 406. From an organizational standpoint, this allows certain requirements to be applied to both, without extensive cross-referencing between the separated sections. IBC discusses criteria applicable to both first and then special criteria for each, which is closer to the way SBC organized things. NFPA (both 101 and 88A) merges all requirements into one section, with separate requirements where allowed. UBC and BOCA, however, have completely separate requirements. Both specifically exempt open structures from the enclosed requirements and vice versa.

NFPA 101 does not discuss any construction requirements for either open or enclosed parking structures but instead references a separate standard, NFPA 220, *Standard on Types of Building Construction*[21]. It is important to check with communities enforcing NFPA 101 to see if they enforce NFPA 220 and/or 88A as well. The classification as ordinary hazard under NFPA 101 is defined as one where contents are "likely to burn with moderate rapidity or to give off a considerable volume of smoke." NFPA

88A has no label regarding hazard or classification, but does have height and area limitations based on fire ratings of the construction of open structures as will be discussed in a subsequent section.

Under all of the codes except NFPA 101 (but including NFPA 88A), both open and enclosed parking structures shall be built of non-combustible materials, that is concrete and/or steel meeting the required fire ratings. (IBC 406.2.6 and 406.3.3.) The floor surfaces shall be concrete or similar non-combustible, non-absorbent materials. An exception is provided, however, allowing a grade slab of asphalt. (IBC 406.2.6) Note that if there is a fuel-fired appliance (such as a furnace or generator) in the parking facility, there must either be a vestibule with two-door separation between the parking structure and the room with the appliance, or a single door if there is 18 in. separation between sources of ignition and the floor. (IBC 406.2.8) SBC has the same requirement, but the height separation is only 8 in. NFPA 88A has some requirements for flames associated with heating equipment, but has an exception if there is a partition separating the equipment from other spaces.

There are certain specific construction types, the hierarchy of which is based on the fire rating of the elements, permitted for use in parking structures. The construction type, in turn, determines limitations on height and area.

Before discussing the differences in those limitations for open and enclosed structures (in the next two sections, respectively) it is useful to give the definitions of related terms. (IBC 502). Because there is variance in the definitions that is, in turn, extremely critical, the following summarizes the definitions under the IBC code, with discussion of any differences in the other codes. Note that BOCA's language was used almost verbatim in this IBC section; therefore unless noted otherwise, BOCA's requirements are the same as those found in IBC.

> Area, building. The area included within surrounding exterior walls (or exterior walls and fire walls) exclusive of vent shafts or courts. Areas of the building not provided with surrounding walls shall be included in the building area if such areas are included within the horizontal projection of the roof or floor above. *UBC is identical; SBC is identical except it does not exclude vent shafts from floor area calculations.*
>
> Basement. That portion of a building that is partly or completely below grade. *UBC defines a basement as any floor level below the first story, as defined below. SBC defines a basement as any building story having a floor below grade (see definition of grade plane below.)*

Grade Plane. A reference plane representing the average of finished ground level adjoining the building at exterior walls. Where the finished ground level slopes away from the exterior walls, the reference plane shall be established by the lowest points within the area between the building and the lot line, or where the lot line is more than 6 ft. from the building, such a point 6 ft. from the building. *UBC uses the term reference datum and defines it as the elevation of the highest adjoining sidewalk or ground surface within a 5 ft. horizontal distance of the exterior wall if that elevation is not more than 10 ft. above lowest grade, or 10 ft. higher than the lowest grade where the highest grade is more than 10 ft. above the lowest grade. SBC uses the term grade rather than grade plane, and defines it as the average of finished ground level adjoining the building wall. Where the finished ground level slopes away, the reference plane is the same as in IBC, i.e.; it uses the lowest points within 6 ft. of the building to find the average.*

Height, Building. The vertical distance from grade plane to the average height of the highest roof surface. *UBC and SBC are essentially the same except they measure to the highest point of a nominally flat roof (i.e., sloped only for drainage) rather than the average.*

A key result of the definition of height of the building is that, for the purposes of height and area limitations, it is based on the elevation of the top of the roof slab, not the height of a parapet wall. Roof top structures, including elevator penthouses, stair enclosures, and light or sign poles, are not included in the calculation of height of the building (as long as they don't exceed one-third of the roof area). It should be noted, however, that height of the building for purposes of zoning is usually based on the top of the parapet. Also height for the specific purposes of high rise provisions uses the lowest elevation of fire department vehicle access, rather than the grade plane.

Height, Story. The vertical distance from top to top of two successive tiers of beams or finished floor surfaces; and for the topmost story from the top of the floor finish to the top of the ceiling joists, or where there is not a ceiling to the top of the roof rafters. *UBC does not contain a specific definition for story height, presumably because it considers the definition of story, as defined above, adequate. SBC's definition is more simply stated as the vertical distance from top-to-top of finished floor surfaces. The definition of story height in IBC then continues.* A basement shall be considered a story where the finished surface of the floor above the basement is:

1. More than 6 feet above grade plane; **or**
2. More than 6 feet above the finished ground level for more than 50% of the total building perimeter; **or**
3. More than 12 feet above the finished ground level at any point.

UBC's definition of a story is the same but with two significant differences. Item 1 is not present; therefore the grade plane doesn't affect the determination of whether or not a level partially below grade is counted as a story. Also, a basement is never considered a story under UBC; see the definition of basement above. SBC's definition of a story is similar, except that 7 ft. is used in lieu of 6 ft. in items 1 and 2 and there is one significant additional difference: "and" is substituted for "or". Therefore, all three criteria must apply under SBC rather than any one under IBC and BOCA.

Mezzanine. An intermediate level or levels between the floor and ceiling of any story with an aggregate floor area of not more than one-third of the area of the room or space in which the level are located (see Section 505.) *UBC simply defines a mezzanine as an intermediate floor placed within a room. SBC's definition is basically the same as IBC.*

Story. That portion of a building included between the upper surface of a floor and the upper surface of the floor or roof next above.

The height and area definitions are extremely critical issues that must be carefully studied early in the design process. Obviously, those familiar with BOCA will have the least difficulty dealing with IBC in the determination of the grade plane. NFPA 101 does not address building height as a criterion for any of the issues discussed herein. NFPA 88A allows open parking structures to be unlimited in height and area under most circumstances, and therefore doesn't bother to define height or area. (See also the discussion under high-rise codes.)

IBC and UBC use the number of tiers as the basis for determining height for open parking structures; however, tier is not defined or used for enclosed structures. (IBC 406.3.5) It is unclear why a different criteria for height should apply to open and enclosed structures when the vast majority of both use sloping parking ramps for vehicular access. Moreover, this difference is yet another example of conflicts that occur under UBC when an otherwise open structure is categorized as enclosed due to the presence of mixed uses.

Where structures have a spiral or sloping floor, the horizontal projection at any cross section shall not exceed the allowable area per parking tier under IBC/UBC. The other codes do not specifically address this issue, primarily because they base height on stories. BOCA and SBC, which traditionally use stories as the controlling factor for building height, do not define "tier." Both BOCA and SBC permit parking on the roof of parking structures, although the roof is not considered a story.

Although a relatively rare circumstance, if the facility consists of a "continuous spiral" floor, each 9'-6" or portion thereof shall be considered a tier, under IBC and UBC. One example of where this might apply is the circular parking structure at Marina City Towers in Chicago, where the traffic flow on the continuous spiral is two-way with 90 degree parking alongside. Another example would be a structure where a circular express helix is employed to rise several stories to parking floors above another use. In these cases, each 9'-6" rise in the circular helix counts as a story for the purposes of height and area determination. It is unclear how the provision defining a tier as 9'-6" originated, but part of the reason it is needed is that UBC and IBC have limitations only on the number of tiers, not stories and overall height as employed under SBC and BOCA. Most people would expect the horizontal projection as used for tiers in rectilinear structures with combinations of flat and sloping floors to also be adequate for a circular helix, as would the definition of story as the space between one floor surface and the top of the floor immediately above. Floor-to-floor heights in parking structures commonly range from a minimum of 10 ft. up to a maximum of 12 ft. (see the Level of Service Criteria in Chapter 3); at shopping centers, floor-to-floor heights may be set at elevations as high as 17 ft. 9'-6" seems unnecessarily restrictive for a helical ramp that provides access to nominally flat parking floors. Theoretically, a parking structure with circular helixes serving six nominally flat floors could have seven or eight tiers due to the counting method for the helices. Local waivers of the specific definition of 9'-6" as a tier when the overall height of the building is within appropriate limits should be possible.

Mezzanines, while not common, have been provided in some parking structures (either open or enclosed.) For example, where parking for over-height vehicles or a ground transportation center requiring high clearances does not require all of a ground floor, a mezzanine may be provided over the remainder. In another situation with high headroom, a mezzanine was employed to provide more office space without losing parking areas. (Be careful to maintain accessibility to a mezzanine in accordance with ADA.)

To be considered a mezzanine, a space must meet the requirements of IBC Section 504. The critical requirement is that the aggregate area of a mezzanine shall not exceed one-third of the area of that room or space in which it is located. The clear height of the tier above, below and at the mezzanine shall be 7 ft. (which is required for parking tiers, in any event.) The benefit of qualification as a mezzanine is that while it shall be considered a portion of the floor below, it does not contribute to the floor area, or to the number of stories for purposes of height limitations. The area shall be included in determining the fire area defined in Section 702 (for the purposes of containing fire spread). There are additional requirements/ limitations on mezzanines in Section 505 that should be studied if/when a mezzanine is contemplated.

It is important to note that aside from the construction type issue, a building with an occupied floor above 75 ft. in height may trigger high-rise fire protection code provisions. This issue is further discussed in Section 5.3.2.3.

Due to the complexities and differences in determining height and areas of parking structures under the various codes, a case study is provided in the Appendix to this chapter.

Table 5-1. Construction Type and Fire Resistive Requirements

Type	Fire Resistive Requirement (hr)			Open Parking Structure		Enclosed Parking Structure	
	Struc Frame[1]	Floors	Bearing Walls[2]	Sq. Ft. Per Tier	Max Height	Sq. Ft. Per Tier[3]	Max Height
IBC							
IA	3	2	3	Unlimited	Unlimited	Unlimited	Unlimited
IB	2	2	2	Unlimited	12 Tiers	79,000	11 Tiers
IIA	1	1	1	50,000[5]	10 Tiers	39,000	5 Tiers
IIB	N	N	N	50,000[5]	8 Tiers	26,000	4 Tiers
UBC							
I FR	3	2	4 / 3[4]	Unlimited	Unlimited	Unlimited	Unlimited
II FR	2	2	4/2	125,000[5]	12 Tiers	39,900	12 tiers
II 1 hr	1	1	1/1	50,000[5]	10 Tiers	18,000	4 tiers
II N	N	N	N	30,000[5]	8 Tiers	12,000	2 tiers
BOCA							
1A	4	3	4	Unlimited	Unlimited	Unlimited	Unlimited
1B	3	2	3	Unlimited	Unlimited	Unlimited	Unlimited
2A	2	1.5	2	Unlimited	12 stories -120 ft.	34,200	7 stories-85 ft.
2B	1	1	1	50,000[5]	10 stories -100 ft.	22,500	5 stories-65 ft.
2C	0	0	0	50,000[5]	8 stories -85 ft.	14,400	3 stories-40 ft.
SBC[6]							
I	4	3	4	Unlimited	Unlimited	Unlimited	Unlimited
II	3	2	3	Unlimited	Unlimited	30,000	6 stories-80 ft.

[1] Under BOCA and SBC, members supporting only one floor can have fire ratings reduced by 1 hour.

[2] Under NFPA 220, interior bearing walls supporting one floor only may be reduced 1 hr for type I construction.

[3] IBC areas are per floor in unsprinklered buildings. Values are tripled if sprinklered. Under SBC, listed values are for unsprinklered structures; if sprinkled values are doubled. BOCA areas listed for enclosed structures are for one and two story buildings, and are reduced as more stories are added. Under UBC, listed area is for a one story structure unsprinklered; multi-story structures may have a combined total area of twice that listed. If sprinklered and height is within the associated limitation, single story buildings may have three times the listed value, while multi-story buildings may have a combined total area four times the listed value.

[4] Exterior/Interior

[5] Unlimited height and area if height does not exceed 75 ft and distance to an exterior opening does not exceed 200 ft

[6] SBC requires that all points on the floor of all open structures be no more than 200 ft from an open side facing on a street or other permanently maintained open space at least 20 ft wide and connecting to a street.

Type	Fire Resistive Requirement (hr)			Open Parking Structure		Enclosed Parking Structure	
IV-P	1	1	1	400,000[5]	8 stories -75 ft.	24,000	2 stories-65 ft.
IV-U	N	N	N	400,000[5]	8 stories -75 ft.	16,000	2 stories-55 ft.
NFPA 88A							
I-443	4	3	4	Unlimited	Unlimited	No Req't	No Req't
I-332	3	2	3	Unlimited	Unlimited	No Req't	No Req't
II-222	2	2	2	Unlimited	Unlimited	No Req't	No Req't
II-111	1	1	1	Unlimited	Unlimited	No Req't	No Req't
II-000	0	0	0	Unlimited 1	Unlimited	No Req't	No Req't

5.3.5.1 Height and Area of Open Parking Structures

Under IBC, the horizontal projection of the parking structure at any cross section shall not exceed the allowable area per parking tier. A basement qualifying as a tier in an open parking structure cannot exceed the area permitted per tier. Basements in other use classifications such as enclosed structures have certain special criteria as will be discussed in the next section. Those criteria do not apply to basement tiers that qualify as open. The area and heights allowed in open parking structures vary according to the specific construction type and fire rating as seen in Table 5-1.

Type IV Heavy Timber construction is also permitted by IBC and SBC (as Type III) but is almost never used in new construction and therefore is not shown in the Tables. We have also neglected to show the requirements for roofs because those would only apply when parking is not provided on the roof--a rather rare circumstance. Non-bearing walls must be non-combustible; where exterior they may be required to be fire-rated by the distance to the property line, as discussed in section 5.3.3 of this chapter.

Note the height in ft. can be the controlling factor under BOCA and especially SBC, which has lower height criteria for the same number of stories. In the Appendix there is a case study that looks at the issues of height and area under each of the codes.

Area and height increases are allowed in open structures as follows (IBC 406.3.6):

- With 50% of the **interior** wall area on a side open, **equally** distributed over 75% or more of the perimeter, the area may be increased 25% and the height by one tier.
- With 50% of the interior wall area open, equally distributed on all four sides, the area may be increased 50% and the height by one tier.

- Structures of Type IB and II construction, with all sides open may be unlimited in area when height does not exceed 75 ft. For a side to be considered as open, the total open area shall be 50% of the interior area of the side at each tier, equally distributed along the side. All portions of tiers shall be within 200 ft. horizontally from such openings.

- Open parking structures constructed to heights less than the maximum above may have individual tiers areas exceeding the above table, provided the gross tier area of the structure does not exceed that permitted for the higher structure. At least three sides of such a structure shall have continuous horizontal openings not less than 30 in. in clear height extending for at least 80% of the side, and no part of such structure shall be more than 200 ft. horizontally from an opening. In addition, each such opening shall face a street, or yard accessible to a street, with a width of at least 30 ft. for the full length of the opening and standpipes shall be provided in each such tier.

For example, under the last bullet above, if a structure is to be type II-A construction and six tiers, it can have 10 x 50,000 / 6 = 83,333 sq. ft. /tier. That approach is not allowed generally, but must meet the special requirements for openings as noted above.

UBC's area and height increases are identical to those above for open structures. SBC does not allow any increases or adjustments to height and area and further has significantly different height and area limitations; however, the very large allowable floor area under type IV-unprotected compensates for the increased requirements. In fact, since only structures with more than 1,000 spaces per floor are likely to have more than 400,000 sq. ft. per floor, many more structures can be of unrated (albeit non-combustible) construction under SBC than under the other codes. However, SBC requires all portions of each floor in **all** open parking structures to be no more than 200 ft. from an open side and requires the open space there to be at least 20 ft. wide. Thus, under SBC, the width (in this case, specifically the lesser of the two dimensions of the structure) of all open structures is typically limited to 400 ft. between two open sides, and to 200 ft. if there is a fire wall along one side per Figure 5-6. Given the 400,000 sq. ft. area for unrated construction, a structure 400 ft. x 1000 ft., with as many as 1300 spaces per floor, could be built with unrated construction under SBC.

BOCA has only the last increase of those listed above, but that calculation is based on exterior wall area. BOCA also appears to have do-loop that is somewhat confusing. Section 406.4 says that heights and areas are subject to the increases allowed in Sections 504.0 and 506.0, which are also those allowed for enclosed structures as discussed in the next section. However, at the start of section 503, BOCA says that open parking structures shall conform to the limitations in Section 406.4. Some have construed this as negating the other permitted increases in 504 and 506; however, the Commentary published by BOCA indicates Table 406.4 in essence is substituted for Table 503.

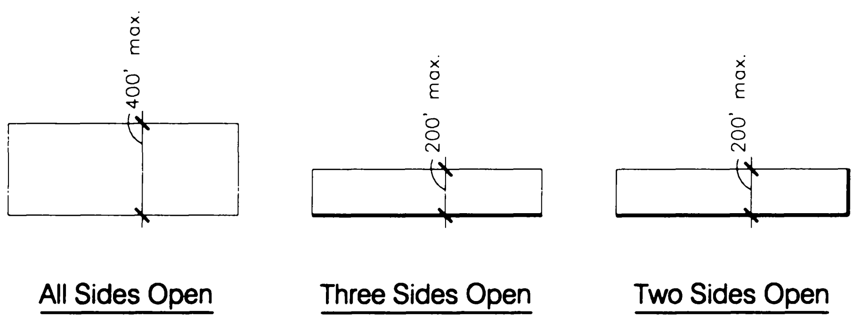


Figure 5-6. SBC limits the width of all open parking structures

Sections 504 and 506 then apply. The only height modification in 504 applicable to parking is for a building that is sprinklered; therefore it won't be used very often. Under BOCA, area per floor in open parking structures can be increased based on additional street/open space frontages, and if sprinklered as discussed in the next section. However, Table 506.4, which adjusts the allowable height and area based on the number of stories, is not applicable to open structures.

The IBC/UBC change from the calculation of openness based on the exterior wall area for classification as open or enclosed to interior wall area for determination of area and height may at first seem puzzling. Some codes originally used interior ceiling height as the determinant for openness. The definition of ceiling height was subject to much debate and interpretation; conversion to exterior wall area eliminated that. Due to basic structural requirements, it would be virtually impossible for a precast concrete structure to meet the 50% open requirement on all four sides for some of the area modification criteria. Therefore, the conversion to interior wall area allowed precast concrete structures to benefit from the area modifications, but only where substantially more than the minimum 20% exterior wall area is open overall.

Interior area will be less than exterior area, as it doesn't include the depth of the structural elements. Therefore, the denominator reduces while the numerator remains constant, so that the percentage open will be higher with interior wall area as the criteria. As it is time consuming to calculate the precise interior wall area with post-tensioned structures, most simply use the exterior wall height less the slab depth, which is conservative, unless a precise calculation is critical to height and area limits. SBC uses clear height rather than interior wall area for the situation where openness is distributed to the full length of two sides. Many local officials under BOCA and UBC have accepted that the interior ceiling height is measured to the underside of tee stems or waffle slabs, thereby simplifying the calculation and effectively increasing the openness by this calculation, which can in turn compensate for the difficulty achieving large openings in precast structures. However, that approach penalizes post-tensioned concrete structures, effectively requiring more openness in those facilities, all other things being equal. The SBC requirement, overall, is easier to use and administer, and a requirement modeled on NFPA 88A would be the most judicious of all, even if a higher factor of openness is mandated.

Note that a minimum opening of 30 in. in any direction is required by IBC only in the paragraph allowing more area per tier for structures of heights less than the maximum. The original purpose of the 30 in. minimum requirement is to allow firemen to crawl through the opening, or trapped individuals to crawl out to the arms of waiting rescuers. This type of evacuation is rarely--if ever--needed in open parking structures. However, it has been argued that it is also a reasonable requirement for natural ventilation to occur under certain ambient conditions such as a no- wind condition. Therefore, keeping openings to a 30 in. minimum dimension may be part of an overall, negotiated agreement on the building code considerations of a unique structure or considered "compensatory action" for a waiver/variance or concession on another issue. A 30 in. minimum dimension would certainly affect the acceptability of screening materials such as perforated metal panels as previously discussed. It behooves the designer to discuss the issue with local building code officials before committing to such an architectural treatment.

The fire resistive construction rating is particularly important because many structures exceed 50,000 sq. ft. per tier. (A typical minimum size for an efficient, economical structure is 110 ft. by 250 ft. or 27,500 sq. ft.; a structure this size would have about 85 parking spaces per tier.) When a structure is to be constructed of precast concrete, a two- or three-hour fire rating requires special design of the tees, with heavier sections to provide adequate cover over reinforcing. Attaining a two-hour rating of a floor slab and a three-hour rating of the structural frame is less difficult in a cast-in-place post-tensioned structure, although it can add to the cost per sq. ft. All of the model codes provide an exception that joint assemblies in open parking structures do not have to be fire-rated, so tee-to-tee joints and expansion joints do not have to be fire rated. (IBC 712.1)

The "200 ft." provision allowing Type IB and II (both A and B) construction to be unlimited in area is often used to achieve unlimited area in mega-structures with Type IIB, non-rated construction. It typically requires that large footprints be segmented into smaller sections, separated by light wells, to keep the width (in this case, the smaller of the two dimensions) under 400 ft. in each section. (See Figure 5-7.) Generally, a light well the full width, except for vehicle bridges across the ends, is employed. Stairs can be located along the light well, with the grade level employed for the exit discharge path. The light well provides an organizing element in the wayfinding system that is beneficial to a large floor plate. Another approach is to "dot" smaller square or rectangular light wells; however, neither wayfinding nor exiting benefits from this approach. Use of this area increase also requires attention to maintaining 50% openness on all sides, and keeping the height under 75 ft. For the side facing the light well to be considered open, the space between the two sections must meet the requirements either for a yard or a court, as discussed in that section of this chapter. Again, SBC is the only code that applies this type of criteria to all open parking structures and further requires that courts used for this purpose open to a street at one end.

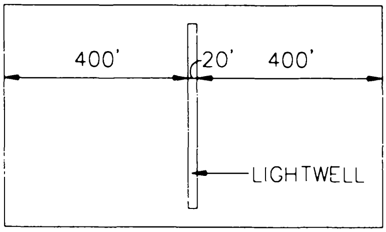


Figure 5-7. Light wells may be required in a large footprint structure to achieve an unlimited floor area classification with non-rated construction.

5.3.5.2 Enclosed Parking Structures

The area and heights allowed in enclosed parking structures also vary according to the specific construction type and fire rating. Note the following general height and area limitations:

503.1 Each part of a building included within the fire walls where such separate uses or areas shall be considered a separate building.
503.1.1 Basements need not be included in the total allowable area provided they do not exceed the area permitted for a one story building.
503.1.3 Two or more buildings on same lot shall be regulated as separate buildings or shall be considered as portions of one building if the height of each building and the aggregate area of the buildings are within the limitations of Table 503 as modified by Sections 504 and 506. The provisions of this code applicable to the aggregate building shall be applicable to each building.
503.1.4 Type I construction. Buildings of Type I construction permitted to be of unlimited tabular heights and areas are not subject to the special requirements that allow unlimited area buildings in Section 507 or unlimited height in Section 503.1.2 and 504.3.
503.2 Party Walls. Any wall located on a property line between adjacent buildings which is used or adapted for joint service between the two buildings shall be constructed as a fire wall in accordance with Section 705 and shall create separate buildings.

The maximum height of the building as permitted by Table 503 (it's requirements for enclosed parking structures are reproduced in Table 5-1 herein) may be increased by one story if the building is provided with an approved automatic sprinkler system; these increases are permitted in addition to any increase in area. UBC and BOCA also allow an additional story if an enclosed structure is sprinklered. SBC does not allow an additional story to be added for sprinklered, enclosed parking structures.

Area increases are allowed by IBC using the following formula:

$$A_a = A_t + A_t I_f + A_t I_s$$

Where:
A_a = Allowable area per floor (sq. ft.)
A_t = Tabular area per floor per Table 503 (sq. ft.)
I_f = Area increase due to frontage
I_s = Area increase due to sprinkler protection = 2.0 if sprinklered, 0 if not.

$$I_f = (F/P - 0.25) * W/30$$

Where:
F = Building perimeter which fronts on a public way or accessible open space having 20 ft. or more width.
P = Perimeter of entire building

W = Minimum width of public way or accessible open space
W must be $\geq$20 ft. and the quantity $W/30$ shall not exceed 1.0.

Note that the actual formulas in IBC state I_f and I_s as percents and therefore multiply and divide factors by 100 at several steps in the process. This cumbersome and confusing procedure has been simplified above. Where open space is used to achieve an increase in area based on frontage thereto, it shall be either on the same lot or dedicated for public use and shall be accessible by a street or approved fire lane. The increase due to sprinkler protection requires that the system be an approved automatic sprinkler system in accordance with Section 903.3.2.

The following buildings may have unlimited area per IBC section 507:

- A one-story unsprinklered building surrounded and adjoined by public ways or yards not less than 60 ft. in width.
- A one-story building equipped with an automatic sprinkler system throughout and surrounded and adjoined by public ways or yards not less than 30 ft. in width.
- A two-story building equipped with an automated sprinkler system throughout and surrounded and adjoined by public ways or yards not less than 60 ft.
- The permanent open space of 60 ft. required as above may be reduced to 40 ft. for a maximum of 3/4 of the perimeter provided that the exterior wall facing the 40 ft. open space has a fire resistive rating of 3 hours and openings therein have protective with a fire rating of three hours.

While similar to IBC, UBC has some fundamental differences that can become critical where an otherwise open parking structure is classified as enclosed due to mixed use. The table for allowable heights and areas gives only the allowable area for a one story non-sprinklered building. (Note: this requirement applies to stories, not tiers as defined for open structures under UBC/IBC. With parking on the roof, a one-story structure will usually be a two tier parking structure.) Paragraph 504.2 of UBC then states that the combined areas of multi-story buildings may be twice that permitted by the table. Thus, if an enclosed structure is of Type II FR under UBC, it is limited to 18,000 sq. ft. per floor as a one or two story structure, 12,000 per floor as a three story structure, and 9000 as a four story structure, if it is not sprinklered. As parking structures almost always exceed any of these areas per floor, effectively, all enclosed, non-sprinklered structures under UBC must be of Type I FR construction. An otherwise open parking structure, classified as enclosed under UBC due to mixed uses, thus must choose between sprinklering the entire building (which is really not necessary or appropriate in any open garage) or designing the parking floors to be of Type 1 FR construction, which is particularly expensive for precast structures. When sprinklered, the areas of one-story buildings may be tripled (54,000 sq. ft. per floor at Type IIFR), while those with more stories are doubled. UBC does allow that floor areas in non-sprinklered buildings may still be increased if there is frontage or separation from other buildings.

BOCA has similar requirements regarding height and area modifications. The allowable areas shown in Table 5-1 above are for one or two story buildings facing on one street or public space not less than 30 ft. wide. Where the structure has more than 25% of the building perimeter fronting on a street or other space at least 30 ft. wide and accessible to fire department vehicles, the area can be increased 2% for each 1% of such frontage. Automatic sprinklers again allow the area to be increased 200% for one and two story buildings and 100 percent for those over two stories.

The kicker under BOCA is that to calculate the permitted maximum areas for a building with more than two stories, the area limitations are reduced as the height increases. For example, with type 2A construction the area per floor is as noted in the table for one or two stories, but it is reduced 5% for three stories, 10% for four stories, on up to 40% for ten stories. The area increases still apply; however, another scale of reductions is applied to type 2B and 2C buildings. As noted previously, these adjustments apply to calculation of maximum floor area in enclosed structures, but not in open ones.

SBC used a formula approach similar to that in IBC, but with different variables and factors. The reader is referred to sections 503.3 and 503.4 of SBC for details. As previously noted, neither NFPA 101 nor 88A has any height and area limitations for enclosed structures.

5.3.5.3 High Rise Buildings

Under IBC Section 403, a building that has an occupied floor more than 75 ft. above the lowest level of fire department vehicle access shall meet provisions for high rise buildings. Open parking structures are specifically exempted from this requirement (Exception 3 in IBC and various specific wording under other codes.) These provisions appear to have come substantially from BOCA.

Under UBC and SBC, high rise provisions only apply to B (Business) and R (Residential) occupancies. However, when these uses are located over an open or enclosed parking structure, and the high rise provision is triggered, the entire building, including the parking, is treated as a high rise. NFPA 101 does not impose any requirements on parking structures, either open or enclosed, qualifying as high rise buildings.

Some communities adopt and enforce the NFPA standard (or a paraphrase thereof inserted into local ordinances) for high rises for all buildings without the exception for open parking structures.

If the combined building with another permitted use over an open parking structure exceeds this height, the entire building is treated as a high rise. The IBC requirements for high rise construction, where imposed, include the following types of special considerations. As with other such discussions herein, specific details of the requirements are not delineated:

- Automatic sprinkler system; open parking structures are, however, exempted.
- With an automatic sprinkler system, Type IA construction can be reduced to Type IB and IB construction to IIA.
- Automatic smoke detection.
- A two-way fire department communication system.
- A fire command station .
- Standby power, light and emergency systems
- Separate lighting circuits and fixtures with minimum lighting levels.
- Exit signs, exit illumination and elevator car lighting connected to standby source.
- Automatic unlocking of any locked stairway doors.
- A two-way communication system to a constantly attended station.
- Special seismic design criteria.

Where an open parking structure is provided under a permitted use, the parking portion does not have to be sprinklered under IBC or BOCA, even when the overall building qualifies as a high rise building. This requirement is extremely significant as most local officials have tried to require the entire building in any mixed use situation, whether or not it qualifies as a high rise, to be sprinklered, although some have accepted sprinklering only the floor immediately below the other use. The fact that IBC and BOCA both specifically state that an open parking structure beneath another use does not have to be sprinklered in a high rise certainly makes it clear that there is no intent to require sprinklering of the entire building whether or not it is tall enough to qualify as a high rise.

Under SBC, if the use above is Group B, sprinklers "throughout" are not flatly required, but can be used as an alternate to reduce other provisions. Under UBC and NFPA 101 if the building is considered a high rise under a mixed use provision, the entire building, including parking floors, has to be sprinklered.

Where high rise codes are triggered, the cost may be only marginally increased or significantly increased, depending on the applicable code and whether other provisions, such as emergency generators, are planned in any event. It may, in turn, be desirable from a cost perspective to avoid parking structures of eight or more floors, except where absolutely required for the project requirements. That is, it may be better to build two separate structures under 75 ft. in height than one-high rise structure. However, without consulting local officials, the lack of uniformity between the codes and the tendency to overrule the open parking structure exception from some or all the high rise provisions at the local level makes it difficult to determine whether or not the provisions apply.

5.3.6 Underground and Windowless Buildings

Buildings spaces that have a floor level used for human occupancy more than 30 feet below the lowest level of exit discharge are considered underground buildings under IBC. Generally speaking, the requirements for underground buildings affect the need for sprinklers, the construction type, compartmentation, smoke control and exhaust, fire alarm systems, voice communication, enclosure of exits, requirements for standby power and emergency power requirements and standpipe systems. Where there are one or two basement parking levels, this section is probably not triggered. Also, parking structures otherwise qualifying are exempted from the specific requirements if they have approved automatic sprinklers. (IBC 405.1)

The requirements in this section of IBC appear to have come substantially from SBC and/or BOCA, both of which have essentially the same requirements. SBC also applies the requirements for underground buildings to 2 levels below grade if the levels are not sprinklered. There are no such special sections for underground buildings in UBC, although there are some similar provisions buried in the specific design detail requirements.

NFPA 88A has two separate and distinct sub-groups for enclosed structures below grade. An underground structure is one with no use other than parking above the below grade levels; a basement structure is one with other uses (retail, office, residential, etc.) above. There are a few specific requirements, including one requiring sprinklers for both basement and underground structures in which the ceiling of a level is not more than two feet above grade. Again, that structure might qualify as open for ventilation purposes, but would still have to be sprinklered under NFPA 88A.

NFPA 101 does have provisions for underground structures as well as windowless ones. Note that while the high-rise provisions apply only if referenced by the specific occupancy section of that code, NFPA's windowless and underground provisions apply to any and all occupancy types, including open and enclosed parking structures.

Under NFPA 101, an underground structure is any portion of a building with a floor level below the level of exit discharge. However, that portion of the building shall not be subject to requirements for an underground building if the story has not less than 20 sq. ft. of emergency access openings entirely above the adjoining grade level in each 50 lineal ft. of exterior enclosing wall area on two or more sides. An emergency access opening is defined as having opening dimensions of not less than 22 in. width and 24 in. height and is unobstructed to allow for ventilation and emergency rescue operations. The bottom of the opening can be no more than 44 in above the floor and the opening shall be readily identifiable from inside and outside. A parking structure floor that is partially underground but meets openness on two sides would almost always have adequate openings to serve as emergency access openings, **if** the openings are entirely above adjoining grade and if the openings are no more than 44 in. above the inside floor elevation. However, if the openings provided to qualify as an open floor are provided via area wells below exterior grade, the access to the areawells must be carefully designed to avoid triggering treatment as an underground structure. For example, a stair may be considered adequate access to an area well, as may an opening at one end where the exterior grade slopes from one end to the other of the light well. Consultation with local officials as to what constitutes acceptable access to the openings is advisable early in the design process.

Similarly, a windowless structure is a structure or portion thereof that may not qualify as underground, but **does not** have "emergency access openings" on two sides of the building. A structure is **not** considered windowless under NFPA if it meets either of the following conditions:

- It is a one story structure or portion thereof, or a first story of a multi-story building where there are grade level doors or emergency access openings (as defined above) on two sides of the building, spaced not more than 125 ft. apart in the exterior walls.
- The structure or portion thereof is above the first story and has emergency access openings on two sides of the building, spaced not more than 30 ft. apart.

As floors at or above grade in parking structures qualifying as open would be provided with openings on at least two sides, windowless structure requirements will not apply to very many parking structures. However, it is again extremely important to note that it is up to the "authority having jurisdiction" to determine if there is adequate access to the openings.

Under NFPA 101, underground and windowless structures with an occupant load of more than 50 persons are required to be sprinklered. As the occupant load factor is 1 occupant for every 200 sq. ft., a floor area of more than 10,000 sq. ft., which in turn encompasses virtually all parking structures, will be covered by this requirement. While sprinklers are not generally required in open or enclosed structures by NFPA, the underground and/or windowless structure requirement overrules that lack of a general requirement. In addition, exits shall be vented to the outside to avoid a build-up of smoke from fires at below grade levels, and special signage is required to assist in egress from underground structures under NFPA 101.

Although IBC's full provisions for underground structures apply only to those spaces more than 30 ft. below the lowest level of exit discharge, Chapter 9 on Fire Protection requires sprinklers in "stories and basements without openings." Those requirements are similar to the NFPA 101 requirements as described above. However, the specifics are slightly different. The openings must be 20 sq. ft. in area, entirely above grade, with a minimum dimension of 30 in. in either direction. At least one opening must be provided in each 50 lineal feet of exterior wall on at least one side of the building. The openings shall be accessible to the fire department and cannot be obstructed in a manner that firefighting and rescue cannot be accomplished from the exterior. The requirements also state that if openings in a story (i.e., not qualifying as basement) are provided on only one side, and the opposite wall is more than 75 ft. from such openings, the story shall be sprinklered. If the openings are provided on two sides however, the 75 ft. criteria is not applied. Again, parking floors qualifying as stories **above grade** will not trigger sprinklers under this requirement **if** all of the openings are entirely above grade on at least two sides and **if** they comply with requirements for fire department access.

However, a third and final criteria in this section of Chapter 9 of IBC applies to a floor classified as a basement. The latter is defined by IBC as a portion of a building that is partly or completely below grade, which in turn means it does not qualify as a story above grade, as previously discussed in section 5.3.5 of this Chapter. If any portion of the basement is located more than 75 ft. from openings, the entire basement shall be sprinklered. This provision does not exempt structures that have openings on two or more sides as the preceding one does; therefore, if a parking floor qualifies as an open parking tier, but **does not** qualify as a story above grade, it appears that it may have to be sprinklered under IBC.

However, it is believed that is not the intent of IBC. UBC's requirements for emergency access openings in its Chapter 9 are quite similar to those in IBC; however, UBC specifically exempts open parking structures from the provisions. That may also have been the intent of IBC, as there is an identical listing of exceptions, including open parking structures at the end of Section 903.2.12. However, the typography places the three exceptions after a subsection for high rise buildings (903.2.12.3), making it appear that the three exceptions only apply to high rise buildings.

BOCA also has similar requirements for stories classified as a windowless story or a basement. However, if **either** of the following exists, the provisions **do not** apply:

- there is an exterior stairway or an outside ramp leading directly to grade in each 50 linear feet of fraction thereof on at least one side of the side of the building; or
- openings entirely above adjoining ground level totalling 20 sq. ft. or more are provided in each 50 linear feet thereof on at least one side of the building.

The relatively minor rewording and/or reorganization of the IBC language from quite similar requirements in BOCA and UBC has the effect of appearing to affect otherwise open parking levels in ways that did not occur under either predecessor code. It is believed that the intent of IBC's rewording was simply to combine requirements found in UBC and BOCA, not to change significantly and increase the requirements therefrom. However, the wording in IBC will be subject to "parsing" and local interpretation, until and unless some experience with application and/or an official clarification of IBC's intent has been gained. Therefore, it behooves the designer of a parking facility situated partially below grade to meet with local officials and obtain an understanding of how this part of IBC is interpreted at the local level.

In sum, a level of a parking structure that qualifies as open, but has openness above adjoining grade on only one side, with openings on one or more other sides provided via area wells below adjoining grade, would be exempt from the windowless story requirements under BOCA and UBC. However, it may not be exempt under IBC if an official chooses to take the wording literally rather than consider the intent and history of the development of the language resulting from the combination of preceding model codes requirements.

5.3.7 Location on Property

The location of the building on the property affects the fire rating of the exterior walls and the protection of openings therein. Table 5-2 summarizes the former while 5-3 summarizes the latter under IBC. It should be noted that the only protected openings likely to be found in open or enclosed structures are doors for required exits.

Table 5-2 Exterior Walls

Construction Type	Bearing	Non-Bearing Walls
Types IA,	Per Table 5-1	1 hr <30 ft.; N>30 ft.
Types IB IIA	Per Table 5-	1 hr <30 ft.; N>30 ft.
Type IIB	NR [1]	NR [1]

Source: IBC Table 602

[1]per Footnote 3 to Table 602.

Table 5-3 Protection of Openings in Exterior Walls

	Unprotected Openings	Protected Openings
Open Structures	Not permitted <5 ft. 10% if 5< dist<10 ft. Unlimited> 10 ft.	Not permitted <3 ft. 15% if 3< dist<5 ft. 25% if 5< dist<10 ft. Unlimited> 10 ft.
Enclosed Structures	Not permitted <5 ft. 10% if 5< dist<10 ft. 15% if 10< dist<15 ft. 25% if 15< dist<20 ft. 45% if 20< dist<25 ft. 70% if 25< dist<30 ft. Unlimited>30 ft.	Not permitted <3 ft. 15% if 3< dist<5 ft. 25% if 5< dist<10 ft. 45% if 10< dist<15 ft. 75% if 15< dist<20 ft. Unlimited>20 ft.

Source: IBC Table 704.8

UBC's requirements for openings are slightly different in that they don't permit any openings in either open or enclosed structures less than 5 ft. from a property line. Open structure walls between 5 and 10 ft. from a property line must have a 1 hour rating of the wall and opening protectives. Another ramification of the prohibition on mixed uses with open parking structures under UBC is the protection of openings. Even though the structure is classified as enclosed, provision of openings in accordance with those for open parking structures allows the enclosed structure to be exempted from the requirements for mechanical ventilation. Table 5-A of UBC requires protected openings in enclosed structures up to 20 ft. In essence, UBC has a "catch-22": you can't have enough openings to qualify for natural ventilation when the distance to the property line is between 10 and 20 ft., despite the fact that if the structure were simply classified as an open structure, there would be no restriction on openings.

Under SBC, any side of an open parking structure within 10 ft. of a common property line or building line shall have a 1 hour fire wall, without openings, except for appropriately designed exit doors. The type of construction further controls the horizontal separations under SBC. We have not reproduced the range of requirements but only alert the reader to significant reductions in permitted openings under SBC compared to those in IBC. The SBC requirement that all points on a floor in all open parking structures must be no more than 200 ft. from a side open to a permanently maintained open space at least 20 ft. in width may also affect the width of the structure and/or its placement on a site.

BOCA requires that exterior walls within 5 ft. of a property line be 2 hr.-rated, while those between 5 and 10 ft. must be 1 hr. rated, except where the required rating per Table 5-1 is higher. Open sides must have a fire separation distance of at least 10 feet. The table values for openings are identical to those in IBC.

NFPA 101 does not address distance to the property line and opening protectives. NFPA 88A requires a 2 hour fire rated wall if the wall of any parking structure, open or enclosed, is within 10 ft. of another building.

There are numerous rules for application of the requirements related to openings in exterior walls in each code. These must be studied in the final design phases. Three, however, affect the provision and/or width of yards are courts as discussed on the next section.

- Buildings on the same property or separated by courts shall be assumed to have a property line between them. (IBC 704.3) There is a specific exception if not more than two levels open onto the court.
- Where a new building is constructed on the same property as an existing one, the location of the assumed property line shall be such that the existing building meets the requirements of section 704.5 (fire resistance ratings per tables 601 and 602; the requirements applicable to parking structures are given in Tables 5-2 and 5-3 of this chapter.)
- Buildings shall adjoin or have access to a public way or yard on not less than one side. Yards shall be permanently maintained. The center-line of an adjoining public way shall be considered an adjacent property line for the purposes of building separations.

5.3.7.1 Required Separations

The following sections discuss, in general, some of the required separations that may affect basic parking design parameters at a conceptual level. No attempt is made, however, to delineate all of the specific required for each type of separation.

5.3.7.2 Yards, Courts and Area Wells

A court is defined by IBC as follows:

> **COURT.** An open, uncovered space unobstructed to the sky, bounded on three or more sides by exterior building or other enclosing devices.

Courts do not have to open directly to the public right-of-way at one end, but if exit discharge is provided via the court, an obvious path of travel to the exterior must be provided. Typically, the path of travel is allowed to cross vehicular connections between the two sides of an open parking structure facing the court at one or both ends if the path of travel is clearly delineated. See Figure 5-8.

Figure 5-8. A light well acting as a court may be employed to meet requirements for distance from any point on a floor to an open side. Photo courtesy of Walker Parking Consultants.

A court can also occur between two legs of a U shaped building. A yard is defined by IBC as follows:

> **YARD.** An open space, other than a court, unobstructed from the ground to the sky, except where specifically provided by this code, on the lot on which a building is situated.

A yard most typically occurs between two separate buildings on the same property or between an exterior wall of a building and a property line. As previously noted, a property line is assumed between walls facing a court or yard. If both walls have openings, the distance to the property line from each wall facing it must be appropriate for the required fire separation and opening protectives for that wall, as well as for natural ventilation per Chapter 12.

Before discussing the specific requirements, it is important to note that in the past the requirements for courts and yards in Chapter 12 of the model codes have not been applied to open parking structures. In fact, while SBC doesn't even address court and yard widths for natural ventilation, UBC only applies its courts and yards requirements to residential uses and BOCA states that the requirements applied where "rooms" required natural light and ventilation. IBC, however, applies its requirements more generally to all situations where courts and yards provide natural light and ventilation. Therefore, IBC Chapter 12 is applicable to open parking structure walls facing such yards and courts, and the requirements would supersede those regarding protection of openings where the yard/court requirement is greater than the distance for unprotected openings.

Under IBC, a light well in a parking facility is only considered a court if the walls facing it are classified as **exterior** wall(s). The classification as an exterior wall is usually a result of the requirement that any point on a parking floor must be no more than 200 ft. from an opening in an exterior wall. Under SBC, this occurs for all open parking structures; under the other codes, it may be necessary to achieve a height or area increase in order to use a desired type of construction. If the wall is **not** considered an exterior wall, the space between walls is not limited in width by requirements for yards and courts. Instead, the wall is subject to the 20% openness requirement for interior walls. However, if a court or yard is not required, but the open space is provided either voluntarily or as a compensation for some other consideration by the local official, it may be appropriate to size the space based on the requirements for yards and courts between exterior walls.

The minimum width of a yard for an open parking structure must be 10 ft. to the property line for purposes of fire separation. The width from the property line to another building opposite is determined by the requirements for that building occupancy. A very tall parking structure meeting all the other openness criteria can be sited with 10 ft. clear to a property line, even if a much taller building on the adjacent property sits right on the property line with a fire wall.

Section 1205 of IBC prescribes that all yards providing natural ventilation (without qualifier) shall be not less than 3 ft. wide for one and two story buildings, with 1 ft. added for each additional story up to a maximum of 17 ft. for buildings of 14 or more stories. Note that this requirement is based on stories, not tiers.

Combining the fire separation and natural ventilation requirements, the yard from an exterior wall to the property line, no matter what is on the other side of the property line, can be 10 ft. in width (minimum for openings in open parking structure) up to nine stories (ten floors) plus 1 ft. for each additional story. This requirement is not particularly onerous and in fact, as discussed in Chapter 3, probably does not provide a reasonable amount of natural light for wayfinding and user comfort if pedestrians use the court at grade.

If the two portions of the building are considered separate buildings due to area limitations or requirements for openings in exterior walls, a property line is assumed down the middle, and each half has to have its own yard. This requirement effectively doubles the yard/court width to 20 ft. up to 9 stories plus 2 ft. for each additional story. It might be slightly unfair due to the fact that if the property line is real, there could be a solid wall 10 ft. away, but the intent is to assure that there is adequate width for ventilation through the openings on both sides.

The requirements for fire separation as well as those for natural ventilation for courts (between two walls of the **same** building) are essentially the same regarding width. Again, the overall width of a court has to be doubled if two opposite sides facing it both have openings to the court. There is also a confusing element in IBC in that there is no minimum length given, but the length is prescribed to increase 2 ft. for every additional story. Courts more than two stories in height shall be provided with a horizontal air intake at the bottom not less than 10 sq. ft. and leading to the exterior of the building, unless abutting a yard or public way. The air intake assures that there will be an air flow available to refresh the supply when heated smoke from a fire causes the air in the court to rise. When there is a light well running the full length of the structure, except for vehicle bridges connecting the two halves at the end, this intake is provided by assuring openness at the grade connection between the two halves of the building. The intake becomes more problematic if smaller light wells (say 20 ft. x 20 ft.) are dotted around the floor to achieve the 200 ft. criteria.

The air intake concept came from BOCA, although its requirements are slightly different. Although not usually applied to parking structures, BOCA requires 3 in. of width for a court or yard for each 1 ft. in height, with a minimum of 5 ft. for a court that opens to a public way on one end and 10 ft. for inner courts. The air intake must be 21 sq. ft. under BOCA. This code requires the length of the court to be at least 1.5 times its width, but it also limits the length of courts to twice the width. This limitation can be problematic for light wells extending most of the length of a structure. As it is clear that a single, long light well is more effective than small ones dotted on a floor plate, the length limitation is generally waived by local officials, if they choose to regulate the width by the BOCA requirement for "rooms."

As previously noted, SBC does not define a court nor have any applicable requirements. The language in the section on open parking structures states that required openings must open to a permanently maintained open space which in turn must connect to a street, presumably at one end. In mega-structures, we have been able to have the sections between light wells considered separate buildings, with "vehicle bridges" connecting both sides across the open space between them, if there is unimpeded access to a public right-of-way, such as a street, at one end. The space needs to be 20 ft. clear width. We were further able to use open stairs that discharged at grade into the open space, with the exit discharge path of travel continuing across the vehicle connection at grade (under the bridges above) to that open space.

While we are on the topic of ventilation openings, Section 1202.5.1.2 of IBC prescribes that where openings below grade provide natural ventilation, the clear horizontal space measured perpendicular to the opening shall be 1.5 times the depth of the opening, which is measured from the average adjoining ground level to the bottom of the opening. This requirement came from BOCA; UBC and SBC didn't have a similar requirement. In its absence, many code officials under UBC and SBC accepted a clear width for such an area well equal to the height of the opening on the wall. Therefore, the BOCA and IBC requirement is roughly 50% more. Moreover, in view of what is permitted as the open width for above grade walls facing courtyards, and/or property lines in urban environments, it seems rather conservative.

5.3.7.3 Fire Walls vs. Fire Barriers vs. Smoke Barriers

The key requirement related to **fire walls** is that they are specifically required between two separate buildings rather than fire barriers that separate occupancies within the same building. The fire wall must provide a complete isolation from top of foundation to or through the roof and must continue to stand should either of the buildings be structurally compromised. Openings in fire walls are limited; typically unprotected glass panels are not allowed. Fire walls in open and enclosed parking structures under IBC and BOCA are required to be 2-hr. rated. Under SBC all fire walls must be 4-hr rated. Under UBC, the concept of mixed uses is treated entirely differently than other uses. "Fire walls" as defined above simply do not exist under UBC. When two separate buildings are located on the same property, a property line is assumed between each, and each must have its exterior walls rated in accordance with the distance to the property line as previously discussed.

Fire barriers that separate occupancies in the same building need only extend to the underside of the floor above. The rating of a fire barrier is based on the elements being separated; most use separations are 2 hours. Openings are required to be rated for 1½ hours, which in turn limits the size of a glass panel to 100 sq. in.; the maximum height is 33 in. and the maximum width is 10 in. These requirements significantly limit glass in doors through fire barriers, which in turn affect passive security as someone could hide behind a door with openings limited to these sizes. Again, note that UBC sharply limits the situations under which open parking structure uses may occur in mixed use buildings and provides special requirements for the separations.

A key application of a **smoke barrier** is the enclosure of an area of refuge. When located inside an enclosed exit stair, the required rating of the stair enclosure prevails. However, if an area of refuge is provided in an elevator lobby or a vestibule outside the stair enclosure, only a smoke barrier is required. Therefore, wire glass walls can be employed to enclose the lobby or vestibule, which significantly improves its passive security.

5.3.7.4 Shaft Enclosures

Where vertical shafts are required to enclose openings and penetrations through floor and roof assemblies, they shall be protected in accordance with IBC 707.1. Openings in or between floors of open parking structures under all of the codes do not have to be protected by a shaft enclosure (IBC 406.3.11) except where there is a fuel fired appliance (IBC 406.2.8), as previously discussed. This exemption means that automobile ramps between parking floors are not required to be enclosed. Also, elevator towers and shafts that are otherwise enclosed do not have to be fire-rated, and most importantly, elevator lobbies do not need to be enclosed. Although some have argued that elevator codes require 2 hr. hoistways, the commonly adopted code for elevators, ASME A17.1[22], states in section 100.1a that hoistways shall have the fire resistive enclosure as required by the building code. Where the building code does not require that the hoistway be fire-rated, a laminated glass wall may be provided to achieve glass back elevators. Unfortunately, many inspectors have a requirement for a 2 hr. rating of the hoistway on their checklist, resulting in arguments at the time of inspection.

As previously noted however, NFPA 101 requires that stairs serving as exits in open parking structures must be enclosed. NFPA 88A has specific requirements for enclosure of vertical openings in enclosed structures, but does not apply them to open structures. This lack of requirement for open structures is construed as not requiring enclosures, except as required for exit stairs via the 88A reference to NFPA 101 for means of egress provisions.

Automobile ramps in enclosed parking structures do not have to be protected in accordance with IBC 406.2. Therefore, enclosure requirements only apply to shafts such as stair and elevator shafts in enclosed parking structures. (IBC 707.2) NFPA 88A, however, requires vehicular ramps in enclosed structures with four or more stories to be enclosed as well if a structure is not sprinklered or it does not have an automatic, supervised fire detection system. While rare that an enclosed structure is not otherwise planned to be sprinklered, this requirement would certainly push the designer toward sprinklers.

As with fire barriers, shaft enclosures shall extend from the top of the floor/ceiling assembly below to the underside of the floor or roof slab above and shall be securely attached thereto. (IBC 707.5) A key issue about shaft enclosures is that the separation need only exist between the occupancy and the shaft. Openings, such as often provided for passive security in stairs and for glass back areas may be provided in exterior walls of both stair and elevator shafts if the separation is properly detailed.

5.3.7.5 Horizontal Assemblies

Floor and roof assemblies are critical components in providing horizontal fire separations. The required ratings for parking floors have been previously presented. Assemblies shall be continuous without openings, penetration and joints except as specifically permitted in sections 707.2, 711.4 and 712. In open parking structures, openings, including tee-to-tee joints in precast concrete structures, and expansion joints do not have to be fire-rated.

The floor assembly between open and enclosed parking structure floors in structures with both occupancies, has to be designed per the requirements for a floor assembly in an enclosed structure under IBC Section 508.3. Openings between the open and enclosed portions, except for exit openings, do not have to be protected. Therefore, openings for vehicular ramps as well as joint penetrations do not have to be protected. It is a bit unclear whether this requirement applies to only a one-level enclosed structure below an open structure or to multiple levels. The IBC language came directly from UBC. The UBC handbook sheds no further light on the issue. Because a basement can be multiple stories under both IBC and UBC, it is generally interpreted that the enclosed portion can be multiple stories. Under SBC section 411.2.6, automobile parking structures shall be separated from other uses. However, since both open and enclosed structures are subgroups within automobile parking structures, the usual interpretation is that they do not have to be separated. Similarly, NFPA 101 treats open and enclosed structures as sub-types within the same group and does not require protection of openings in floors. NFPA 88A does not specifically address openings in floor assemblies but those for vertical openings discussed in the section on shaft enclosures above are generally applied to expansion joints and other floor openings as well. BOCA does not have any similar language and therefore the openings between open and enclosed structures are technically required to be protected. However, as vehicle ramps between the floors of each do not need to be protected, many local officials will waive the fire rating of the joints and separation of vehicular ramps at the juncture of the open and closed portions. Otherwise, a fire sprinkler curtain is often used at the separation.

5.3.7.6 Structural Members

The fire resistance ratings of structural members and assemblies shall comply with the requirements for the type of construction, as previously presented. The only requirement regarding structural members in parking structures that is of particular concern is IBC Section 713.4 that requires impact protection of the fire resistive covering of any structural member subject to impact damage from moving vehicles. This provision can affect the use of steel framing in parking structures required to have fire-rated structural members.

5.4 FIRE PROTECTION SYSTEMS

Fire protection systems, whether required by code or installed voluntarily to attain some other code exemption, shall be installed, repaired, operated and maintained in accordance with the International Fire Code (IFC). (IBC 901.2) The other codes reference other documents, and/or multiple pieces of multiple documents. Therefore, no attempt has been made to list all codes affecting fire protection via reference.

As noted in the preamble to this chapter, fire protection officials have substantially more leeway to assess risks and mandate protective measures under NFPA codes than is provided under IBC. IFC specifically states that the code official is authorized to enforce the provisions of the code and to render interpretations of the code. However, the official's interpretations must be in compliance with the intent and purpose of the code and shall not have the effect of waiving requirements specifically provided in the code. The official may grant modifications and approve alternative materials and methods that are in compliance with the intent and purpose of the code and provide equivalent or higher protection in terms of quality, strength, effectiveness, fire resistance, durability and safety.

Under NFPA, the "authority having jurisdiction" has the right to demand a higher level of protection, such as provisions for standpipes and sprinklers where not otherwise required, if it is the opinion of the fire official that the risks are higher than otherwise anticipated in the model code. For example, one local official argued on one project that standpipes should be provided in a parking structure (not otherwise required to have them by the building code), because a local zoning board had previously approved a reduction in stall width. The official argued that the cars will be parked closer together than otherwise permitted, and therefore the risk of fire spread from car to car was higher than "normal." Fortunately, by providing the official with extensive information on the risk of fires in parking structures as discussed at the beginning of this chapter, we were able to convince the official that the risks were not as high as he had perceived. Under the NFPA, the official also has significant leeway to grant modifications in required fire protection systems based on the local fire-fighting capabilities.

One word of note to managers of design projects is that fire protection systems must be tested in accordance with the International Fire Code. When required, the tests shall be conducted in the presence of the building official. Required tests shall be conducted at owner expense. It is unlawful to occupy portions of a structure until the required fire protection systems within that portion of the structure have been tested and approved. (IBC 901.5) The contractor shall provide the building inspector with certification that each fire protection system is installed in compliance with the applicable codes and technical standards and that the appropriate acceptance tests have been conducted. (IBC 901.6)

Under IBC, an approved supervising station in accordance with NFPA 72 shall monitor automatic sprinkler systems and/or fire alarm systems. (IBC 901.7).

5.4.1 Sprinkler Systems

Under IBC/IFC, an automatic sprinkler system shall be provided throughout all buildings classified as enclosed parking structures, except enclosed structures classified as Group R-3. An open structure with an R-3 rating also does not have to be sprinklered. (IBC 903.2.11) An automatic sprinkler system shall also be provided throughout all buildings used for storage of commercial trucks or buses where the fire area exceeds 5,000 sq. ft. (IBC 903.2.11.1)

An automatic sprinkler system is also required in S-2 uses for stories and basements without openings. (IBC 903.2.12) As previously discussed in the section on underground buildings, this provision would not apply to open parking structure levels that qualify as stories above grade, and that have openings that meet the requirements for fire department access on two or more sides. It can be construed that sprinklers would be required if the level qualifies as a basement, whether or not it has openings on one or more sides. However, it is believed that it was not the intent of IBC to modify the requirements from UBC and BOCA, neither of which would require sprinklers if a parking level qualifies as open under those codes. Therefore, it is important to meet with local officials and discuss the design and local interpretation of the intent of IBC to avoid an unpleasant surprise during the permitting or inspection processes.

UBC has essentially the same requirements except for the general one regarding sprinklering all enclosed structures. Therefore under UBC, a structure that is enclosed because of mixed-use, but is above ground level and has openings does not have to have sprinklers. Conversely, basement levels and stories above grade without adequate openings and access to fight fires could be required to be sprinklered. UBC notes in its handbook that openings to areawells and lightwells can be considered as adequate access to openings if there is a stairway into the areawell or other reasonable means of access. Again, designs assuming access via areawells and lightwells should be reviewed with local officials for concurrence as to the acceptability of the access.

BOCA requires sprinklers in enclosed structures if a fire area exceeds 12,000 sq. ft., among other requirements. Note that this requirement applies both to enclosed structures in Group 2 (that house only passenger vehicles that will accommodate not more than nine passengers), and those in Group 1 (that either house larger vehicles or include fueling or repair of vehicles.) As almost all parking structure floors will be considered a fire area and will exceed the prescribed limit of 12,000 sq. ft., the other requirements for enclosed structures are moot. As previously noted, under BOCA, parking structure levels that qualify as open will be exempt from the requirements for sprinklers in windowless structures if there are openings on just one side that are adequate for emergency access.

NFPA 101 does not generally require sprinklers in open or enclosed structures but gives substantial credit for other criteria (such as walking distance) where provided. It does, however, require sprinklers in underground structures, as previously discussed. Those requirements are similar to the ones for openings in underground structures under IBC. NFPA 88A has an even broader requirement: sprinklers are required in any parking structure, open or enclosed, where the ceiling is 2 ft. or less above grade. Sprinklers are also required by 88A for enclosed structures of Type III or Type IV construction over 50 ft. in height; however, it is rare that such structures would not qualify as open.

Under SBC, sprinklers are required for enclosed parking structures over 65 ft. in height and exceeding 10,000 sq. ft. per floor. Most parking structures above grade will be designed to be open, so few above-grade structures will be required to be sprinklered under that provision. Parking structures qualifying as basements shall be sprinklered; note that although a basement is any floor below grade, under SBC "grade" is the average of the exterior grades around the perimeter. Therefore, an open parking structure floor that is below exterior grade for more than about half of its perimeter may have to be sprinklered. Bus structures serving as passenger terminals or for storage or loading of four or more buses must be sprinklered, under SBC. This condition automatically occurs under IBC because the loading areas are classified as enclosed structures, whether or not they meet openness criteria.

5.4.2 Standpipes

Before discussing the specific requirements for type and location of standpipes in parking structures, it is helpful to define a few terms. Standpipes consist of a piping system with valves that allow a hose to be attached to deliver a water stream to fight fires. Standpipes reduce the need for firemen to hand-lay hoses connected back to fire department pumpers in order to fight a fire. In some cases, a preconnected hose accompanies the hose valves so that firemen don't have to drag hose into any particular area. Pre-connected hoses also allow building occupants to fight fires.

Class I standpipes have 2 ½ in. hose connections and are intended for use by fire departments and those trained in handling heavy fire streams. They are provided first in stairs and at horizontal exits, with additional standpipes located to provide a maximum distance of 150 ft. from any point on the floor to a hose connection. If the building is sprinklered, the maximum distance is increased to 200 ft.

Class II standpipes have 1 ½ in. hose connections with attached hose and are intended to be used by building occupants and by the fire department during initial response. When required or permitted, they are provided so that all portions of a building are within a 100 ft. hose and a 30 ft. stream from a nozzle at the end of the hose.

A Class III system has both Class I hose connections for use by the fire department and Class II hose connections attached to hoses for use by building occupants. They are located to meet Class I coverage requirements. In other words, they are located to meet the 150 ft./200 ft. distances allowed under Class I, but have both Class I and Class II connections at each location. The code is worded to require Class III standpipes except for several circumstances. Most parking structures fall under the special requirements and thus are required to have only a Class II **or** only a Class I system, as will be discussed below.

Automatic wet systems are fully charged with water and connected to a water supply with enough water pressure to meet fire fighting needs as soon as a hose valve is opened. Such a system is subject to damage where freezing occurs and could therefore be unable to provide water when needed. Manual wet systems have water in the pipes, but are connected to a supply of insufficient pressure. The fire department has to connect to an inlet valve and increase the pressure to adequate levels using a fire department pumper. Manual dry systems do not have a water supply attached to the system and require water to be pumped into the system by the fire department after arrival at the site.

Obviously, the occupants of the building will have little success attempting to fight a fire with a Class II system if there is no water in the pipe until the fire department arrives and "charges" the system. An automatic dry system is filled with pressurized air instead of water, and has a valve that automatically lets in water from a connected "wet supply" when a hose valve is opened anywhere in the system. Semi-automatic dry systems are not pressurized with air, but instead have a special device that admits water into the piping on activation by a remote control device located at each hose connection valve.

Automatic dry systems are the usual choice where an automatic supply is required, but freezing would damage an automatic wet system. However, it is highly desirable to use a manual dry system wherever permitted by code or local officials.

Under IBC, standpipe systems shall be installed throughout buildings where the floor level of the highest story is located more than 30 ft. above the lowest level of fire department access, or where the floor level of the lowest story is more than 30 ft. below the highest level of fire department access. (IBC 905.3) The standpipe system so required shall be a Class III automatic wet system, except for the following:

Class I standpipes may be used in buildings otherwise required to have Class III standpipes if the building is protected throughout by an automatic sprinkler system in accordance with NFPA 13. *This provision, which effectively allows standpipes to be located using the 150 ft./200 ft. maximum distances, and with only the Class I hose connections, but without hose, would apply to any building that is sprinklered and is also required to have standpipes. In the case of parking uses, it would usually only occur in enclosed structures. It would also, however, apply to any open structure that for some reason is sprinklered and still must have standpipes. This situation would most likely only occur if some local ordinance or official overrides the exemptions for not sprinklering open parking structures.*

- Open parking structures where the highest floor is not more than 150 feet above the lowest level of fire department access may have only Class I manual standpipes, again without hose. NFPA lowers the trigger for automatic systems to 75 ft. *Because open parking structures get special considerations due to the demonstrably lower fire risk, they are allowed to have only a manual system complying with type I requirements. It may also reflect the fact that most fire marshals don't want civilians to attempt to fight a vehicle fire. Note that this applies whether or not the building is subject to freezing. If the building is subject to freezing, the system can be a manual dry system under section 905.8; if not, it has to be a manual wet system. It has been argued that the NFPA trigger of 75 ft. overrules the 150 ft. criteria in IBC, because the 75 ft. criteria is included in NFPA 14, which is referenced by IBC. However, the normal interpretation is that NFPA 14 is overruled by any specific provisions in IBC that contradict it, such as the 150 ft. limit.*
- Where open parking structures are subject to freezing temperatures, Class I manual dry standpipes are permitted, provided the outlets are located as required for a Class II system. NFPA 14 requires a dry system if subject to freezing. *Again, this is a special provision that allows manual dry standpipes without hose everywhere in a structure subject to freezing, not just if the building is lower than 150 ft. as the immediately preceding exception would allow. In other words, open parking structures taller than 150 ft.* ***and*** *subject to freezing can have manual dry standpipes with Class I valves only, but they are required to comply with Class II locations, i.e. with 130 ft. hose and stream. The IBC requirement is significantly clearer than the requirement in NFPA 14, which can be interpreted to mandate that only dry*

standpipes be used, which in turn means that other means of protection such as heat tape are not permitted. IBC clearly permits dry standpipes but does not mandate them.

- Class I standpipes are allowed in basements protected throughout with an automatic fire-extinguishing system. *This provision is essentially a clarification of the first exception noted above to make it clear that it does apply to basements, including parking structures, which are sprinklered.*

Section 905.8 further states that any and all standpipes that are subject to freezing (in the opinion of the building official) may be dry standpipes complying with NFPA 14.

In addition to the above requirements, which are based primarily on height, there is also a requirement based on floor area. Both open and enclosed parking structures, which are in group S-2 under IBC, are exempted, so the area requirements are moot. An additional section requires Class I standpipes in buildings qualifying as being underground as previously discussed.

Under IBC 905.4, Class I standpipes must have one hose connection for each floor above or below grade in each required stairway. Those connections are to be provided at the intermediate floor landing, unless otherwise approved by the local official. This requirement is a distinct departure from BOCA, UBC and SBC, which have always required the standpipe hose connections to be located at the floor landing. However, it is a requirement in NFPA 14, which has long been referenced by the codes for specific design criteria. Essentially, the three model codes have yielded to the NFPA 14 standard on this issue in IBC. Under NFPA 14, however, local officials have the option to choose to have the connections provided at the floor landings. Where it has been discussed under prior codes, the local officials have almost always preferred to have the hose connections at the floor landing rather than the intermediate landing. Discuss the issue during design to determine the local preference.

Class I standpipes shall also be located on each side of the wall adjacent to the exit opening of a horizontal exit. Risers and laterals of Class I standpipes not located within an enclosed stairway shall be protected by a degree of fire resistance equal to that required for vertical enclosures. Since no such enclosures are required in open parking structures, protection of standpipes in open parking structures is not required. Also, if there is an automatic sprinkler system, such as is required in enclosed parking structures, the fire resistant enclosure is also not required. Class I standpipes are also required to be interconnected at the bottom so that if any one hose connection is activated, all of the other risers are activated.

Fire resistant protection of risers and laterals of class II standpipe systems is not required. Interconnection of Class II standpipes is not required. (IBC 905.5) Note however that NFPA 14 requires interconnection of all standpipes so some fire officials may require it.

Class III systems are required to be located to meet both Class I and Class II above, and shall be protected per Class I. Interconnection of Class III standpipes is required. (IBC 905.6)

In the past, the requirement for interconnection was frequently ignored or waived with manual dry systems; however, today interconnection is usually required no matter what type of water supply is provided.

Cabinets containing fire-fighting equipment such as valves, hoses, extinguishers etc, shall not be blocked from use or obscured from view. In parking facilities, this requires providing a walkway to the cabinet. It is better to provide a walkway meeting minimum requirements (usually 36 in. wide) than to simply prohibit parking in the parking stall in front of standpipes. If the space is big enough to park in someone will do it! Cabinets must meet specific requirements not repeated here. (IBC 905.7)

Normally, the hose portion of the requirement is required to be laid out around obstructions. It is desirable to provide a drawing showing the specific layout for building permit application.

The other codes have slightly different terminology and varying requirements.

BOCA has substantially the same requirements. Therefore, two and three level open structures probably don't need standpipes, but structures with four or more tiers as well as all enclosed ones usually will require them.

SBC's requirements are somewhat different. Class I automatic wet standpipes are required in any building in which the highest floor is more than 30 ft. above the lowest level of fire department access. Class I standpipes are also required in buildings of less height under SBC if there is more than 10,000 sq. ft./story and any portion of the building's interior is more than 200 ft. from the nearest point of fire department access. Note that the latter is not the same as the 200 ft. requirement in open parking structures; a side can be open but not have fire department vehicle access. Therefore open structures of three floors or less may need standpipes if there isn't fire department access on most, if not all, sides. Also although the terminology is different, the standpipes provided under this provision must be manual wet as defined in IBC rather than automatic wet as required for taller buildings. Enclosed and underground buildings are also covered by this second requirement, but are then excepted if the building is sprinklered. Therefore, standpipes are not required in most enclosed structures. Under SBC, there is no specific allowance for dry standpipes in parking structures where freezing might occur. However, paragraph 904.3.5 of SBC permits manual dry standpipes to be used where, in the opinion of the local official(s), a constant and automatic water supply is not necessary. The demonstrably low fire hazard of parking structures is usually considered adequate grounds to use dry standpipes.

UBC requires Class III standpipes, with hose, in unsprinklered buildings that are more than 150 ft. in height and class I and II **or** III standpipes unsprinklered buildings that are more than four stories but less than 150 ft. in height. Class I standpipes without hose are required in sprinklered buildings that are more than four stories. Open and enclosed structures that are less than four stories in height, but have more than 20,000 sq. ft. per floor must also have Class II standpipes with hose if unsprinklered. Where Class II standpipes may be subject to freezing, the building official may authorize the use of Class I standpipes in the locations required for Class II standpipes.

NFPA 101 does not require standpipes in open or enclosed structures, even though when they are required by other codes, they have to comply with NFPA 14.

5.4.3 Portable Fire Extinguishers

Portable fire extinguishers are normally required by reference to fire protection codes. IBC requires that the size and distribution of portable fire extinguishers comply with IFC. That code, in turn, says that occupancies involving flammable or combustible liquids of low hazard should have a maximum travel distance to a fire extinguisher of 30 ft. if type 5-B extinguishers are provided. If type 10-B extinguishers are provided the travel distance is increased to 50 ft. However, IFC also references NFPA 10. The other model codes also typically refer to NFPA 10. NFPA 10 says that if the Fire Marshall wants extinguishers, provide them wherever requested. We have found that most fire marshals don't particularly want civilians to attempt to put out vehicle fires with portable extinguishers. Also, portable extinguishers are routinely stolen from parking structures. Thus, where standpipes and/or sprinklers are provided, many local officials will waive the extinguisher requirement. Instead, as a compensatory action, a large capacity, wheeled extinguisher may be provided at an appropriate location, for use by the owner's trained staff, and extinguishers are also provided in occupied rooms and spaces.

5.4.4 Fire Alarms

Approved fire alarm systems and approved automatic smoke detection systems are not required in parking structures, either open or enclosed, (IBC 907.2) except as follows:

- where high rise requirements are triggered; fire alarms shall then be provided in accordance with IBC 907.2.12.
- where the lowest level of the structure is more than 60 ft. below the lowest level of exit discharge; a manual fire alarm system with emergency voice/alarm communications shall then be installed in accordance with NFPA 72. (IBC 907.20) However, where such an alarm system is **not** required, a public address system shall be provided that is capable of transmitting voice communications to the highest level of exit discharge and all levels below.

Note that under SBC, fire alarms are not required in any parking structure, whether open or enclosed. UBC requires fire alarms where there are more than 100 sprinkler heads. At first glance, BOCA does not appear to require fire alarms. However, an exception to Section 919.5 does require alarms when an automatic sprinkler system is required. Under NFPA, enclosed parking structures with a total floor area of more than 100,000 sq. ft. (or about 300 spaces) shall have a fire alarm system. Open structures do not need alarms.

Where required, manual fire alarm boxes shall be located not more than 5 ft. from the entrance to each exit. Additional fire alarm boxes shall be located so that the travel distance to the nearest box does not exceed 200 ft. The manual fire alarm boxes must be designed in compliance with Section 907.4. When required by other codes, the basic requirements for manual alarms are similar.

5.5 MEANS OF EGRESS

Means of egress, or routes for emergency exit, are critical issues in any building code. One has only to hear of a tragedy in which people died because fire exits were not provided, were improperly designed or were blocked, to understand why means of egress are important to designers and building code officials alike. The following sections discuss the various aspects of designing means of egress (hereinafter abbreviated MOE) in parking facilities.

Under IBC as well as the other major codes, the MOE is defined to include three distinct elements; the exit access, the exit and the exit discharge. This approach helps understand the requirements. The exit access is that portion of a MOE system between any occupied point in a building and the exit itself (that is a stair, ramp, or horizontal exit). (IBC 1003.1) It is extremely important to note that exit access includes any and all portions of a parking floor, including drive aisles that may be part of the path of travel from a parking space to an exit. A ramp with parking on it (hereinafter called a parking ramp) cannot be used as an exit, as will be discussed later in this section, but it is part of the exit access.

The exit discharge is the connection between the exit itself and the public way. Exit discharge includes the path of travel from the portal at the exterior of the building to the public way and includes yards and courts. Note that a horizontal exit is specifically an exit from one space into another space and is not an exit discharging to the exterior. (Also IBC 1002.1)

Where multiple occupancies exist, the means of egress requirements shall apply to each portion of the building based on the occupancy of that space. Where two or more occupancies use portions of the same egress system, those egress elements shall meet the most stringent requirements of all occupancies that it serves. (IBC 1003.2.1.2) For example, where there is occupied office space above an open parking structure, as otherwise allowed by the code, stairs serving both uses must be enclosed because enclosure is required by the office use. However, a stair serving only the parking levels would not have to be enclosed.

5.5.1 Minimum Number and Size of Exits

Typically, both open and enclosed parking structures shall have at least two MOE from every floor. Automobile ramps cannot be considered MOE, unless pedestrian facilities are provided. Although "pedestrian facilities" is not further defined, it is generally interpreted to be a sidewalk at top of a curb or delineated by bollards or other guards. SBC does not permit a vehicular ramp to be used even if it does have such pedestrian facilities.

The sole exception to the prohibition of the use of automobile ramps as an exit for MOE is that NFPA 101 allows a vehicular ramp to serve as the second exit for an open parking structure if it discharges **directly** to the street. The latter effectively limits the use of parking ramps for fire exits to one floor above the street. An express ramp that serves all floors could qualify. Also, under NFPA, if there is only one level below the level of exit discharge, a vehicular ramp discharging to the street can serve as the second exit from that space. However, to serve as an exit, the express ramp is subject to slope, landing and handrail requirements as discussed later in this section. Few designers will choose to use design an express ramp to those provisions, so most will choose to provide two exits.

Where no persons other than parking attendants are permitted, there shall not be less than two 3 ft. wide stairs; lifts may be installed for the use of employees only, provided they are completely enclosed by non-combustible materials. (IBC 406.3.8) Neither BOCA or SBC has this exemption. In mechanical structures qualifying as open, only one exit is required. (IBC 1005.2.1.1) SBC and UBC do not have this exemption. NFPA exempts mechanical and attendant-only structures from being considered as parking structures altogether. Although not totally clear, it is believed those structures default to the same provisions as other storage uses of ordinary hazard.

Elevators, escalators and moving walks are not permitted to be part of a MOE, except where an elevator is an accessible means of egress (AMOE) as discussed in the subsequent section on those requirements. (IBC 1003.2.9)

Although the details of different types of MOE components are discussed in more detail later in this chapter, it is useful to mention the minimum and maximum permissible widths of various exit components here, as it may impact upon the required number and location of exits. The minimum width of an exit stair is 44 in. (IBC 1003.3.3.1); this is denoted as a nominal width because handrails may project 3 ½ in. into this width and stringers and other trim may project 1 ½ in. Under NFPA and BOCA, a stair serving an occupancy load less than 50 people can be 36 in. wide.

However, as discussed later in this chapter, some stairs may now also have to meet requirements to serve as accessible means of egress. In order to facilitate evacuation of those in wheel chairs, the minimum width of an accessible means of egress is 48 in. clear between the handrails, which equates to as much as 55 in. of nominal width used for calculating the required width and occupant load.

The maximum permissible width of an exit stair is 60 in. between handrails, or about 67 in. nominal; over this dimension an intermediate handrail is required. (IBC 1003.3.3.11.2) Note that under SBC and UBC, the maximum nominal width is 88 in. Therefore the permissible width of stair between handrails under IBC has been reduced for those used to working under those two codes.

The minimum clear width of a door when fully open, where one is located in the path of travel to the exit, is 32 in. (IBC 1003.3.1.1) Over 48 in., two door leaves are required under all of the codes except BOCA and NFPA. The latter does require one of the doors to be at least 32 in.

The minimum width of a ramp under IBC 1003.3.4.4.1 is the same as that for corridors, or 44 in.; both corridors and ramps require 36 in. clear between handrails. UBC and BOCA also have 44 in. minimum if the occupant load served is over 50 persons and 36 in. if less than 50; the same also applies to corridors. There is no maximum width for corridors, as there is no handrail requirement. SBC does not have a minimum width for ramps, but requires 44 in. clear width in corridors (see table 1004 therein). All permit handrails to protrude into the specified width.

Under IBC, ramps are required to have handrails in accordance with the same requirements for stairs, and therefore, a ramp wider than 60 in. clear between handrails requires an intermediate handrail. (IBC 1003.3.3.11.2) This requirement could be a significant issue if a pedestrian bridge also serves as a horizontal exit and has to be ramped to meet floor elevations. The other codes do require handrails on both sides of ramps, but without any maximum clear distance apart.

In parking structures, there is commonly an aisle provided between parking spaces for access to stair and elevator towers when those elements project from the facade of the parking facility (sometimes referred to as "outboard" towers). The minimum width of an aisle serving as part of the exit access is 36 in. for Group B and M occupancies. No minimum width is given for other uses. (IBC and UBC) However, under UBC the minimum width of any exit access component is 24 in. If the aisle is also part of an accessible route, the minimum width is also 36 in. SBC mandates aisles to comply with the same standard as corridors or 44 in. BOCA only applies aisle width requirements to assembly uses; NFPA does not have any requirement for aisles in parking structures. Therefore the minimum width otherwise required for the occupant load using the aisle generally controls the width.

5.5.2 Occupant Loads and Required Exit Width

A key determinant in all MOE issues is the occupant load. To avoid excessive references to subsections, we will simply note the (IBC 1003.2.2.)

Both open and enclosed parking facilities have an occupant load of one person for every two hundred square feet (gross) under all of the building codes. NFPA does not give an occupant load for parking structures. In the absence of a definitive load, most local officials will accept one person for 200 sq. ft. as it is used in all of the other codes.

The required exit width is then calculated at 0.3 in. of width per person for stairs, and 0.2 in. of width for other components, if the building, such as an open parking structure, is not sprinklered. If the building is sprinklered, the required exit width of stairs is calculated at 0.2 in. per occupant and the required width of other egress components is calculated at 0.15 in. per occupant.

Where a space also provides egress for another space, the combination of the number of occupants for both spaces shall be employed. Where exits serve multiple floors, only the occupant load of each floor considered individually shall be used in computing the required capacity of exits at that floor, provided that the exit capacity is not decreased in the path of travel. That is, where floors have different footprints, the occupant load shall be based on the largest floor in terms of sq. ft.

Where means of egress from floors above and below converge at an intermediate level, the capacity of the means of egress from the point of convergence shall not be less than the sum of the two. For example, where exits from above-grade and below-grade levels converge and there is then a corridor to the exterior of the building, the occupant load for the corridor is the sum of the two.

Where mezzanines exist with egress through another floor or space, the occupant load of the mezzanine shall be added to that room or space's occupant load and the capacity of the total occupant load shall be used for design.

To develop a rule of thumb for conceptual design, it is useful to look at the required exit width per 100 parking spaces per floor. An open parking structure will require 45 in. to 52 in. of stair width for each 100 parking spaces per floor. The required aisle width is 30 to 39 in. per 100 parking spaces. As the minimum width (nominal) of exit stairs is 44 in. to 55 in., one standard exit stair will typically be required to meet the exit width requirements for each 100 parking spaces on the floor with the greatest number of parking spaces.

The required exit width should be roughly equally distributed among the exits to be provided. Where there are multiple means of egress, the loss of any one shall not reduce the available capacity by more than 50%. This effectively requires that where only two MOE are provided from a floor, each must accommodate at least half of the occupant load. If for example, one stair is intended to be significantly wider to serve as a primary entry to the facility for every day use, while another is purely an emergency exit, the latter has to be designed for at least 50% of the occupant load, even though the total width is more of the two is more than the minimum required.

Occasionally, there will be two different types of exits serving the same floor. For example, an open parking structure serving a shopping center may be designed with its floor elevations matching the mall levels. Pedestrian bridges connect each parking level to the mall, which can be considered as horizontal exits if properly designed. If there is 100,000 sq. ft. on the largest parking floor, the occupant load is thus 100,000 sq. ft./200 sq. ft./person, or 500 persons. If only stairs provide exiting, 150 in. exit width is required. Three exits of about 50 in. width would usually be provided. However, two stairs at say 48 in. width plus one horizontal exit would also meet the requirements. The required width of the horizontal exit is then calculated as follows:

2 @ 48 in. stairs provides exiting for 2 x 48 in./0.3 = 320 persons

Therefore the horizontal exit would have to serve:

500-320 = 180 persons

which in turn requires:

180 persons x 0.2 in./person = 36 in. of width at the horizontal exit.

The pedestrian bridge is likely to be much wider than for normal purposes. Using the information in Chapter 3, a parking structure serving a shopping center may have up to 45% of the parking capacity arriving and departing in the same hour. This floor has 325 spaces; and it can be presumed that all parkers use the bridge connection direct to the mall. The required width of the bridge to provide LOS A is as follows:

V = 45% x 325 spaces = 146 vph

v = 146 vph/0.85 peak hour factor = 172 vph flow rate

At 2.5 persons per car, 430 persons per hour are expected to cross the bridge in each direction in the peak hour. According to Table 3-13, a LOS A bridge operates at 420 pph per ft. of width; thus 1.02 ft. of width, or about 12 in. is required for the traffic moving in one direction. Remember that these calculations are based on an effective width. Eighteen inches additional width must be provided to walls or other limiting elements. Therefore the required width of the bridge to maintain LOS A under normal operating conditions is:

18 in. + 12 in. + 12 in. + 18 in. = 60 in.

Given that the bridge is going to be this wide, another option is only two exits. The bridge at 60 in. in width serves 60/0.2 = 300 people as a horizontal exit. The stair would then have to handle only 200 people; however, this is less than half of the total load, so the stair must be designed to handle at least 250 people, which then requires an exit width of 250 x 0.3

= 75 in. width. Note that this stair would have to have an intermediate handrail as it will exceed 60 in. clear between the outside handrails.

This example also shows the type of occupant load that the various building codes use for exiting from parking facilities. Clearly, 200 sq. ft. per occupant is designed to model the presence (and capability of exiting in the event of a fire) of pedestrians associated with every single car parked on a floor, which will rarely, if ever, occur.

The only type of use where the occupant load for parking structures might be considered low is parking serving special event facilities. If 85% of the capacity of a special event facility tries to exit in 30 minutes, the flow rate of a floor with 325 spaces is 325 x 0.85 = 276 vehicles. At 2.5 persons per car, the equivalent pedestrian flow is 691 persons in 30 minutes or 115 persons per 5 minutes. Therefore, the occupant load is still conservative. Of course, if the structure or the street network can't handle the vehicular flow, and all 276 vehicles were backed up and sitting on the floor waiting to get out, the equivalent pedestrian volume to be evacuated in an emergency is 690 persons, or 38% higher than the required occupant load under the building code.

It is better to design the parking structure to allow vehicular exits without such back-ups, but sometimes it is not possible to control the circumstances. Following the celebration of America's Bicentennial in Philadelphia in 1976, the streets were so backed up that it took more than an hour for any cars to be able to exit from the parking facilities nearest to the Liberty Mall. At one underground parking facility, the vehicles sitting in the aisles, motors running, overwhelmed the mechanical ventilation system and people started to be affected by carbon monoxide poisoning, requiring an emergency evacuation. The problem reportedly didn't happen at better ventilated and/or open structures but it did happen at this particular structure. Given that ventilation requirements in today's codes are ??? higher than in the past, the code required occupant looks are reasonable for truthfully all circumstances.

5.5.3 Exit Access

A significant concern with the language that has evolved in IBC from combining bits and pieces of the other codes is the treatment of parking floors as part of the exit access. NFPA first developed the approach separating means of egress into the three components of exit access, exit, and exit discharge in 1956.[23] In most other codes, however, there was an exit (a continuous unobstructed means of egress to a public way) and a travel distance to it. All of the codes specifically stated that sloped parking floors could not serve as the exit. Therefore, design requirements, such as slope limits, for exits did not apply to parking floors.

Over time, more and more focus was placed on details of the exit access beyond simply the travel distance and width. Also, the code groups have made a conscious effort to "mainstream" accessibility and have adopted similar design criteria for such elements as floor slopes, even though the element is not otherwise required to be an accessible element. This evolution was not noticed by the parking industry. Today, many parking designers continue to think of means of egress requirements a simply an exit and a maximum travel distance to it.

The code groups intend the provisions of exit access to apply to parking floors. They probably did not realize all of the implications of applying accessible ramp criteria to parking floors, but they **intend** to apply criteria to them. The most recent versions of all of the relevant codes require that the slopes of parking floors conform to the requirements of exit ramps when they exceed a 1:20 slope, or 5.0%. This is a significant concern because slopes between 5.0% and 6.5 % are regularly used on parking ramps; indeed a slope of 5% is considered LOS A in Chapter 3 of this text. Admittedly, few local officials have attempted to enforce the code in this way, and therefore most parking designers remain blissfully unaware of the requirement to design parking floors as part of the exit access system.

UBC 97 section 1003.3.4.1 requires that "ramps" used in a means of egress system—which by definition includes exit access—must comply with the requirements in section 1003.3.4. Under section 1003.3.4, a "ramp" with a floor slope over 1:20 (5.0%) has to have a 5 ft. long landing for every 5 ft. of rise. If a parking structure has 10 ft. floor-to-floor height, this requirement can probably be met with intermediate landings halfway up the ramp that may coincide with a center cross-over. However, with more than 10 ft. floor-to-floor height, two landings are required. Handrails are required at "both sides" of ramps over 1:20 slope. Guardrails are naturally provided at the edge of sloping parking bays, but technically the design would have to have a continuous, grippable, handrail that a person could use for guidance and/or support. How this handrail would be useful for anyone when cars are parked adjacent to the guardrail is certainly a viable question, and one of the reasons the parking industry needs to get special exceptions for parking facilities from these requirements in the next cycle of official code changes. Prior to the 97 edition, UBC only required ramps to be designed with landings and handrails if the slope exceeded 1:15 or 6.67%, which is a slope exceeding that classified as LOS D, and therefore rarely if ever used. Even if a local official had checked the slope, the design would not have triggered ramp design requirements. UBC has a maximum slope of 1:12 (8.3%) if the component is part of an accessible route, or 1:8 (12.5%) if not. Technically therefore, express ramps with slopes up to 1:8 and with landings and handrails could be considered part of the exit access from a portion of the floor. Practically speaking however, no one would choose to provide the landings or handrails and therefore, only speed ramps rising 5 ft. or less would be used as part of the path of travel to an exit.

BOCA and SBC may not be quite so black and white regarding application to parking floors; there are ways to "parse words" in specific places to argue that ramp criteria should not apply. However, both codes say that ramps used as a component in a means of egress system must be designed to meet the requirements therein. Any other requirement that might otherwise be cited is intended to specifically require ramps, rather than stairs, in certain cases. For example, in the first sentence in the section on ramps (1013.1, General), SBC says that changes in elevation 12 in. or less in "exit access corridors, exits and exit outlets" shall be designed as ramps. The purpose of this sentence is to require that ramps, not stairs, be provided where changes in elevation are relatively small. The next sentence is more general, stating that ramps in means of egress shall be designed per that section. Both BOCA and SBC's published Commentary emphatically state that all ramps, whether required or otherwise provided, must comply.

Technically, BOCA requires landings in all ramps, but doesn't define ramp; theoretically, it could require landings in ramps of 2% slope. The Commentary, however, states that 5.0% is the intended trigger. Under BOCA section 1016.0, a ramp used in a means of egress system has to have 5 ft. landings for every 30 inches in rise, which is significantly more difficult to provide in parking facilities than UBC's requirement. A 10 ft. floor-to-floor height will require three landings; up to 12'-6" will require four. After the landings are put in, there is not much benefit to designing the parking ramp over 5.0%. For example, with a 10 ft. floor-to-floor height and 5.5% ramp slope, the run without landings is 181'-10"; with three 5 foot landings added, the run is 196'-10", only three feet less than if 5.0% slope without landings had been employed. It will be difficult to frame 5 ft. long landings without extending them the full width between columns (20 ft. or more), and the floor will have a washboard effect. Handrails are required by BOCA only at the edge of the ramps; there is no cross-reference to a section that requires intermediate handrails.

SBC's requirements are essentially identical to BOCA's; again they don't have a minimum slope trigger for providing landings. They do use the trigger of 1:20 or 5.0% for providing handrails and therefore most consider the landings only to be required above that slope. NFPA's requirements are also similar to BOCA and SBC. In the ramp section, there is an exception for "ramps providing access to vehicles...." However, the intent of this exception, based on the initial submittal to NFPA requesting that the exception be added to the code, is ramps providing pedestrian access to transportation vehicles, such as boarding ramps for airplanes or cruise ships.

IBC goes a step even further and uses the ADAAG/ANSI definition of "ramp" as **any floor surface** with a slope over 1:20, anywhere, period. A ramp has to have landings for every 30 inches in rise **and** handrails must be provided no more than 30 in. from any point on the ramp, which effectively requires handrails at 60 in. on center. This requirement then effectively prohibits the use of parking floor slopes over 5.0%.

According to experienced code consultants, a request to any of the code groups for an interpretation of the applicability of ramps would yield an opinion that they do apply. However, it is also believed that the code groups did not contemplate this application. Because the intent is to ensure accessibility, it is believed that the code groups would give an appropriate exception applying special design criteria to parking facilities, in light of the fact that special accommodations are given to the disabled via parking spaces with an accessible path of travel to the exits.

It is therefore the intent of the parking industry to request an exception in IBC that parking floors sloping between 5.0% and 6.7% not be subject to the requirements for ramps at least as regards handrails and landings. Also, an exception will be requested providing that vehicular ramps not used for parking or normal pedestrian occupancy are exempted from exit access requirements. In the interim, the issue should be discussed with local officials early in the design process and a specific waiver of the handrail and landing requirements should be requested, on the basis that disabled parking is provided with accessible routes not employing sloped parking ramps.

5.5.4 Travel Distance

At least two of the exits shall be placed a distance apart equal to not less than one half the length of the maximum overall diagonal dimension of the area served, measured in a straight line between the center of the exits or the exit doorways. (See Figure 5-9) Additional exits where required should be arranged a reasonable distance apart.

In IBC, the maximum travel distances to an exit for both open and enclosed parking facilities are 300 ft. in non-sprinklered facilities but increase to 400 ft. if the facility is equipped with an automatic sprinkler system throughout. This requirement apparently came from BOCA and SBC. BOCA has the same distances for enclosed structures. SBC has 200 ft. for enclosed non-sprinklered structures and 250 for enclosed sprinklered ones. NFPA 101 has the same travel distances for open structures, but reduces the distance to 150 ft. in non-sprinklered enclosed structures and

200 ft. for enclosed parking structures with sprinklers. Conversely, a non-sprinklered parking structure with 50% open on all four sides may have the travel distance increased to 400 ft. under NFPA. UBC has 300 ft. for open structures, 200 ft. for enclosed non-sprinklered structures and 250 for enclosed sprinklered ones.

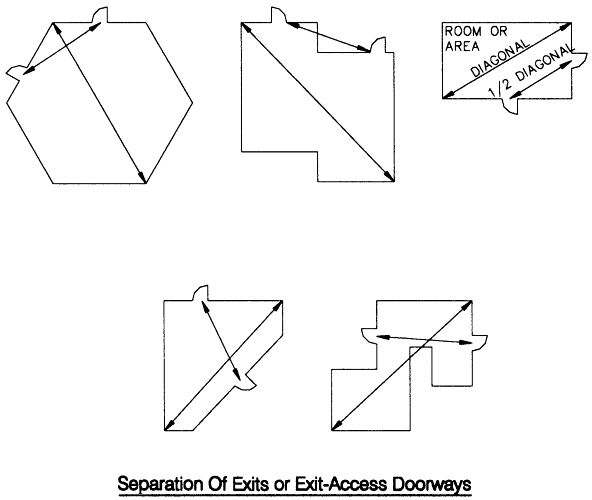


Figure 5-9. Exits must be located a minimum distance apart. Source: UBC Handbook.

Local officials, in the absence of full understanding of the risk of fires in parking structures, have a tendency to believe that these distances are too great. Local officials may obtain significant modifications to the requirements of the national codes. For example, the South Florida Building Code reduces travel distances in an unsprinklered facility to 100 ft., with sprinklered facilities allowed only 150 ft. Therefore, it is important to check the local building code amendments early in the design process, rather than relying on a knowledge that the adopted code is one of the national model codes.

Travel distance must be measured on a straight line along the "natural and unobstructed" path of exit travel. NFPA requires it to be along the center of the path, curving around corners and obstructions; which in parking structures is usually the drive aisle; this requirement would tend to slightly increase the walking distance if enforced. All codes technically require that the actual travel distance be used for sloped surfaces (i.e., the hypotenuse of the triangle formed by the rise and run of the slope.) With a parking ramp sloped at 5% and a floor-to-floor height of 10 ft., calculating along the hypotenuse adds about 3 in. to the run of 200 ft., which is certainly negligible. The maximum slope of a ramp serving as an exit access is 1:8 (or 12.5%) under UBC. With landings for every 30 in. of rise and the same 10 ft. floor-to-floor height, the run is 98 ft.; calculating parallel to the ramp adds less than 8 in. or still less than 1%.

Where NFPA is enforced, open stairs are not permitted by right; however, an open stair can be considered part of the exit access rather than the exit itself; the path of travel down the stair is then included in the exit distance. This approach may considerably increase the required number of exit stairs. Where an open stair is to be considered part of the exit access (the path of travel to the exit), the measurement along stairways shall be made on a plane tangent to the stair tread nosings in the center of the stairway. (See Figure 5-10)

Required access to exits shall not be through any intervening space or rooms except through corridors providing direct access to the stair, or foyers, lobbies and reception rooms. For example, the exit path to a stair can be through an enclosed elevator lobby, should one be provided. Under all of the codes except NFPA, such a stair can be open to the elevator lobby and a fire rated separation between the parking and elevator lobby or stair is not required. Interior courts that are enclosed on all sides are considered interior intervening rooms, unless they are 10 ft. or more in width and provide direct access to a public way.

In smaller structures of up to approximately 55,000 sq. ft. per floor or less than about 200 parking spaces per floor, with stairs located at both ends, the requirement for two means of egress will likely determine the required number of exits and only the minimum width at each will be required. The capacity of the means of egress shall be approximately equally distributed to the individual exits.

In moderately sized structures, travel distance is likely to be a controlling factor, particularly when the preferred stair locations are not in diagonally opposite corners and the path of travel must follow sloping parking floors. It should be noted that UBC requires at least three means of egress where the occupant load exceeds 500 persons; this occurs at 100,000 sq. ft. per floor. A parking structure with that foot print will almost always require more than three exits by travel distance in any event.

In mega-structures with more than about 150,000 sq. ft. per floor, occupant load will begin to play more of a factor. Up to that point, stairs can usually be widened to provide the required capacity while meeting the travel distances. However, because stairs wider than 60 in. nominal width require an intermediate handrail, and become significantly more difficult to frame and construct, designers may choose to provide more "standard" stairs rather than fewer wide ones. For example, in a structure of 150,000 sq. ft. per floor, the occupant load is 750 persons which in turn requires 225 in. of exit stair width; three stairs at 6'-3" in width could be provided, four at 4'-8" or five at 3'-9". Three well-placed stairs may be able to meet the travel distances, but four would really be a better solution for a floor plate this large. UBC specifically requires four exits when the occupant load exceeds 1000 persons, which occurs at 200,000 sq. ft. per floor.

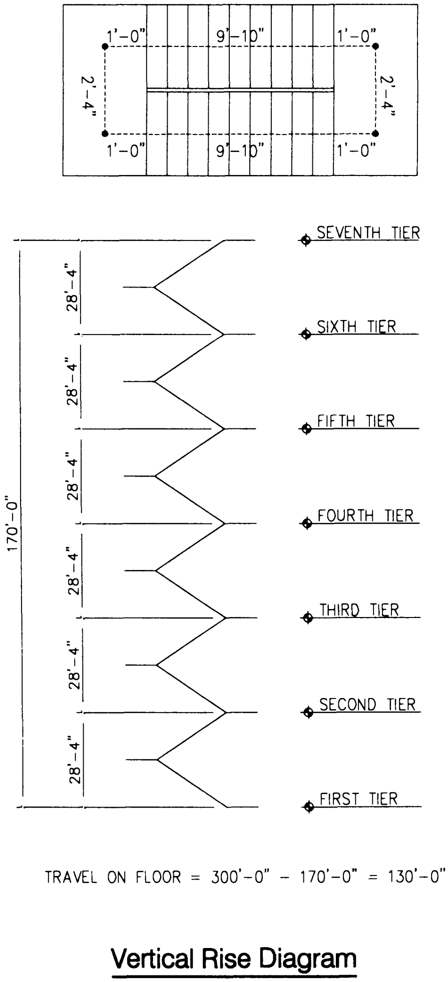


Figure 5-10. Under NFPA 101, including the path of travel down the stairs in the required travel distance may allow the stairs to be constructed unenclosed.

5.5.5 Exit Stairs

While not going into all the required details that an architect might require for complete design of exit stairs, a few are important to initial planning. For example, it is important that the enclosure of a stair not reduce the driving aisle to narrower than required for the turning movement in to the stalls opposite the stair. Where areas of refuge are required, a stair enclosure can become significantly longer than can be accommodated in the depth of a parking stall.

This problem can require that a stair be rotated so that the run is parallel to a drive aisle, which in turn can cause a loss of parking spaces. Technically, this orientation means the length of the stair enclosure cannot exceed the vehicle projection. See Figure 5-11.

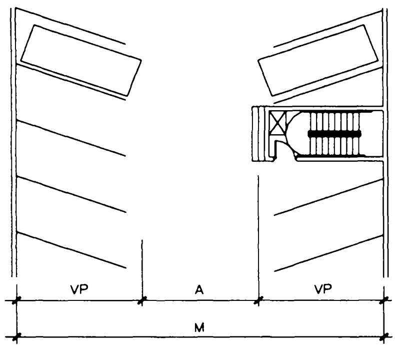


Figure 5-11. Stair and elevator enclosures should not encroach into driving aisles.

Stair treads shall be 11 in. wide minimum and risers shall be no less than 4 in. and no more than 7 in. high. A flight of stairs shall not have a vertical rise greater than 12 ft. Note that an economical way to design an open exit stair in a precast parking structure is to use one continuous run, floor-to-floor, through a cut-out between the tee stems. However, this option is limited to floor-to-floor heights of 12 ft. or less. (See Figure 5-12)

Enclosure of exit stairs is not required in open parking structures under IBC, UBC and BOCA. Under SBC, enclosure is not required in open parking structures having all sides open, or where the stair is located on an open side. Under NFPA, stairs are required to be enclosed in both open and enclosed structures unless the **entire** facility is sprinklered. Again, however, a stair can be open under NFPA if it is treated as part of the exit access and not as the exit itself. The path of travel down the stair is then included in the overall travel distance otherwise permitted. Also, some local fire officials have been willing to waive the enclosure of stairs in settings where the risk of violent crime is relatively high, on the basis of the provision that a requirement can be modified if "its application would be hazardous under normal occupancy conditions in the judgement of the authority having jurisdiction." (NFPA 101 Section 4.6.1.3).

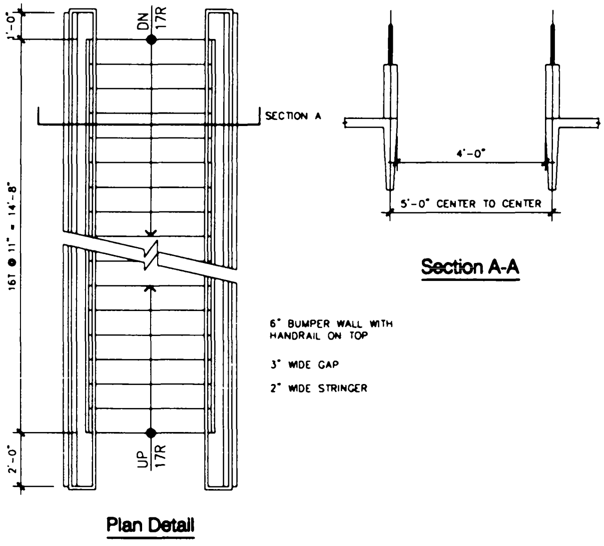


Figure 5-12. A continuous, open stair placed between tee stems is an economical design solution for precast parking structures

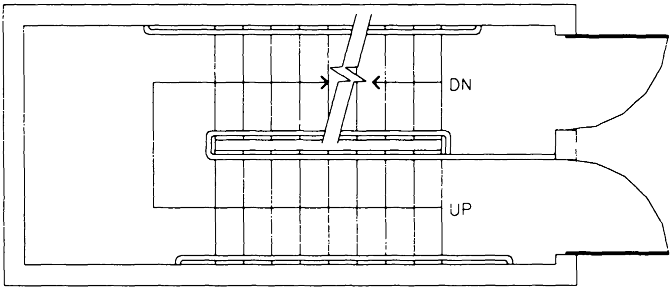
In enclosed structures, most stairs are required to be enclosed. An exception is exterior exit stairways where the stair is exterior to and separated from the building. This might occur where NFPA is enforced, or where a parking structure that is above-grade cannot qualify under UBC as open because of mixed uses, and the local building official declines to waive the requirement for stair enclosures entirely. These stairs may have sides open where the side faces yards, courts and public ways, if the building does not exceed 5 stories or 75 ft. in height. The separation between the stair and the building must be at least 2 hours for buildings with four stories or more and at least 1 hour with less than four stories. The separation must extend for at least 10 ft. past the stair, either on the sides of the stair, or the face of the building.

Enclosed stairs on the exterior of a structure may still have unprotected openings, such as either open sides or extensive glass walls for passive security, if they meet the requirements for distance from the property line, whether or not they otherwise qualify as exterior stairs. However, the same provisions for extension of the required fire separation beyond the end of the stair apply. The fire separation required between the stair and the parking floor shall also extend at least 10 ft. above the topmost landing of the stair or the adjacent roof.

For security reasons, it is common to close off the spaces beneath the last flight to grade because it may afford a hiding place for those of criminal intent, and/or sleeping areas for the homeless. When enclosed and the space is considered usable, the walls and soffit shall be fire rated as required for the enclosure. Space under exterior stairs shall not be used for any purpose, whether enclosed or not.

A stairway in an exit enclosure shall not continue below the level of exit discharge unless an approved barrier is provided to prevent persons from unintentionally continuing into levels below. See Figure 5-13.

Note that IBC requires stairway floor numbering signs with specific information as described in 1005.3.2.4.



Stair Barrier

Figure 5-13. A barrier is required to prevent persons from unintentionally continuing below the level of exit discharge in an enclosed stair

5.5.6 Accessible Means of Egress

One of the benefits of IBC and ADAAG 2000 is that the requirements for accessible means of egress have been coordinated; both comply with ICC/ANSI 117.1-1998.

Accessible spaces shall be provided with not less than one accessible means of egress; where more than one means of egress is required from a space, at least two accessible means of egress are required. Note that accessible means of egress are not required in alterations to existing buildings under IBC, but may be required under ADAAG. See Chapter 10 of this text.

An accessible means of egress can include accessible routes; stairways complying with certain requirements; elevators complying with certain requirements and horizontal exits or smoke barriers.

Where a building has four or more stories above or below the level of exit discharge, at least one required accessible means of egress **shall** be an elevator, unless the entire building is sprinklered **and** the floor being served has either a horizontal exit or an accessible ramp. An elevator serving as an accessible means of egress, whether required by the number of stories, or voluntarily, must be provided with standby emergency power and emergency operation and signaling devices so that it can be used for evacuation purposes. The elevator shall be accessed from either an area of refuge or a horizontal exit, except in open parking structures or buildings equipped throughout with automatic sprinkler system, as defined by the code. Therefore, all parking structures (whether open or enclosed) with four or more stories will have to at least one elevator with the required emergency power/operation/signaling provisions but most will not have to have the area of refuge connected thereto.

Although neither an accessibility nor a means of egress requirement, note that IBC, UBC and SBC require that buildings with four or more stories must have at least one elevator sized to accommodate a 24 in. by 76 in. stretcher in the horizontal, open position. That elevator shall be marked with the international symbol for emergency medical services (the star of life.) BOCA and NFPA do not have this provision, but many jurisdictions have adopted a similar requirement by local ordinance. Although the cab sizes of "standard" elevators with 3000 lb. or more capacity are technically large enough to hold a stretcher, they need to have the door on the short side of the cab rather than the long one as provided with standard elevators. However, they are a lot more space-efficient than a "hospital" elevator, the smallest of which is usually 4000 lb. If larger capacity is not required for other reason, a 3000 lb. elevator with a side door is usually provided.

When a stair is part of an accessible means of egress, it must be enclosed and have a clear width of 48 in. between handrails **and** have an area of refuge or connect to a horizontal exit. Under IBC and ADAAG 2000, stairways in open parking structures or buildings equipped throughout with automatic sprinkler system, e.g., enclosed structures, as defined by the code, are exempt from **both** requirements. However, the wording in UBC, BOCA and SBC is slightly different regarding open parking structures. They exempt open parking structures from the requirement for areas of refuge but not specifically from the 48 in. clear width requirement. Therefore, stairs required to be AMOE, but which are open and don't have areas of refuge still must have 48 in. clear stairs under BOCA, SBC and UBC.

NFPA does not exempt open parking structures from requirements for areas of refuge, although many local officials will grant waivers on the basis that all of the other relevant codes do. NFPA only requires stairs serving an area of refuge to be 48 in. clear between the handrails.

When areas of refuge are required, they must be provided at the same travel distances as that permitted for the occupancy. One area of refuge 30 in. by 48 in. shall be provided for each 200 occupants or portion thereof. Therefore, as parking structures have one occupant for every 200 sq. ft., there must be one area of refuge for every 40,000 sq. ft. of parking floor where NFPA or other local requirements insist on areas of refuge. Therefore, while every stair may not need to be an accessible means of egress based on the minimum number of AMOEs required, each and every stair may need to be an AMOE to meet the travel distance to an area of refuge and/or the required minimum number thereof. Each area of refuge must connect to a stair, elevator or horizontal exit meeting the requirements for an AMOE. Note that the requirements for area of refuge for horizontal exits are different from those serving stairs. When an elevator lobby is used as the area of refuge, the shaft and lobby shall be smokeproof enclosures, unless it also has a horizontal exit or smoke barrier.

Where an area of refuge is required, it must have two–way communication system from the area of refuge to a central control point approved by the fire department. If that control point is not constantly monitored, there shall also be a public telephone system accessible from the area of refuge. The two-way communication system shall include both audio and visual signals. Instructions and identification requirements are also covered in all of these model codes, although not further discussed here.

5.5.7 Horizontal Exits

A horizontal exit is a connection between two spaces or uses that is sufficiently protected to be considered an exit from one space into the other. It is not simply an exit to the exterior not requiring a stair. As previously discussed, pedestrian bridges connecting a parking structure to an adjacent building can be horizontal exits from either. Another common application is where a building only has two stories, a horizontal exit may be more feasible than a stair. For example, the large exiting requirements of assembly spaces can sometimes best be accommodated by some combination of horizontal exits and stairs, rather than stairs alone. Therefore, a horizontal exit from a movie theatre has been provided into an adjacent parking structure. Horizontal exits, however, shall not be the only exit from a building and shall not comprise more than half of the total exit width or number of exits required from a building.

Where a horizontal exit is provided, merely going into the other space is considered as the exit, and the other space does not have to have enlarged exits to accommodate both its own load and that of the space exiting into it. The use on the receiving side shall have enough other exits to accommodate its own needs, unless the horizontal exit is intended to go both ways. The separation between the two buildings or spaces at a horizontal exit shall be two hours with doors being self-closing or automatic and consistent with the required fire rating. Doors must open in the direction of egress.

NFPA requires that the floor area on either side of a horizontal exit shall be sufficient to hold the occupants of both areas, providing at least 3 sq. ft. of clear floor area per person. Where a horizontal exit has discharged into a parking facility, local officials have usually required a defined holding pen that is separate from vehicular drive areas.

5.5.8 Ramps

Where a ramp is part of a means of egress, it shall have a running slope not greater than 1:12 (8.33%). Maximum cross slope is 1:48 (2.08%) Ramps that are part of the access through a space to a means of egress (rather than part of the exit itself) shall have a slope not steeper than 1:8 or 12.5%; however, those ramps cannot be part of an accessible route. As previously discussed, the definition of a ramp in IBC is any path of travel that has a floor slope exceeding 1:20, or 5.0%. Parking ramps with floor slopes exceeding 5% are allowed to be part of the path of travel to an exit, but the need for landings for each 30 in. rise then kicks in. The real problem, however, is that the handrail requirements under IBC require intermediate handrails at 60 in. spacing. It is then impossible to use the ramp for vehicular travel. One accommodation of the requirement is to use 5.0% maximum ramp slopes for the main parking slopes and make up any shortfall with speed ramps at the ends. Most other details for exit ramps are identical to those for ramps that are part of an accessible route.

5.5.9 Exit Discharge

A means of egress shall exit directly to the exterior at grade or with direct access to grade. A maximum of 50% of the number and capacity of exit enclosures are permitted to egress through areas of the level of discharge, provided:

- the path of travel is free and unobstructed and readily apparent;
- the entire path of travel across the area is enclosed and separated as required for the enclosure of the stair or other exit component; **and,**
- the entire level of discharge is protected throughout by an automatic sprinkler system.

The issue of discharging through the level of exit discharge sometimes becomes an issue where the exit distance on large footprint floors requires interior stairs. The normal interpretation for open parking structures is that up to half of the required exiting (both in number and width) can be via interior stairs and can simply discharge into parking areas because no enclosure of the stairs and no sprinklers are required. UBC's Handbook specifically notes that "...the fire hazard is so low in open parking structures that the code assumes that once an individual has exited the fire floor, he or she has reached a point of safety equivalent to an enclosed stairway." By extension then, enclosure of the exit discharge is also not required.

However, some local officials will not interpret it this way and will not allow parking structures to have interior stairs unless there are enclosed corridors extending to the exterior. Providing a corridor is obviously very difficult to do where there is parking at the level of exit discharge.

In enclosed structures, an enclosed connection is required to the exterior but it is usually waived due to the provision of sprinklers. Because NFPA requires exit stairs to be enclosed in both open and enclosed structures, a waiver of the NFPA requirement to enclose the path of travel to the exterior usually has to be obtained from the local official, unless the path of travel from the base of the stair to the exterior is also considered to be part of the exit access rather than exit discharge, under the provision allowing open stairs. More open stairs may be required, but they would definitely be worth the elimination of an enclosed corridor through parking areas.

5.6 VENTILATION

Under all of the codes, open parking structures do not need mechanical ventilation. For enclosed structures, IBC and BOCA both reference the *International Mechanical Code* (IMC) requirements. IMC section 403.5 requires ventilation at a rate of 1.5 cfm per sq. ft. of floor area. The automatic operation shall not reduce the ventilation rate below 5 cfm per person. With the occupant factor of 200 sq. ft. per person, the low setting is 5 cfm/200 sq. ft. or about 0.025 cfm/sq. ft., slightly less than 10% of the full capacity required. IMC, however, has a special exception to continuous operation for parking structures. The ventilation system is not required to operate continuously if it is designed to operate automatically upon detection of a concentration of carbon monoxide of 25 parts per million by approved automatic devices. The intake openings shall be located a minimum of 10 feet away from any hazardous and noxious contaminants including streets, alleys and loading docks. Often the intake is extended to 10 ft. above the roof. Exhaust air may not be directed onto walkways.

Normally, these systems are controlled by automatic carbon monoxide (CO) monitors that activate the ventilation system when the level of CO reaches a predefined threshold and automatically deactivate the system when the level of CO detected drops below a lower threshold. Prior to about 1993, the systems often were designed to activate at 35 ppm and deactivate at 25 ppm. In 1993, BOCA adopted the 25 ppm "on" trigger. Because setting the "on" and "off" triggers at the same concentration will be hard on the equipment, one would normally set the "on" trigger to 25 ppm and the "off" trigger to a lower concentration. However, the CO sensor equipment is not very accurate at levels below 25 ppm that one might otherwise select for shut-off, such as 15 ppm. Therefore, shut-off is usually set to occur when the CO level remains below 25 ppm for five minutes. An alarm is also programmed at 100 ppm, which, while rare, would signal that the ventilation system has been overwhelmed.

SBC requires six air changes per hour, but by reference to a requirement for mechanical ventilation for repair structures, further requires that there be **positive** means of both inlet and exhaust of at least 0.75 cfm per sq. ft. of floor area. UBC requires a minimum of 1.5 cfm/sq. ft. of gross floor area, with an alternative means being 1400 cfm/ operating vehicle. The latter is based on the instantaneous movement rate of vehicles but not less than 2.5% of capacity. Under UBC, parking structures, whether open or enclosed, are exempted from the mechanical ventilation requirements if they have the openness to qualify as an open structure. This exception allows structures that are open, but have been classified as enclosed due to mixed uses to not have mechanical ventilation.

NFPA 101 does not address ventilation, but NFPA 88A requires a system that provides 1.0 cfm per sq. ft. per hour during hours of normal operation.

UBC also requires that offices and cashier booths as otherwise permitted inside enclosed structures have a source of fresh air intake under positive pressure. Recently, this provision has been required by local officials in a parking structure that has the required openness, but is classified as enclosed for mixed use reasons, on the basis that only the mechanical ventilation, not the positive source of fresh air supply, is excepted for open structures. This specific provision is not present in the *International Mechanical Code*, which is referenced by IBC and BOCA.

5.7 SANITATION

Under IBC, plumbing fixtures shall be provided in storage occupancies, such as parking structures, on the following basis:

Water closets: 1 per 100 occupants
Lavatories: 1 per 100 occupants
Bathtubs/showers: not required
Drinking fountains: 1 per 1000
Service sinks: 1

Separate facilities for each sex are not required in occupancies in which 15 or less people are employed; most parking facilities will so qualify. IBC specifically states that restrooms for employees are not required in a kiosk, which can be inferred to include cashier booths, but may be in an adjacent building if the path of travel to the restroom from the work area is less than 500 ft. Given the occupant load of one per 200 sq. ft., the water closet and lavatory requirements correspond to one pair (toilet and sink) of fixtures for each 20,000 sq. ft. of area on a floor, or roughly one pair of fixtures for each 50 to 65 parking spaces **per floor**. This is an absurdly high number for a parking structure.

Although the plumbing fixtures are technically required, they can be provided for employees only; customer facilities are not required for storage occupancies. Indeed, as discussed in the chapter on security, it is strongly recommended that customer/patron restrooms not be provided in parking structures, but rather should be provided at the destination served. Due to relatively low use, public restrooms can be locations for violent crime.

BOCA 99 references the International Plumbing Code, which has the above requirements. UBC 97 requires essentially one water closet and lavatory in every parking facility; separate facilities by sex are required where there are more than 4 employees. An appendix table in UBC provides an alternative means of calculating the required number of fixtures; but this table applies only where the local entity adopts the Appendix. This table requires calculation based on occupant load, with one occupant is calculated for every 5,000 sq. ft., and one male and one female water closet per every 10 occupants. Therefore, two sets of fixtures are required for every 50,000 sq. ft. or for every 125 to 160 parking spaces, or about 25% less than IBC.

Local officials will usually waive the requirements based on documentation of the maximum number of employees present at any one time and the clear intent of the code not to require public restrooms in parking facilities. However, the codes do require at least one employee restroom in most facilities, unless there are facilities located in adjacent buildings which are within 500 ft. of the work area of the employee, i.e., a cashier booth.

5.8 GUARDRAILS AND VEHICULAR BARRIERS

The IBC requirements regarding pedestrian guardrails are closest to those in NFPA Section 5.2.2.4; UBC's requirements BOCA and SBC's are similar to those in IBC except where noted otherwise herein.

Pedestrian guardrails shall be provided in parking structures, both open and enclosed, where the vertical distance to the ground or surface at the change in grade exceeds 30 inches under IBC section 1003.2.12. (Note: an apparently typographical error in IBC references 1003.13, a section that does not exist.) SBC requires pedestrian guards in parking structures when the difference in elevation is more than 3 ft.; however, section 1015.1 requires them at all openings in floors and roofs where the difference is more than 30 inches.

BOCA 99 section 406.5 for open parking structures requires guards at all open-sided floor areas, without any specific height differential; the same section does have a specific exception that guards are not required for mechanical structures on the side open to the hoistway. BOCA 408.3.2 does not have a similar requirement for guards in enclosed structures, except where there is parking on the roof. It is clearly not the intent however, to not require guards in enclosed structures. As all parts of the parking areas (whether open or enclosed structures) are exit access components as previously discussed, they are required to have guards at open sides where the change in elevation is more than 15 ½ in. by section 1005.5 of BOCA.

Guardrails in parking structures shall be at least 42 in. in height under all of the codes. BOCA 99 allows that where the difference in grade is less than 30 in., the guard need only be 36 in. high, but it is the only code to require guards at a lesser difference in floor elevation.

Guardrails for most occupancies are required to be such that a 4 in. diameter sphere shall not pass through any openings up to a height 34 in. above the floor; an 8 in. sphere is employed for the space from 34 in. to 42 in. Note that this requirement comes from NFPA, but is a significant change from almost every other recent code's requirement. It recognizes that while tight spacing of intermediate members is appropriate in the lower portion of the guardrail, it is not necessary to extend it to the 42 in. guard height. This change will give substantially more freedom to the design of exterior precast panels, which may be held to a height of say 34 in. with a thin rail at the required guard height. Under the other codes, two rails would be required, even though it was questionable that a toddler could get to or fall through the 8 in. space just below the top handrail.

Technically, IBC, as well as NFPA, has an exception that allows in Storage uses (which would include open and enclosed parking structures) as well as factories, high hazard and secured detention/penal facilities, to employ a 21 in. sphere rather than the 4 in./8 in. ones otherwise required. However, this may simply be an oversight; given the more likely presence of youngsters in public parking facilities as compared to other S uses, it is strongly recommended that the design standard for other uses be followed. BOCA 99 and UBC 97 both still have the 4 in. requirement to the top of the guardrail, but has similar exceptions to the openings limitation as IBC, except that BOCA specifically states that parking structures and open parking structures shall use the 4 in. standard. UBC allows a 12 in. sphere to be used in storage uses, but only in areas not accessible to the public.

In recent years, there has been controversy over BOCA's adoption of language prohibiting a ladder effect in guardrail design. It is **not** present in UBC 97, IBC, NFPA 101 or SBC. The purpose of this requirement is to discourage youngsters from attempting to climb a handrail or guardrail and accidentally fall over it. The problem is that the interpretations of ladder effect have varied widely.

- Does it have to begin close to the floor?
- Is a single top handrail with a 4 in. space open below to the top of a precast panel a ladder effect?
- What about two horizontal rails over a panel?

- Does angling horizontal rails in such a way as to make it very difficult to climb avoid a ladder effect? (Can a child climb an angled ladder from the underside?)

BOCA 99 section 1021.3 not only prohibits the ladder effect, but specifically states that open guards in the uses required to follow the 4 in. sphere standard shall have balusters or be solid. It doesn't allow even one intermediate horizontal member. IBC's language mentions balusters or ornamental patterns and does not specifically prohibit a ladder effect.

Conversely, although not specifically addressed by codes, it is very important to not create enough of a space on a ledge or other projection that a person may try to climb on to it and therefore need a yet higher guardrail. In one reported incident, a man who parked his vehicle tightly to the bumper wall climbed onto the car bumper and then onto such a ledge. When opening the hood to deal with a mechanical problem, he lost his balance and fell backwards, over the parapet, to his death. According to the usual theory of liability, a 42 in. guard as required by code would have been adequate to protect the owner and/or designer from liability for this accident; however, the presence of enough of a ledge for someone to stand on effectively raised the height to which a guard should have been required.

If an upturned structural beam is present behind a precast panel, it can create such a ledge. Several options to avoid triggering the need to begin calculating the required guard height at the top of a ledge, are shown in Figure 5- 14.

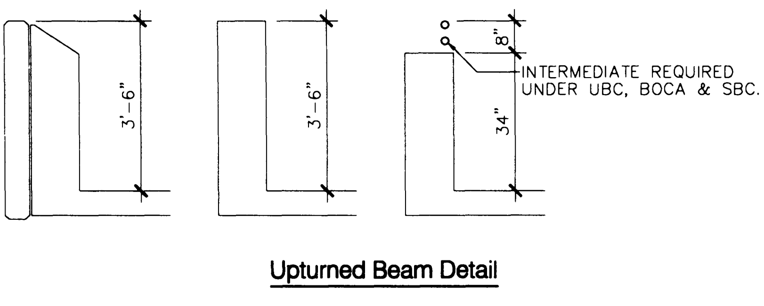


Figure 5-14. Designs that avoid creating a ledge changing the required height of a guardrail.

The loads on pedestrian guardrails are the same as those for any handrail: a concentrated load of 200 pounds at any point and in any direction along the top, and a horizontal load of 200 lb. over an area of 1 sq. ft. anywhere in the railing. The requirement in IBC is identical to that in UBC and BOCA.

Under IBC, vehicle barriers shall be not less than 2 ft. in height and shall be placed at the ends of drive aisles and parking spaces where the difference in adjacent floor elevations is greater than 1 ft. The barrier shall be designed to resist a load of 6000 lb. applied horizontally in any direction to the barrier system and shall have anchorage or attachment capable of transmitting this load to the structure. The load shall be assumed to act a minimum of 1'-6" above the floor over an area of 1 sq. ft. Barriers in structures accommodating trucks and busses shall be designed in accordance with an approved method for design of traffic railings.

Instead of vehicular barriers, BOCA requires wheel guards wherever required in open structures; in enclosed structures it somewhat bizarrely requires a wheel guard at the roof to prevent any vehicles striking the parapet wall or guard. Most parking consultants avoid using wheel guards because of the trip and fall hazard. Moreover, there have been a number of accidents where vehicles jumped curbs or wheel stops and crashed through a guard rail designed only for pedestrian loads. The vehicles then fell a number of stories to grade, not only killing those in the vehicle but folks at grade below. It is much preferable to design the parapet wall to take the vehicular load then to rely on a curb or wheel stop.

The design load under SBC is 10,000 lbs. ultimate applied as a point load 18 in. above the floor anywhere along the guard. BOCA requires vehicular barriers to meet Section 4.4 of ASCE 7-95.[24]

The requirement in UBC is that vehicle barriers are required where the difference in elevation is more than 5 ft.; barriers must have a minimum vertical dimension of 12 inches and shall be centered at 18 in. above the parking surface. The applied load is the same as IBC, however.

NFPA 101 does not address vehicular barriers.

The IBC, UBC and SBC vehicular barrier requirements cite specific requirements for location (end of parking spaces and drive aisles, etc.) that may leave unintended gaps. The experienced parking designer uses a vehicular guard at the edge of a grade separation that exceeds the prescribed amount, period, unless it is clear that a vehicle won't reach it rather than splitting hairs over whether it is required by code.

5.9 OTHER

Note that for the purposes of life safety, approved numbers or addresses shall be provided for all new buildings in such a position as to be clearly visible and legible from the street or roadway fronting the property. Letters or numbers shall be a minimum of 3 inches in height and a minimum stroke of ½ in. of a contrasting color to the background itself. (IBC 501.2)

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Chapter 7

SAFETY

Donald R. Monahan

While many people consider safety and security synonymous, *safety* as used here refers to the prevention of accidental injury or damage to persons or property, as opposed to *security,* which is protection of occupants and premises from criminal activity. A related issue, *life safety,* refers to proper design of the structure to prevent collapse, and design features to provide safe egress for patrons in case of a fire as well as provide systems to extinguish fires or prevent the spread of fire. Life safety provisions are mandated by building codes, while other safety considerations are left to the judgement of the owner, operator and designer. The purpose of this chapter is to discuss design or operational features that are generally not addressed by building code, but that may constitute a safety hazard.

Although it is rather callous to view safety and security of patrons strictly in monetary terms, a history of safety and security problems in a parking facility will likely result in loss of revenue due to reduced patronage. In addition, damages awarded for personal injury claims will increase expenses. The resulting reduction in profit will get the attention of most owners and operators. Monetary damages awarded in rape or assault cases are generally very high, often in the range of $100,000 to $500,000 or more, while the cost per accidental injury claim may be lower (usually less than $100,000). However, the number of liability claims for accidental personal injury or property damage is high enough that the annual aggregate amount is quite significant. Therefore, prevention of personal injury liability claims due to accidents is as important as prevention of personal injury due to criminal activity.

The issues and features required for Pedestrian Safety versus Vehicle Safety are distinctly different as discussed in the following sections.

A. P. Chrest et al., *Parking Structures*

7.1 PEDESTRIAN SAFETY

Pedestrian safety issues are readily apparent from the history of personal injury liability claims that are filed with the insurance carriers in a typical parking operation.

7.1.1 Liability Claims Experience

Table 7-1 summarizes the claims experience of a national parking operator with approximately 1,400 facilities comprising over 300,000 parking spaces [Monahan 1995]. This data represents a four-month period from October 1994 through January 1995. The total number of claims were 113, which is a small number compared to the number of parking spaces managed. However, the aggregate dollar amount of these claims was approximately $180,000 for a four-month period, or approximately half a million dollars annually. This is a significant sum. While insurance may cover some of the cost, a substantial amount of the claims may be less than the deductible amount.

Table 7-1. Parking Facility Liability Claims
October, 1994 - January, 1995

		Slip & Fall	Trip & Fall	Assault	Vehicle Damage	Damage from Gate	Other Injury
No. of Claims	113	64	18	7	10	6	8
% of Total	100%	57%	16%	6%	9%	5%	7%
Dollar Amount	$179,857	$81,075	$16,362	$31,050	$18,260	$17,260	$15,850
% of Total	100%	45%	9%	17%	10%	10%	9%
Value per Claim	$1,592	$1,267	$909	$4,436	$1,826	$2,877	$1,981

Table 7-1 indicates that slip/fall and trip/fall represent almost three-quarters of the total claims. Claims for accidental vehicle damage were 9%

of the total claims, and injury from gate arms were responsible for 5% of the claims. Other personal injuries represented 7% of the claims. Therefore, 94% of the claims were for accidental injury or damage. Only 6% of the claims were as a result of criminal activity. The low number of claims related to criminal activity is likely an indication of good security precautions by this operator.

While a major criminal incident was not reported, Table 7-1 indicates that the highest dollar amount per claim was for personal injury due to assault ($4,436 average per claim). The highest average dollar amount per claim for accidental injury or damage was related to gate-arm malfunctions ($2,877 average per claim). Although slips or trips and falls represent 73% of the total number of claims, the dollar value of those claims was only 45% of the total dollar amount of all claims. The average dollar amount for slip/fall and trip/fall is approximately $1,200.

Therefore, the following issues regarding accidental injury or property damage require on-going attention in your parking facilities to reduce personal injury liability claims and out-of-pocket costs:

- Eliminate trip hazards or provide adequate visibility of trip hazards.
- Maintain floor surfaces to minimize slips.
- Minimize conflicts with vehicles.
- Provide adequate barrier rails.
- Provide designated walkways for pedestrians.
- Increase safety precautions at parking equipment.
- Flag potential obstacles and low clearance areas.

7.1.2 Slip or Trip Hazards

Liability concerns have made it important to eliminate curbs and wheel stops in areas where pedestrians are likely to be present [English 1989, Box 1994]. When adjacent bays are "level" (sloped for drainage, of course) and parking spaces are vacant, pedestrians are likely to cut across the parking area between cars. The cars necessarily create shadows, and a curb or wheel stop becomes a potential tripping hazard. Even without shadows, the poor contrast of a concrete curb or wheel stop against a concrete floor may not provide adequate visibility. Poor lighting may contribute to this problem.

Curbs may still be appropriate in certain areas. Where pedestrian activity is virtually non-existent, such as at perimeter walls, curbs are often employed to cover connections between exterior panels and floor slabs. Curbs are also desirable at parking equipment islands. Pedestrian activity should be prohibited in vehicle entry/exit areas and separate sidewalks provided. Painting the faces and edges of curbs a high-contrast color can further reduce the hazard. Additional lighting should be used at entry/exit areas to enhance the visibility of obstacles in those areas.

Inadequate lighting is the most frequently cited contributing factor in personal injury claims. Table 7-2 indicates the IESNA minimum maintained illuminance levels for safety [IESNA 1999].

Table 7-2. Illuminance Levels for Safety

Hazards requiring Visual Detection	Slight		High	
Normal Activity Level	Low	High	Low	High
Illuminance Levels				
Lux	5.4	11	22	54
Footcandles	0.5	1	2	5

Source: IESNA Lighting Handbook

A detailed discussion of visibility, including the minimum illuminance and contrast required for object detection, is included in Chapter 9.

Proper maintenance of the lighting system is important. The parking facility operator should monitor the parking facility daily for expired lamps and replace them immediately. When lamps are replaced, the fixture lenses should be cleaned. An operator should keep a log of the maintenance activity to enhance the owner's defense in the event of a personal injury incident. Each light fixture should have a separate identification label attached to the fixture so the maintenance activity can be traced to each fixture.

Ice is one of the most frequent causes of falls in a parking facility. Good drainage design is the first line of defense. A minimum floor slab slope of at least 1/8-inch per foot is recommended, while a slope of ¼ inch per foot is preferred. Camber of structural elements due to post-tensioning or prestressing will negatively impact drainage slopes, and must be carefully analyzed.

Roof floor areas exposed to the weather that must drain to covered areas are particularly vulnerable to icing problems in the winter. First, the sun melts the ice or snow on the uncovered sections. The water then drains into the covered section and refreezes. Closer spacing of floor drains and/or embedded snow melting equipment can help, but snow melting or heat tracing of drains is expensive, both as to first cost as well as operating cost. If snow melting is not employed, the owner must be vigilant, monitoring all icing spots as they occur, and treating those spots with sand and/or non-chloride de-icers.

A slippery floor is another potential hazard, especially in a sloping ramp facility. The skilled concrete finisher may take pride in creating a perfectly smooth floor, but it belongs in an industrial plant, not a parking facility. Application of floor sealers that don't penetrate the concrete and harden on the surface can magnify the potential hazard. A rough broom or rough swirl finish provides both good traction and a durable floor surface.

A roughened floor surface should be carried into the stair/elevator tower, because snow and rain often accumulate in these unheated areas also. *Rubber stud flooring* can be applied to lobbies to correct this problem. *Abrasive nosings* are also desirable on stair treads. Wherever possible cast-in-type strips should be used rather than pressure-applied strips, which are less durable.

Expansion joints must be carefully designed, and temperature conditions at the time of installation properly considered, in order to minimize excessive buckling of the flexible gland, which may result in a tripping hazard. Expansion joints installed in the winter are particularly vulnerable to this potential problem. See Chapter 12.

Missing drain grates also pose a potential tripping hazard. Drain grates should have vandal-proof hardware or rectangular, hinged grates should be provided. See Chapter 12.

Concrete floors that have scaled due to freeze-thaw deterioration, or that have spalled due to chloride-induced corrosion of reinforcing steel, can also result in potential trip hazards. Asphalt parking lots that have potholes or excessive cracking may also be a problem. A vertical deviation in the floor surface of as little as half an inch can create a hazard. Proper maintenance and repair of pavement surfaces is important.

7.1.3 Pedestrian/Vehicle Conflicts

Parking access aisles are sized to allow adequate vehicle turning movement into the stall. The aisle dimension is oversized with respect to the width required for through movement of vehicles. Thus, adequate width is available for both pedestrians and vehicles to occupy the same aisle. However, this design practice also presents challenges with regard to pedestrian safety.

Adequate vertical illuminance in the drive aisles is particularly important to assure adequate visibility of pedestrians walking from between parked cars into the drive aisle (see Chapter 9). Interior shear walls and columns between parking stalls should also be avoided as they may obstruct the driver's view of pedestrians. Doors from stair towers or elevator lobbies should not open directly into the drive aisles. If doors directed into drive aisles cannot be avoided, then a barrier rail should be provided outside the door to prevent pedestrians from walking unknowingly into the drive aisle.

Designated walkways may be painted on the floor at the side of the drive aisle with adequate signage to direct patrons to use the walkway. If pedestrians use a different route than the designated walkway, then the patron often assumes the risk of any potential accidental injury. However, if a trip hazard happens to be in the designated pedestrian path, then the owner will likely be held liable for any injuries that occur.

Pedestrian crossings at vehicle exits can also be a problem. Ramps steeper than a 15% slope coming out of below grade parking areas may prevent adequate driver visibility of pedestrians over the hood of the vehicle. A level area at least 15 feet long should be provided in advance of the pedestrian crossing. Adequate lateral site clearances should also be provided. Fences, walls or other obstructions should be set back at least 15 feet. If these design features cannot be accommodated, owners should install devices warning pedestrians of oncoming traffic such as signs, audible alarms, and flashing lights. Owners should also install warning devices for the motorists such as signs and mirrors, which enhance visibility at blind intersections.

7.1.4 Pedestrian Barrier Rails

Guardrails are required by code at changes in elevation of the walking surface, but are optional for barriers between vehicles and pedestrians or between vehicles and equipment.

The Uniform Building Code [ICBO 1997] requires a guardrail where the surface is more than 30 inches above or below the adjacent grade. However, anywhere that the grade differential is more than 6 inches may be a potential hazard. If the grade differential of 6 inches to 30 inches occurs next to an active pedestrian area, a guardrail should be provided. Good professional judgment should be exercised. A handrail should always be provided if there is any possibility of severe injury.

Codes also prescribe a minimum height of railing (typically 3'-6"). Courts have tended to hold owners to literal compliance with the code; that is, if the handrail is even half an inch low, the owner is liable for an accident. Therefore handrail heights should be carefully designed for conditions common only to parking facilities that affect the rail height, such as sloping, *cambered*, and warped floors, etc. Attention to minor details such as these will reduce owner liability. Because of normal construction tolerances, one should not design to the absolute minimum rail height.

In recent years, life safety and/or building codes have been substantially tightened to require intermediate rails at a spacing no greater than 4 inches. This standard is designed to prevent a toddler not only from going through between the rails, but also from getting his or her head stuck. A facility designed under a prior standard (generally, 9-inch or 6-inch spacing) will usually not be required to upgrade to the current code. However, an unsafe condition that is clearly apparent should be corrected. Some codes [BOCA 1999] prohibit horizontal rails to prevent children from climbing the rail and falling off. Designers often use picket rails or wire mesh screening as a result.

At roofs of parking structures, over-height rails or fencing on top of the vehicle barrier rail should be considered. Roofs of parking structures can provide a convenient place for suicides. In addition, the roof is sometimes used as an observation deck, particularly at airports, where small children may sit on top of the wall.

7.1.5 Pedestrian Hazards at Parking Equipment

Other than for assault, injury or damages due to parking equipment (gate-arm) malfunctions result in the highest average dollar amount per personal injury claim (see Table 7-1). Any vehicle access into or out of the parking facility could be used as a short cut for pedestrians to enter or exit. Therefore, it is important to provide a separate pedestrian walkway alongside the parking equipment, whether or not pedestrians were intended in that area. Pedestrians pushing a metal baby stroller or pulling a rolling baggage carrier can inadvertently trigger the detector loops at a parking gate. Wheelchair patrons can also activate the gate mechanism. Adequate signage should be provided to prohibit patrons from walking through the parking equipment drive lanes, and direct them to a designated walkway.

Also, many manufacturers provide auto-reversing gate-arm mechanisms. While this feature may minimize potential damage, contact must be made before the gate mechanism reverses. Therefore, non-contact reversing mechanisms should be specified. Further, gate arms should be cushioned to minimize damage in the event contact with the gate-arm occurs.

7.1.6 Low Clearance Obstacles

Most codes prescribe minimum *overhead clearances* for pedestrians and vehicles. These standards should be adhered to, even in isolated areas.

While nearly every parking structure typically has a low clearance or "headache" bar posted at the vehicle entrance, often there are isolated areas with low clearance such as pipes or signs mounted perpendicular to a wall, that are out of a vehicle travel path, but are accessible by pedestrians. Watch especially for reduced clearance at curbs. Low clearance (less than code minimum of 7'-0" for vehicles or 6'-8" for pedestrians) obstacles should be flagged with warning signs and/or diagonal black and yellow striping on the obstacle. Even those precautions will not always prevent an unalert patron from walking into the obstacle. Therefore, a barrier rail around the low clearance area is recommended.

Clearance bars at all entrances stating the minimum *vehicular clearance* have become a standard in the industry. It is not recommended, however, that a fixed, heavy obstruction be employed. In one reported case, a cashier was knocked unconscious by a falling clearance bar while making a tour of the facility at closing time. He was found, still unconscious, more than 30 minutes later. Luckily the person who found him was honest and summoned help rather than leaving him there and absconding with the day's receipts. In other cases, a main beam has been deliberately designed at the posted clearance height to keep oversize vehicles out. This tactic not only raises patron tempers, but also does not eliminate liability if adequate advance warning doesn't exist. Most parking consultants now use a long, large-diameter (8-inch), hollow PVC tube hung from chains for a clearance bar at every entrance lane. This tube creates sufficient noise to be noticed by the driver when hit, while minimizing damage to vehicles or pedestrians.

Other traffic control devices may become projectiles. Sand-filled barrels are commonly used as inexpensive traffic barriers. However, if knocked over, these drums will roll down a sloped parking ramp with substantial speed and momentum. Some manufacturers make flat-sided, plastic barrels striped with reflective sheeting for high visibility. Ballast in the form of sand bags can be added as required to keep the barrel in the desired location.

7.2 VEHICLE SAFETY

Moving vehicle accidents were not part of the claims analysis presented in the previous sections. Accidents involving two moving vehicles, or a moving vehicle striking a parked car, are generally a result of driver negligence rather than the fault of the parking facility design or operation. It is generally the responsibility of the parties involved in the accident to resolve the incident between them. Therefore, unless the accident involves one of the operator's employees or vehicles, it would not be recorded as a claim against the operator.

A study of vehicular accidents in parking lots [Box 1981] indicates that about two-thirds involve a moving vehicle striking a parked vehicle, less than one-third involve a moving vehicle striking another moving vehicle, about 6% involve a vehicle striking a fixed object, and only 1% involve a vehicle striking a pedestrian. Further, an unpublished study of a large neighborhood shopping center found that only 14% of all parking lot accidents occurred at night [Box 1981]. An unpublished university study indicated that only 17% of all parking lot accidents occurred at night [Box 1981]. Therefore, poor lighting may not be the cause of most accidents. Other issues such as speed, site distance, and geometric design may be more important.

The same study indicated that the overall accident rate averaged 12 accidents per 1000 spaces per year. Low and medium turnover parking facilities had half the average number of accidents, while high turnover facilities had twice the average number of vehicle accidents.

7.2.1 Moving Vehicle Striking Parked Vehicle

A moving vehicle striking a parked vehicle occurs most often when pulling into (21%) or backing out (59%) of a stall. A particularly vulnerable situation occurs where parking is provided at the perimeter of a parking lot or structure that is at 90 degrees to the typical rows of parking. When a vehicle backs out of the end stall, the last vehicle parking in the typical row may be broadsided (see Figure 7-1). This situation can be avoided by not using end-parking stalls, however, the parking capacity will likely be reduced, and the parking efficiency will be lower.

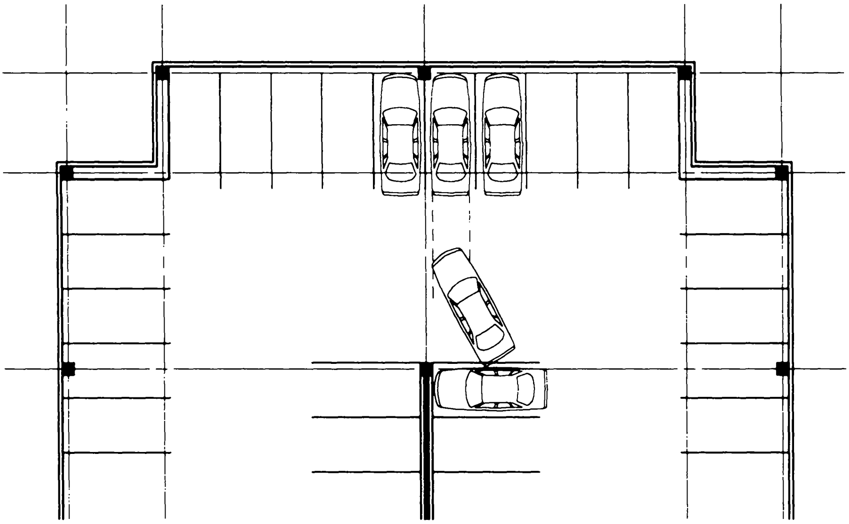

Figure 7-1. Typical End Parking Accident

7.2.2 Accidents with Two Moving Vehicles

Accidents involving two moving vehicles typically occur as a vehicle backs or pulls out of a stall and strikes a vehicle traveling in the drive aisle (58% of this type of accident). This situation generally occurs due to inattentiveness of the driver, although excess vehicle speed in the drive aisle may be a contributing factor. Signage should post speed limits and/or other speed reduction devices should be considered to control vehicle speeds. However, speed bumps are not recommended as they represent a potential trip hazard for pedestrians.

Another potentially dangerous area occurs at vehicle crossovers at the ends of parking rows. Twenty-one percent of moving vehicle accidents occurred at intersections of parking lot aisles. Adequate turning maneuverability and adequate width are often not provided at two-way traffic crossovers. While two, 12-foot lanes are adequate for the passage of opposing vehicles with a straight approach, turning vehicles swing a much wider path, though not as wide as semi-trailers. The maneuver of the inside vehicle at a turn must be initiated far in advance of the cross-over, often necessitating the elimination of the parking stall at the end of the row adjacent to the cross-over. If an island is provided, the length of the island should be less than the depth of the stall with an adequate radius to facilitate the turning maneuver of the inside vehicle. Figure 7-2 indicates the appropriate design criteria. Of course, cross-traffic conflicts in parking lots or structures should be minimized, if possible.

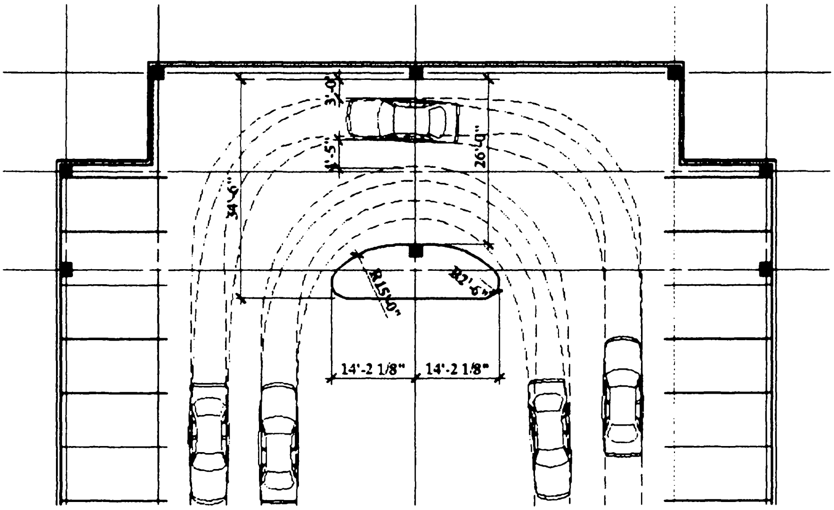

Figure 7-2 Design of End Crossovers

Two-way traffic aisles result in the most cross-traffic conflicts. These conflicts may be manageable if the parking lot or structure has a small capacity (less than 500 stalls), or if the peak hour traffic flow is primarily in one direction (all inbound or outbound, such as the peak employee arrivals or departures at an office complex). However, if the traffic characteristics of the land use result in high in and out volumes occurring at the same time (such as at shopping centers and cinemas), special attention is required in cross-traffic areas. Site distances at those intersections should be increased. Obstacles to adequate visibility such as landscaping in a surface lot or shear walls in a parking structure should be avoided in cross-traffic areas. Traffic control devices such as stop signs or yield signs should be installed. Even round-abouts are gaining popularity in surface lots at four-way traffic intersections. Lighting should also be increased in those areas, although be careful not to overdo the lighting, which may result in excessive glare.

7.2.3 Vehicles Striking Fixed Objects

Incidents involving a vehicle striking a fixed object often occur when a driver backs out of a stall. Backing over a curb, hitting a column, striking a pipe bollard, hitting a light pole, or running into a wall are the most frequent causes of these types of accidents. Pipe bollards are used to protect plumbing risers, parking equipment or other fixed objects that are susceptible to damage. However, pipe bollards are often too short to be seen by a driver backing out of a stall. A minimum height above floor level of 4'-0" is recommended, which corresponds to a typical driver's eye-level of approximately 45 inches. Columns or curbs that are vulnerable to maneuvers in and out of parking stalls should be adequately protected and identified with pipe bollards, high reflectance paints, etc. Plumbing risers in locations susceptible to vehicle damage should be protected with steel guards or bollards. Backing maneuvers are particularly susceptible to poor lighting; the vehicle headlights assist forward maneuver visibility.

7.2.4 Vehicle Barrier Rails

Finally, barrier rails are required at the perimeter of a parking structure to provide adequate restraint to prevent a vehicle from crashing through the rail and dropping to the ground below. As crazy as this situation appears, such an incident actually occurred during rush hour in downtown Seattle in November 1987. A car fell five stories onto a downtown street below. Two other vehicles were crushed and three people killed. Therefore, adequate barrier restraint is a real concern.

In recent years, many building codes have begun to address the issue of preventing out-of-control vehicles from breaking through exterior and interior railings at adjacent areas with different floor elevations. The Uniform Building Code [UBC 1997] specifies a vehicle barrier where any parking area is more than 5 feet above the adjacent grade. Vehicle barriers must have a vertical dimension of 12 inches and must be centered at 18 inches above the parking surface. The barrier must resist a 6,000-pound load applied at 18 inches above the parking surface.

Although not a code requirement, the Parking Consultants Council, National Parking Association [NPA 1987] recommends the following:

> "Vehicle restraints should be placed at the perimeter of the structure and where there is a difference in floor elevation of greater than one ft. Vehicle restraint systems should be not be less than 2 ft in height and should be designed for a single horizontal ultimate load of 10,000 lb. applied at a height of 18 inches above the floor at any point along the structure. Openings in railings or spacing of components should conform to other sections of the local governing code. If

vehicle restraints and handrails are used, no other barriers such as wheel stops or curbs should be necessary."

We recommend that the NPA standard be followed except when the locally adopted code has a higher standard.

Unfortunately some codes have well-intended but misguided standards. One state requires an 8-in. wheel stop at every parking stall. This requirement not only creates maintenance and tripping problems, but also causes damage to vehicles since many cars have an under-body clearance less than 8-in. Some codes specify that the barrier must stop a vehicle moving at a specific speed. To calculate the force applied to the barrier, which is necessary for design, one must use an energy equation that requires assumptions that many designers are not qualified to make. Some discussion with local code officials regarding the vehicle barrier standard may be required.

Another need for vehicle restraint occurs at entry/exit locations. Inadequate design for turning movements threatens not only the parking control equipment but also a cashier in a booth. The most frequent problem is not providing enough space for turning into the lane and getting aligned properly before reaching the ticket dispenser, card reader, or cashier.

It is considered good practice to provide a concrete-filled steel post, solidly anchored in the curb, at each piece of parking equipment. Casting a pipe sleeve in the curb facilitates replacing the post, should it be damaged. One word of warning: check for all possible angles of approach. For example, vehicles backing out of nearby stalls can hit the gate from the back side of an island.

7.3 SUMMARY

The damages awarded due to personal injury as a result of criminal activity may be in the hundreds of thousands, or even millions, of dollars and justify the attention that has been given in the industry to security of parking lots and parking structures. The more frequent incidents of personal injury or vehicle damage due to accidents that occur in parking facilities have not received the same priority or attention due to the much smaller dollar value of the potential damages. However, the aggregate annual amount of those damages is significant, and justifies appropriate action to reduce potential claims and increase potential profits. Several ideas have been presented here to reduce the potential for those claims.

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Chapter 8

MECHANICAL ACCESS PARKING STRUCTURES

Donald R. Monahan

Most of the discussion in this book is centered around self-park, ramp-access, multi-level parking structures. Ramp-access garages use sloping floors for vertical circulation of vehicles and typically require a minimum footprint about 100 ft long by 90 ft wide where there is no parking on the ramp. A more efficient and cost-effective design, with parking on gently sloping ramps (maximum slope of 5%), requires a minimum footprint about 150 ft long by 120 ft wide. In congested urban areas, it is difficult to find sites of size adequate to accommodate a ramp-access garage. The solution is a mechanical-access parking structure.

Mechanical-access parking structures use machines, lifts, elevators or other mechanical devices to move vehicles from street level to an elevated parking stall and back to street level. Systems are available that park 22 cars on a footprint equivalent to two parking spaces (20 by 24 ft). Early lift devices were manually operated; however, advances in technology have resulted in many automated systems. Systems are available ranging from simple devices that double or triple-stack vehicles in a parking space to sophisticated lift systems in high-rise buildings with over 1,000 parking spaces stacked like boxes on shelves in a warehouse.

The purpose of this chapter is to present an overview of the types of mechanical parking systems available, and the issues surrounding the design, operation, and cost of mechanical parking structures.

8.1 HISTORY

Car stackers have been in use since the 1920s and consist of driving a vehicle onto a platform that is raised to allow a vehicle to park underneath (see Figures 8-1 and 8-2). Two and three-tier devices are available. A disadvantage of this system is that the lower vehicle must be moved in order to retrieve the upper vehicle.

A. P. Chrest et al., *Parking Structures*

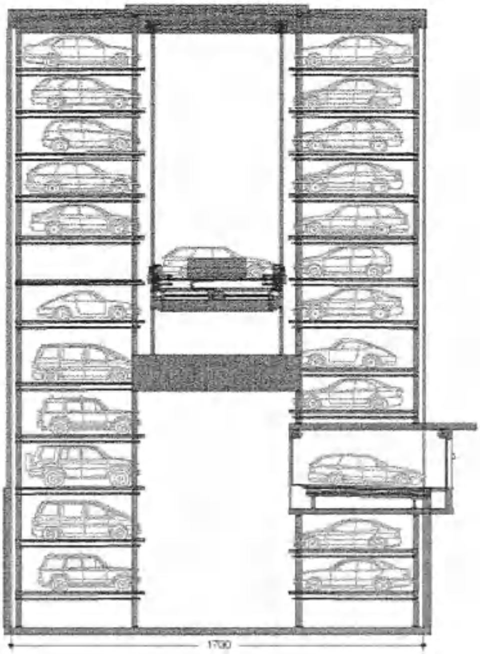
Photo Courtesy of Liftco Equipment Co

Figure 8-1. Double Car Stacker

Photo Courtesy of Liftco Equipment Co.

Figure 8-2. Triple Car Stacker

Early elevator systems involved surrendering one's vehicle to a parking attendant who drove the car onto the elevator. The attendant then operated the elevator both vertically and horizontally to a vacant space on an upper floor. When the elevator reached the desired space, the attendant either drove the car into the parking stall or a pallet or rollers automatically moved the car into the parking stall. The storage configuration often consists of a single row of stalls on each side of a center elevator access atrium (see Figure 8-3) although systems with tandem stalls on each side are also in use. Obviously, the tandem stalls complicate the retrieval of vehicles since half the spaces may be blocked by another vehicle. Other systems use a



Courtesy of SpaceSaver Parking Co.

Figure 8-3. High-rise Lift System

circular configuration of parking stalls with a spiral vehicle lift in the center.

The first elevator system was the 1000-space Kent Garage constructed in New York City in 1928. In 1931, a 400-car, twenty-level garage was constructed for the Carew Tower in Cincinnati. This facility operated until 1978.

In the post-war era of the 1950s, automotive sales increased dramatically and many mechanical access garages were constructed in Chicago, St. Louis, Detroit, Philadelphia, Cleveland, and other major urban areas. Many operated successfully for over twenty years until escalating land values led to demolition.

Problems with these garages consisted of slow elevators, overheating of hydraulic components, vibration, and inflexibility (only one vehicle could be stored or retrieved before accommodating the next patron). These systems were also plagued with high maintenance costs and equipment breakdowns. If only one elevator was provided, and it was out of service, the operator could not retrieve the patron's vehicle.

In the mid 1970s, more advanced mechanical methods were available and many new facilities were installed in Europe, Asia and Central America. Although multiple elevators were often used, these systems still lacked speed, convenience, and reliability.

By the 1980s, advances in technology allowed for faster, safer and more reliable systems. Much of this technology was developed for automobile assembly plants in addition to automation of manufacturing warehouses.

In the 1990s, computer electronics greatly enhanced mechanical access parking facilities with faster, more reliable, less expensive and more compact systems. Computers now fully control vehicle movements. Components primarily consist of solid-state electronics. Modern systems include redundant backup equipment, and sensors monitor equipment degradation before failure occurs. Hydraulic components are virtually eliminated, decreasing maintenance costs and failures, thereby increasing reliability, and increasing speed of storage and retrieval. Labor costs are also reduced by total hands-off automatic operation.

Because of these advances in technology, mechanical-access parking systems are now gaining more widespread acceptance. There are nearly 500 automated parking systems installed worldwide, primarily in Japan, South Korea, Australia and all over Europe. Mechanical parking in Japan has increased from 50,000 spaces in 1975 to over 1.6 million spaces in 1996. The first fully-automated parking garage in the United States is scheduled for completion in July 2000 in Hoboken, New Jersey.

Automated parking is certainly a viable option for solving parking deficits, particular on small sites in congested urban areas where large surges of traffic to and from the facility are not anticipated.

8.2 TYPES OF MECHANICAL PARKING SYSTEMS

The types of mechanical parking systems can be categorized as follows:

Low-Rise Stackers
Rotary Lifts
Puzzle Parking
High-Rise Stackers

8.2.1 Low-Rise Stackers

Low-rise stackers consist of hydraulic or cable operated lift systems that allow double or triple stacking of vehicles in a single parking space. Most devices require moving the lower vehicle before retrieving the upper vehicle (called *dependent* parking). Therefore, these devices are best suited for low-turnover, long-term parking facilities, such as at a condominium or apartment complex, that do not have a large surge of arriving or departing patrons. The typical height for a double-stacked unit is 11 to 13 ft, while a triple stacked unit will be 16.5 to 19.5 ft high. Inclined platforms reduce the overall height (as low as 9'-6" for a double-stack unit) allowing these lift devices to fit into existing parking structures (see Figure 8-4). However,

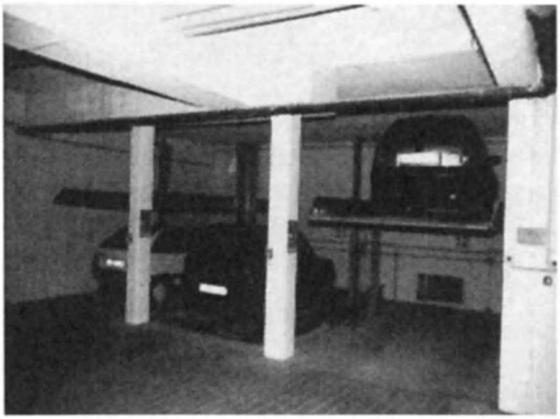


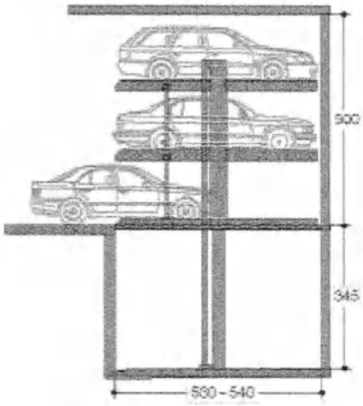
Photo courtesy of Klaus Parking systems

Figure 8-4. Dependent Double Stacker

one must be careful to analyze the structural capacity of the floor system if car stackers are used on elevated garage floors as the live load is more than doubled with retrofit of the car stacker system.

Independent car stackers can retrieve any vehicle without moving another vehicle. A pit must be provided to accommodate these machines (see Figure 8-5).

These stackers occupy a footprint of 10 ft by 20 ft. The parking efficiency is then 100 (triple stacker) to 150 (double stacker) square feet per stall (ground level area only) including the access aisle.

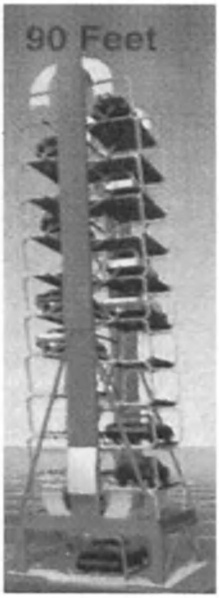


Courtesy of SpaceSaver Parking Co.

Figure 8-5. Independent Car Stacker

8.2.2 Rotary Lifts

Rotary lifts consist of a steel tower with a conveyor that lifts vehicles in a narrow circular loop up one side and down the other similar to a ferris wheel (see Figure 8-6). One such device (Auto Space Tower by Auto Space Corporation, Boston, MA) is 20 ft wide by 24 ft long and holds 22 cars in a 90-foot high tower. The average retrieval time is 45 seconds with a maximum retrieval time of 80 seconds. Each 22-car tower can handle incoming cars at about 2 per minute and outgoing cars at an average rate of one per minute. The device is portable so it is capable of being moved and re-erected on another site.



Courtesy of Auto Space Corporation

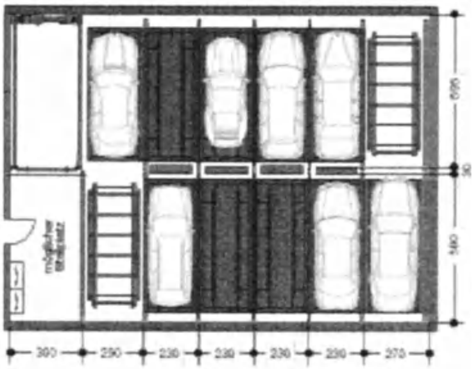
Figure 8-6. Rotary Lift

An arriving customer simply drives onto the bottom pan of one of the towers, gets out, pushes a button, takes a computer card, the safety sweeps are activated, the patron walks away, and up the car goes. Upon return, the patron enters the computer card and the vehicle returns by the shortest route.

The parking efficiency of this system is 50 to 60 sq. ft per stall (ground level area only) including an access aisle. The cubic volume of the space occupied by the rotary lift is 50% less than a typical ramp-access garage.

8.2.3 Puzzle Parking

Puzzle Parking consists of a checkerboard pattern of parking "cells" on 2, 3 or more vertical tiers where cars are parked on pallets that are moved along vertical and horizontal rails to a vacant slot (see Figure 8-7). The system works like the "numbers puzzle" game in which there is one empty location. The player can move the game blocks in all directions, with the purpose of organizing them in a specific order. At least one cell must remain vacant to allow pallets to be shuffled around to gain access to the vehicle that is being retrieved. The computer-controlled system operates by moving pallets on a cushion of air. Computers track the location of each vehicle and work around the maze of cars in order to move the cars to the exit in the shortest and fastest way possible. The computer software allows the simultaneous movement of pallets within the system so two cars can be retrieved simultaneously. Multiple entrances and exits can be accommodated. Any vehicle can be delivered to any location.



Courtesy of SpaceSaver Parking Co.

Figure 8-7. Puzzle Parking

The potential disadvantage of this system is that a breakdown of only one cell could prevent retrieval of a patron's vehicle. However, every component of the system is backed up at least once. Two computers are typically used to monitor each other and take over if one fails. Intelligent software continuously monitors system performance, allowing for easier servicing through preventative maintenance.

Speed of operation is the biggest concern with this system. Manufacturers are reluctant to quote the average speed of this system as it is dependent upon the configuration of the facility. Obviously, shuffling several vehicles to gain access to the vehicle being retrieved takes time. The larger the number of cells and levels, the slower the system.

Since there are no access aisles, the cubic volume of space with this system is 50% less than a typical ramp-access garage. The overall parking efficiency (total floor area basis) would then be 150 sq. ft per stall.

8.2.4 High-Rise Stackers

There are two types of high-rise stacker systems – circular and rectangular.

Figure 8-8. TreviPark System

The circular system consists of parking stalls on a continuously sloping spiral floor. The elevator or transport device is located in the center. The TreviPark system (see Figure 8-8) fits into a 72-foot diameter circle and holds 12 cars per floor, accommodating between 72 and 108 cars in one unit (six to nine levels). Total cycle time for retrieval takes between 15 seconds and one minute based on location within the circular garage. The typical parking efficiency is 220 sf per stall. The Grando System (see Figure 8-9) consists of a 30-meter (100-ft) diameter circle and holds 24 cars per floor. The recommended size for one unit is 220 to 300 cars or about 9 to 12 levels. Each unit has 4 entrance and 4 exit chambers, and a center shuttle unit with 4 tender arms (transports up to 4 vehicles at one time). In a 250-space unit, the average retrieval time is 80 seconds or about 45 minutes to one hour to empty the entire facility. Either system can be constructed above or below ground.

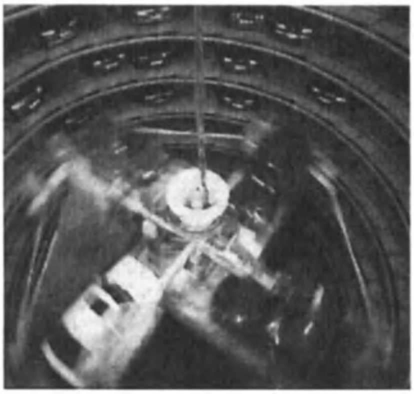


Figure 8-9. Grando Parking System

The rectangular systems generally consist of a row of parking stalls on either side of a center atrium for the vehicle transport system. The vehicle transport system consists of vertical lifts and robots that move the vehicles laterally to the parking chambers. Typically, one elevator is provided for every 100 parking spaces and one robot for every 50 spaces.

The system works by driving a car onto a pallet in the entrance chamber that is similar in appearance and size to a single-car residential garage. After the driver leaves the vehicle, sensors determine whether the vehicle is the appropriate size, and whether attachments or appendages exist that exceed chamber dimensions. Video cameras and motion sensors are also used to detect the presence of people or animals before stowing the vehicle. Digital cameras store images of drivers and vehicles for identification in the event of a lost ticket. The car is then automatically moved on pallets to an open parking space using flexible transfer car transport technology found on automobile assembly lines throughout the world. Movements are controlled by computer and allow several cars to move independently throughout the parking structure at the same time. The use of pallets to move, park and retrieve cars eliminates the need for any kind of machinery to touch the vehicle. The pallets also stop vehicle drippings, such as oil, snow, ice, salt and other debris from falling onto cars below during transportation and parking. However, the storage of empty pallets can be a problem. Some systems use racks to transport vehicles. A floor is then required under the rack in the parking chamber in order to prevent vehicle drippings from falling on vehicles below.

These systems can be built up to twenty stories high, above ground, underground, or both, and with any façade or architectural design. A system can also be modified, expanded, or relocated after installation. The typical parking efficiency is about 220 sq. ft per stall.

8.3 OPERATIONAL ISSUES

The experience for the patron is very similar to valet parking. However, since storage and retrieval of vehicles is automated, no valet attendants are required to park the vehicles, resulting in tremendous labor savings. Also, patrons may take their keys and lock their vehicles, providing a greater level of security and comfort for patrons compared to an attendant valet operation. This additional level of security may reduce the apprehension and aversion of many patrons toward valet parking.

Also, the issuance of tickets (valet coupons) and collection of revenue can also be automated by pay-on-foot stations at the entrance and exit chambers. After entering the facility, patrons leave their cars and proceed to the pay-on-foot station to obtain an electronically-encoded ticket. Once the ticket is taken, the transport mechanism then stores the vehicle and the computer tracks the vehicle storage location for that ticket. Upon returning to the facility, patrons then insert their tickets into the pay-on-foot station, which calculates and displays the fee due, receives payment from patrons in cash or by credit card, determines where the vehicle is stored and then retrieves the vehicle. For monthly permit parkers, a coded-card is inserted into the pay station upon arrival to store the vehicle and again upon departure to retrieve the vehicle. Cars are rotated on a turntable, if necessary, and returned to the exit chamber in a forward drive position for easy exit from the facility.

Since the upper levels of the parking facility are not occupied, and there are no vehicles operated above the ground floor, there is no need for lighting, mechanical ventilation, fire exits, etc. Interior lighting and stair access requirements are minimal for maintenance and repair personnel only. Utility costs for lights and ventilation are greatly reduced compared to a ramp-access garage. Those costs are offset by the increased cost to operate the lifts and robotic transfer devices. Property and insurance costs are also reduced as the public does not have to access the upper levels of the building.

Mechanical parking structures offer greater security for patrons as well as for their vehicles. Patron security is enhanced, as patrons do not have to walk to remote, unattended areas of the parking structure to retrieve their vehicles. Mechanical parking structures have secure customer lobbies at the ground level where patrons wait for their vehicles to be delivered to them.

The access design for arriving and departing patrons is a significant concern. Just as with any parking facility, one must first identify the service rate of the typical entry and exit procedure.

The entrance service rate is a function of the time it takes the patron to align the vehicle, enter the facility, retrieve travel items from the vehicle, and operate the entrance equipment. This procedure could typically take 1 to 2 minutes or up to 5 minutes depending on the dexterity of the individual and user-friendliness of the equipment. The time for the pallet to clear the entry chamber and provide another pallet in the re-entry position is a matter of seconds. The entrance service rate is likely about 30 vehicles per hour compared to 300-400 vehicles per hour for a typical lane in a ramp-access garage with a ticket dispenser or coded-card reader. Therefore, about 10 times as many entrance lanes are required compared to a typical ramp-access garage.

When patrons desire to retrieve their vehicles and depart the garage, they insert their coded tickets or key-cards into the pay station, which begins retrieving the vehicle. The process of retrieving the vehicle takes from 1 to 2 minutes depending on where it is parked in the facility. The patron completes the payment transaction while the vehicle is retrieved. This time is typically faster than the corresponding time it would take to access your vehicle on foot, and drive down the ramping system of a typical ramp-access garage. The difference is that each patron is a transport device while the number of transport devices in an attended valet operation (runners) or in a mechanical parking structure (lifts and robots) are limited. The key to the exit design is to provide enough lifts and robots corresponding to the size of the garage and the anticipated peak hour departure volume. In a typical mechanical parking structure, one elevator is provided for every 100 spaces, and one robot is provided for every 50 spaces. This system will have a service rate of about 50 to 100 vehicles per hour per exit chamber.

The arrival/departure characteristics of the user's destination or land use that the parking facility serves will then dictate the number of entry and exit chambers that must be provided (see Chapter 4). If the peak hour traffic is predominantly inbound in the morning and outbound in the afternoon, such as at an office building, an access chamber can function as both an entrance and an exit. However, if the inbound and outbound traffic remain at a consistent level throughout the day, then separate entry and exit chambers should be provided, although there could be some dual use as the percentage of inbound and outbound traffic varies throughout the day.

In terms of the access design, mechanical parking structures are no more of a challenge than an attended valet operation. The number of runners for an attended valet operation or the number of lifts and robots for mechanical parking must be sized for the peak hour arrival/departure traffic. Obviously, neither type of operation is well suited for large surges of traffic over a short period. However, there are many types of land uses that don't have large surges in arrivals and departures for which mechanical parking structures are particularly appropriate such as hotels, restaurants, apartments, libraries, museums, etc.

8.4 DESIGN ISSUES

This section discusses design issues related to the International Building Code 2000 (IBC 2000) recently published by the International Code Council that was formed from the three previous code agencies: The International Council of Building Officials (ICBO), Building officials and Code Administrators International (BOCA), and the Southern Building Code Congress International (SBCCI). Since owners and designers in the United States are just discovering mechanical access parking as a viable alternative to ramp-access garages, it is felt that the IBC 2000 will likely be adopted by the time these new projects are built.

Mechanical parking structures are classified in Group S-2 just as ramp-access garages are. A mechanical access parking structure may be open, just as a ramp-access garage, provided adequate perimeter openings are provided. However, for protection of the equipment and moving parts from environmental deterioration, it is generally desirable to enclose the mechanical-access parking structure. Therefore, mechanical parking structures are then subject to the provisions of Section 406.4 of IBC 2000 for enclosed garages.

Enclosed mechanical parking structures should consist of noncombustible materials of Type I or II construction. The allowable height and building area is as follows:

Table 8-1. Allowable Height and Area

	Type of Construction			
	Type I		Type II	
	A	B	A	B
Max Height, ft.	Unlimited	160	65	55
Max # of stories	Unlimited	11	5	4
Max Area per Floor, sf	Unlimited	79,000	39,000	26,000

The fire resistance ratings for building elements is taken from Table 601 of the IBC 2000 as follows:

Table 8-2. Required Fire Rating in Hours

	Type I		Type II	
	A	B	A	B
Structural Frame	3	2	1	0
Exterior Bearing Walls	3	2	1	0
Interior Bearing Walls	3	2	1	0
Floor Construction	2	2	1	0
Roof Construction	1 ½	1	1	0

Generally, steel-frame structures are used for mechanical parking structures. Depending upon the area, height and required fire rating, the structural steel frame may have to be fireproofed.

A one-hour rated firewall must be provided around the perimeter of the building. The maximum area of exterior wall openings is listed in the following table:

Table 8-3. Maximum Area of Perimeter Wall Openings
Fire Separation Distance, ft

	0-3	3-5	5-10	10-15	15-20	20-25	25-30	30+
Unprotected	None	None	10%	15%	25%	45%	70%	No Limit
Protected	None	15%	25%	45%	75%	No Limit	No Limit	

An automatic sprinkler system must be provided in accordance with the International Fire Code. The high-rise provisions of section 907.2.12 do not apply as the floors that may be located more than 75 ft above the lowest level of fire department vehicle access are not occupied. However, buildings with an atrium must have smoke detectors installed at the atrium ceiling. A fire alarm system is required where the atrium connects two or more stories.

Mechanical parking structures must meet a number of design requirements clearly intended for self-park, ramp-access garages, but not specifically addressed or excluded for mechanical-access parking structures. For instance, the clear height of each floor in vehicle areas must be 7 ft. Accessible parking stalls must be 8'-2" clear. Guardrails shall be provided in accordance with IBC section 1003.2.12 at exterior and interior vertical openings where vehicles are parked or moved and where the vertical distance to the ground or surface below exceeds 30 inches. Two-foot high vehicle barriers are required at the ends of parking spaces where the difference in floor elevation is greater than 1 foot. The vehicle barrier must resist a 6,000-pound load applied at a height of 18 inches. Mechanical ventilation is required despite the fact that no vehicles are operated above the ground floor. It may be possible to obtain a variance with respect to the foregoing requirements based on the fact that the vehicles are not driven into the parking space, but are stored by mechanical devices that control the speed and placement of the vehicle. Mechanical parking system manufacturers should strive to change these provisions of the IBC 2000.

The provision of fire exits for mechanical parking structures is somewhat vague. While Table 1003.2.2.2 specifies an occupant load for parking garages of 200 sq. ft per occupant, only the ground floor of a mechanical parking structure is occupied. Since the ground level functions differently than a typical parking garage, the building official may require a higher occupant load for that level. Business or industrial uses require an occupant load of 100 sq. ft per occupant. The location of a fire exit at that level should not exceed 250-ft travel distance for a sprinklered building. At least two fire exits are required, separated by at least half the maximum diagonal dimension of the building.

One or more convenience stairs and gangways may be required for access to equipment for maintenance and repairs as well as for emergency access to vehicles in the event of a vehicle fire. Since the equipment for the lifts and robots is typically provided on or near the ground level, fire access to that equipment is less of a problem.

The means of egress for patrons must be illuminated with emergency lighting arranged to provide initial illumination that is an average of 1 foot-candle and a minimum at any point of 0.1 foot-candle measured along the path of egress at floor level. Illumination levels shall be permitted to decline to 0.6 foot-candle average and a minimum at any point of 0.06 foot-candle at the end of the emergency lighting time duration (typically 90 minutes).

Full-time lighting of the upper parking levels may not be required. However, low-level security lighting similarly to emergency lighting may be desirable. Enhanced task lighting should be available to facilitate repairs and maintenance.

An elevator is not required in a mechanical parking structure. A man-lift may be provided as a convenience feature for maintenance and repair personnel access to upper levels in a high-rise building.

The ground level employee and public use areas must meet the accessibility requirements of the Americans with Disabilities Act (ADA). Accessible parking spaces must also be provided in accordance with the ADA.

Structural loads are similar to that required in ramp-access garages, except as limited by the vehicle transport system. Most platforms are designed for a maximum vehicle load of 5500 pounds. Sensors should be placed in the entry chamber to check for oversize and overweight vehicles before they are transported.

Mechanical parking structures require tighter tolerances in their construction compared to ramp access garages. Alignment of the vertical and horizontal transfer devices is extremely critical. Specifications need to incorporate the required tolerances that may vary with each manufacturer. Construction contractors need to be advised that these tolerances may be less than for typical parking structure construction.

Similarly, the foundation system design must consider lower tolerable total and differential settlements. While ramp-access garages may tolerate up to 2 inches of total settlement and 1 inch of differential settlement, these values are likely to decrease by 50% or more for a mechanical-access garage due to the alignment tolerances for the vehicle transfer system.

8.5 COST ISSUES

Cost issues consist of construction cost and operational costs.

8.5.1 Construction Costs

The costs cited are for the construction cost of the mechanical parking equipment, the construction cost of the services or utilities to operate the equipment, and the construction cost of the building enclosure (if required) including customer lobbies. The cost of the land or site improvements or environmental remediation are not included. Soft costs for design fees, legal fees, financing costs, etc. are also not included.

The installed cost of a double car stacker is in the range of $7500-$8500. Triple stacker units cost about $24,000 and include a pit. Puzzle parking systems will cost about $8000 per space. These prices are installed costs for the machinery only and do not include the cost of any building enclosure, land costs, site improvements for access drives, patron waiting facilities, etc.

High-rise stackers will cost about $12,000 to $20,000 per space, including the building and auxiliary facilities, but not including land costs. The price will vary depending on the architectural treatment of the façade, number of entry and exit chambers, extraordinary foundation costs, etc.

The high-rise stacker under construction in Hoboken, New Jersey consists of a seven-level structure with a capacity of 324 spaces on a 100-ft. square lot. The total floor area is about 70,000 sq. ft or 216 sq. ft per space. The total construction cost is about $6.5 million or about $20,000 per space. Enhanced features include an AVI access system ($98,000), a five year extended warranty ($300,000), a brick façade ($800,000), environmental remediation ($75,000-$100,000), and extraordinary costs for a deep foundation system ($150,000 to $200,000). Without these extraordinary costs, the construction cost per space would be about $16,000.

It should be noted that the equipment for the mechanical parking system can be depreciated over 7 years while the building is depreciated over 39½ years. The additional depreciation and tax benefits may enhance the financial feasibility of a mechanical parking structure.

8.5.2 Operational Costs

Operating expenses consist of cashiering, management costs, security costs, utilities, insurance, supplies, housekeeping, snow removal, equipment maintenance and miscellaneous expenses. Walker Parking Consultants has a database of operating expenses from a survey of 59 ramp-access garages varying in size from 208 spaces to 3000 spaces with a median size of 632 spaces. Little or no published data exists as to operational costs for mechanical-access parking structures. Therefore, the following paragraphs generally discuss how each of these operational costs for a mechanical-access parking structure should compare to a typical ramp-access garage.

Labor costs for revenue collection must be compared for like kinds of operation whether the parking facility is a ramp-access garage or mechanical-access garage. For instance, cashiering can be automated with pay-on-foot stations in a ramp-access garage just as is done in an automated mechanical-access garage. However, ramp-access garages may have multiple pedestrian access locations separate from the vehicle entry/exits that may require additional pay station equipment for an acceptable level of patron awareness and convenience. In a mechanical-access parking structure, an automatic pay station is required at each entry and exit chamber.

Therefore, one pay station is required for every 100± parking spaces in a mechanical parking structure. These pay stations can cost from $50,000 to $80,000 each depending on the equipment features. Equipment that accepts bills in addition to coins will add cost. The number of different denominations of bills accepted will add cost. The ability to give change adds cost as well as the ability to accept debit or credit cards for payment. While these pay stations represent a significant initial investment, they are generally less expensive in the long run than providing cashier labor.

Cashier labor is about 25 to 50% of the total operational cost for a typical ramp-access garage. Cashiering salaries and benefits add about $120 per space per year in operating costs for a typical ramp-access garage.

Mechanical parking structures function most closely like attended valet parking. Since the lifts and robots in a mechanical parking structure replace the runners in a valet parking operation, there is a huge labor savings for mechanical parking systems.

Management costs for ramp-access garages and mechanical-access garages are likely to be quite similar for the same capacity or same revenue generated.

Security costs will be significantly less in a mechanical parking structure as the upper floors are not occupied. Also, third party intruders do not typically have access to the vehicles on the upper levels. Further, patrons may lock their vehicles and take their keys. Therefore, the risk of theft and vehicle property damage is greatly reduced compared to ramp-access garages.

The median operating cost per space for utilities in a ramp-access garage is about $60 per year or $5 per month. Although the lighting in a mechanical parking structure is a third to half that of a typical ramp-access garage, the energy savings for reduced lighting are offset by the power required for the vehicle transfer equipment. One can calculate the energy costs of the equipment by multiplying the power consumed by the equipment times the average number of storage and retrievals per hour, times the average duration of each storage or retrieval, times the number of operating hours annually times the utility rate. The utility costs in a mechanical parking structure may be similar, or somewhat higher than, a ramp-access garage.

Insurance costs are likely to be less for a mechanical parking structure than for a ramp-access parking structure because of the reduced risk of personal injury, theft and property damage as vehicles are stored in a relatively inaccessible, secured location.

The cost of supplies in a ramp-access garage is about $8 per space per year. This cost is not likely to be much different for a mechanical-access garage.

Housekeeping expenses in a ramp-access garage are typically about $20 per space per year. Housekeeping expenses may be somewhat less in a mechanical parking structure as the area occupied by the public is severely reduced.

Structural maintenance may or may not be less in a mechanical parking structure compared to a ramp-access garage. Concrete floors in ramp-access garages are subject to freezing and thawing as well as potential deterioration from de-icing salts carried into the structure by vehicles. Mechanical parking structures are typically enclosed and therefore not subjected to precipitation, however, vehicles will carry in ice, snow, and de-icing salts that will fall off onto the pallets, floor, and frame of the mechanical garage. Therefore, structural maintenance is required in a mechanical parking structure, but to a lesser extent than in a ramp access garage.

Snow removal is not a concern where the mechanical parking structure is totally enclosed. However, clear access must be maintained at the entry and exit drives. Some limited snow removal cost should be included for mechanical parking structures in northern climates.

According to industry manufacturers., the total operating cost of a fully-automated, mechanical parking structure will be in the range of $25 to $55 per space per month ($300 to $660 per space annually) depending upon the number of spaces, the level of activity, and the hours of operation. According to Walker Parking Consultants' 1996 survey, the median operating cost for a ramp-access garage without cashiering is $374 per space per year. Therefore, the non-cashiering expenses of a mechanical-access garage may be approximately 1.5 times that of a ramp-access garage.

8.6 SUMMARY

The construction cost of mechanical-access parking structures is typically 50% to 100% more expensive than a ramp-access parking structure, however, mechanical parking structures represent an economically viable solution for expansion of parking on small sites in congested urban areas. Not only may it be physically impossible to accommodate a ramp-access garage on a site that is less than 150 ft long, but the inefficient parking configuration on a small floor plate may drive the cost of the ramp-access garage up to the typical cost of a mechanical-access parking structure. Since a mechanical-access garage requires a much smaller footprint than a ramp-access garage, the potential savings in land cost will further enhance the economic viability of mechanical parking.

Past problems with slow retrieval of vehicles in high-rise mechanical parking structures have been overcome by the use of multiple lifts and robots that can operate simultaneously using sophisticated computer software.

The reliability of mechanical-access parking systems has improved tremendously in the last 10 to 20 years. Multiple transfer devices, multiple lifts, and multiple computers provide redundancy and adequate backup in the event of a failure. Sensors detect equipment degradation so maintenance is performed before failure occurs. Solid-state electronics have replaced the old hydraulic systems of the past.

Mechanical parking systems are more user-friendly than ever before. The time has come to discard the past horror stories, and accept the new technology.

8.7 REFERENCES

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   c. AutoSpace Corporation, Boston, MA.
   d. ShinMaywa Automated Parking Systems, Los Angeles, CA.
   e. CAR-SAFE, KRUPS Parking Systems, Dortmund, Germany.
   f. Klaus Parking Systems USA, Inc., Toronto, Ontario, Canada.
   g. ParkPlus, Bloomfield, NJ.
   h. ChessPark, ASSA Industries Ltd., Rishon Le-Zion, Israel.
   i. TreviPark Automatic Parking System, TREVICOS Corporation, Boston, MA.
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Chapter 9

LIGHTING

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Lighting is one of the most critical elements of parking structure design. Lighting is required for visibility of fixed objects, vehicles and pedestrians. As stated in the IESNA Lighting Handbook, "Vision depends on light. It is the role of those responsible for lighting design to provide an environment in which people, through the course of vision, can function effectively, efficiently and comfortably."

In many ways, good lighting is more critical in parking facilities than in other building types. Vehicles and pedestrians frequently use the same circulation aisles, and drivers must be able to see pedestrians walking suddenly from between parked cars into driving aisles. Drivers must be more alert to potential hazards, with less time to see, recognize and react to objects entering the field of vision (central 120 degrees in front of both eyes) than is necessary for pedestrians.

As noted in Chapter 7, slip or trip and fall accidents represent over 50% of personal-injury liability claims in parking facilities. Therefore, adequate visibility of pavement surface and curbs is very important.

As discussed in Chapter 6, parking facilities are at somewhat higher risk of violent crime than all other land uses except residential. Lighting is not only the most critical element in reducing crime; it is also a major contributor to the user's perception of security and safety.

As in other chapters, the actual and complete design methodology is not presented. Instead, the focus of this text is on the adaptation and application of standard engineering approaches for the specific needs of a parking structure. Basic concepts and critical issues are discussed so that all team members can be satisfied that the lighting design is "state of the art" while meeting owner and user requirements.

A. P. Chrest et al., *Parking Structures*

9.1 BASIC CONCEPTS

The fundamental concepts of vision and task visibility form the basis of the lighting design.

9.1.1 Vision

Light is radiant energy propagated in the form of electromagnetic waves. The human eye is sensitive to electromagnetic waves in the *visible spectrum,* which ranges from violet and blue light at the shortest wavelengths (380 nm) to orange and red at the longest (770 nm). Ultraviolet light is just outside the spectrum at one end, while infrared light is outside the other end. The peak visual response occurs at a wavelength of about 555 nanometers (nm).

Visual acuity, color recognition, contrast detection and brightness perception are greatest within a 2-degree field of view from the line of site known as the fovea. Vision outside of the fovea is known as off-axis or peripheral vision.

Even with corrective lenses, not everyone has perfect vision. Designers must consider common vision deficiencies within the general population when establishing illumination levels.

Vision decreases significantly with age because of a reduction in light transmittance to the retina due to thickening and yellowing of the eye lens. Light transmittance in the eye at 20 years old is more than four times greater than at 70 years old. Also, there is a certain amount of scattering of light that occurs within the eye that can interfere with vision. The amount of scattering within the eye also increases with age, resulting in greater susceptibility of older people to glare from bright light sources in the field of view.

About 8% of males and 0.5% of females are color-impaired. Most "color-blind" people can distinguish yellows from blues, but confuse reds and greens.

9.1.2 Visibility

In order to see a task at all, it must receive (or generate) some minimal amount of illumination. Likewise, it must have sufficient size and adequate amount of contrast with its background. The visibility of the task can be impaired by excessively bright light sources in the field of view. Therefore, visibility is primarily a function of illuminance, contrast and glare.

9.1.2.1 Illuminance

Illuminance is the quantity of light falling on a surface. The illuminance, *E*, at a point on a surface varies directly with the luminous intensity of the light source, *I*, and inversely as the square of the distance, *d*, between the light source and the point (see Figure 9-1). If the surface at a point is normal to the direction of the incident light, the illuminance is expressed as follows:

$$E = I/d^2$$

This equation holds true within 0.5% when d is at least five times the maximum dimension of the light source (or luminaire) as viewed from the point on the surface.

Light falling on a horizontal surface (floor or table) is known as horizontal illuminance. The horizontal illuminance at a point varies with the cosine of the angle of incidence (θ) from the light source and is expressed as follows:

$$E_H = I/d^2 \cos\theta$$

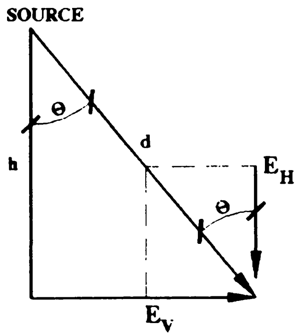


Figure 9-1.
Illuminance Calculation at a point.

Similarly, light falling on vertical surface (wall) is known as vertical illuminance. The vertical illuminance at a point varies with the sine of the angle of incidence (θ), and is then expressed as follows:

$$E_V = I/d^2 \sin\theta$$

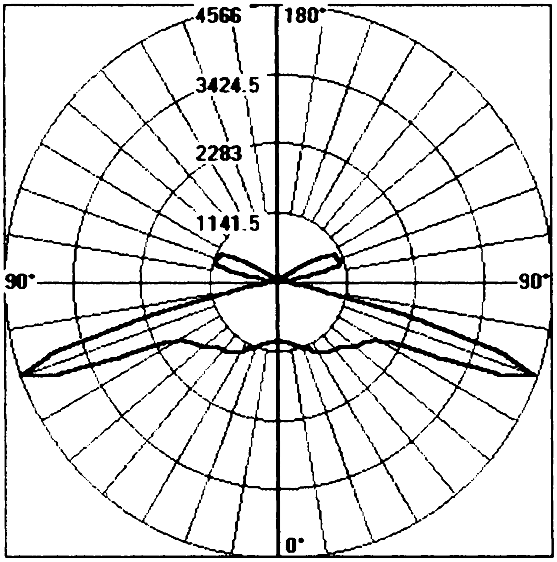
The luminous intensity of the light source, *I*, is expressed in candelas (cd). At one time called candlepower, it was defined in terms of flame or filament standards. For practical purposes, the terms candela and candlepower are equivalent. The current definition of the candela is:

...the luminous intensity in a given direction, of a source that emits monochromatic radiation of frequency 540 X 10^{12} Herz (Hz) and that has a radiant intensity of 1/683 watts/steradian (w/sr).

The lumen is a unit relating radiant energy (in watts) to visually effective light for a standard human observer. One lumen is defined as the luminous intensity of a uniform light source of one candela falling on one square unit of surface area on a sphere surrounding the light source with a radius of one unit. If the sphere's radius is 1 meter, then the illuminance on the sphere's wall is one lumen per square meter, or 1 lux (lx). If the radius is 1 foot, the illuminance is 1 lumen per square foot, or 1 footcandle (fc). One footcandle is then equal to 10.76 lux. The conversion from footcandles to lux is often rounded to 10 for ease of use. The total light output of a uniform light source of one candela is then 4π (12.56) lumens (equals surface area of a sphere with a unit radius).

After the luminaire locations are selected, the illuminance calculation procedure involves establishing a grid of points at a uniform spacing throughout the surface or plane to be analyzed. In accordance with IESNA publication LM-64, the maximum point spacing is 2 meters (6 feet) for the covered levels of parking structures, or a maximum point spacing of 10 meters (30 feet) in surface parking lots or on roofs of parking structures. One must then determine the luminous intensity from the luminaire to each calculation point.

The luminous intensity of a luminaire is calibrated in a testing laboratory at various vertical angles around an arc above and below the fixture as



Notes:

1. Lighting intensity measured in candelas.
2. Vertical line through fixture is at 0 degrees (down) and 180 degrees (up).
3. Maximum intensity occurs at a 70-degree angle from nadir.

Figure 9-2. Polar Graph of Photometric Test Lithonia PGR Luminaire shown in Figure 9-2. These vertical sections are then repeated at various horizontal angles laterally around the fixture. The lighting intensity is then reported in a table with the vertical angles listed in rows along the side and the horizontal angles listed in columns across the top. One then calculates the horizontal and vertical angle from the calculation point to the light fixture, interpolates the luminous intensity from the laboratory photometric table, and then calculates the illuminance in accordance with the appropriate formula above.

The illuminance at a point is a function of both direct and reflected light. Further, the illuminance at a point is the sum of the contribution from each luminaire within the lighted space. Obviously, the hand calculation of the illuminance at a point is quite laborious, but easily accomplished with computer software. In fact, computer software is available that quickly calculates both direct light and inter-reflected light, as well as model structural elements that potentially obstruct or alter the light distribution.

The results of the illuminance calculations are then tabulated for the average of all points, the maximum calculated illuminance at any point, and the minimum calculated illuminance at any point. These results are then compared to the IESNA illuminance standards for compliance (see Section 9.2.1).

9.1.2.2 Contrast

Another important luminous quantity is luminance. Luminance relates directly to perceived "brightness", that is, the visual effect that illumination produces. The eye does not "see" direct light; visual response only occurs when the light is reflected from an object. Adequate luminance contrast of an object against its background is required for proper visibility.

Luminance is equal to illuminance times the reflectance (ρ) of the surface divided by pi.

$$L=E\rho/\pi$$

Tables 9-1 and 9-2 indicate the reflectance properties of different surfaces and colors. The unit of measure for luminance is candelas per square meter. Since luminance is more directly related to visibility than illuminance, there is a trend in the lighting industry to specify minimum luminance standards rather than minimum illuminance.

Table 9-1. Reflectance of Building Materials and Outside Surfaces

Material	Reflectance (percent)	Material	Reflectance (percent)
Bluestone, Sandstone	18	Asphalt (free from dirt)	7
Brick		Earth (moist cultivated)	7
Light buff	48	Granolite pavement	17
Dark buff	40	Grass (dark green)	6
Dark red glazed	30	Gravel	13
Cement	27	Macadam	18
Concrete	40	Slate (dark clay)	8
Marble (white)	45	Snow	
Paint (white)		New	74
New	75	Old	64
Old	55	Vegetation (mean)	25
Glass			
Clear	7		
Reflective	20-30		
Tinted	7		

Source: IESNA Lighting Handbook

Table 9-2. Reflectance of Various Colors

Color	Reflectance	Glidden Color
White	90%	AC-98
Yellow	74%	AC-630
Pink	53%	AC-296
Grey	41%	AC-516
Orange	29%	AC-592
Green	20%	AC-677
Brown	19%	AC-595
Red	18%	AC-528
Blue	11%	AC-722
Purple	11%	AC-749
Black	4%	AC-780

Source: Glidden paint Company

Contrast is defined as the difference in luminance or brightness of the object against its background and is calculated as follows:

$$L_t - L_b / L_b$$

Where L_t equals the luminance of the target and L_b equals the background luminance.

Contrast is enhanced by painting the object so that the contrast against its background will be increased. A concrete wheel stop against a concrete floor will have little contrast since the object and its background will have similar reflectance. Painting the wheel stop yellow will greatly enhance its visibility.

The amount of contrast required for adequate visibility of a small target has been researched extensively by the Roadway Lighting Committee of the Illuminating Engineering Society. The contrast at which the object can be detected 50% of the time is called the threshold contrast. For a 99.9% probability of detecting the object, the threshold contrast should be multiplied by a factor of 2.6. The required contrast varies with the light level and age of the observer.

Figure 9-3 indicates the required contrast at a 99.9% probability of detecting a 6-inch high concrete curb viewed at a distance of 20 feet. Note that the amount of contrast required increases significantly at light levels less than 0.5 footcandles. Conversely, very little benefit in terms of greater object detection occurs when the illuminance exceeds 3 footcandles.

Figure 9-3. Required Contrast vs. Illuminance

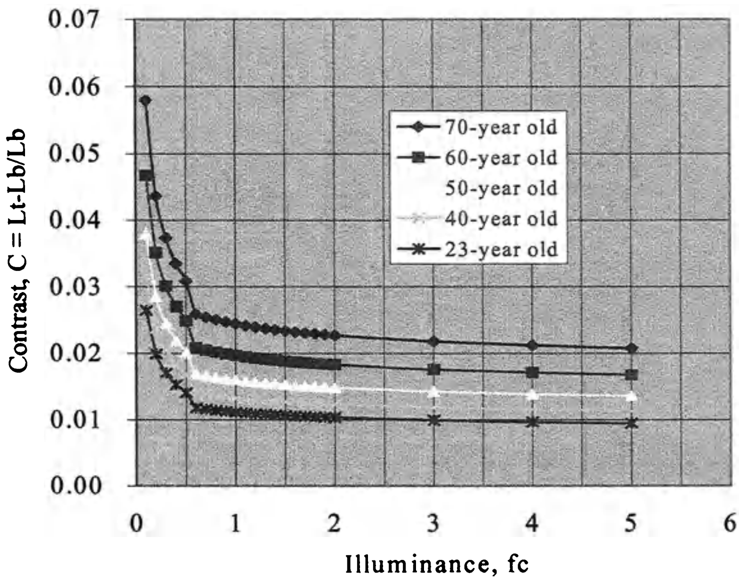
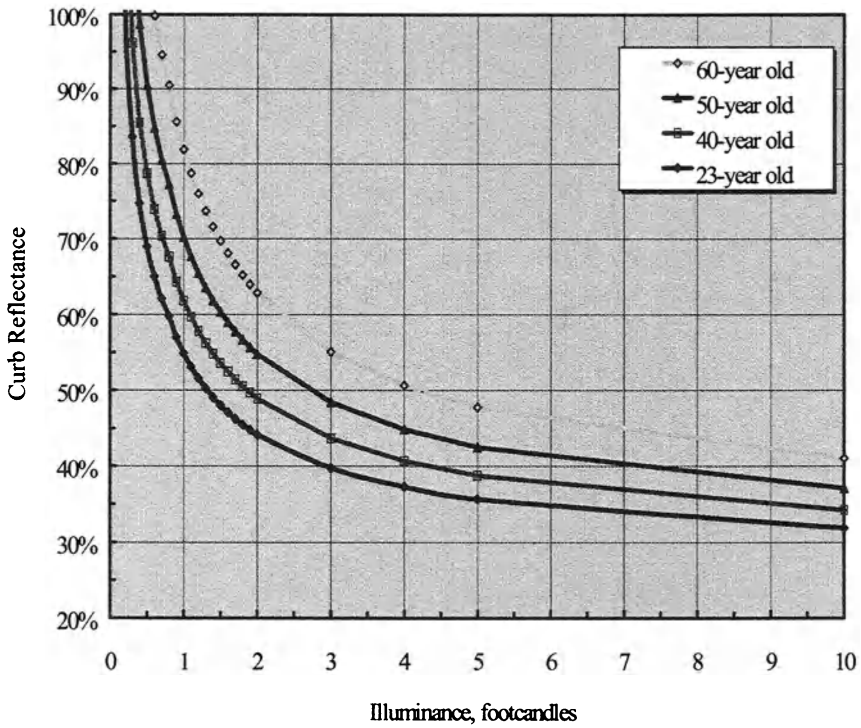


Figure 9-4. Required Reflectance of 6 inch Concrete Curb on Concrete Floor



How does this information translate to the visibility of wheel stops or curbs? By manipulation of the visibility formula, one can derive the reflectance value required for the wheel stop or curb. This calculation is illustrated in Figure 9-4. For a minimum illuminance of 1 footcandle, the required reflectance for a 30-year-old observer is approximately 40%. For a 70-year old patron, the required reflectance is over 70%. Therefore, for a 40-year old observer, a clean concrete wheel stop may not need to be painted. However, for the 70-year old observer, the curb or wheel stop should be painted yellow or white.

Visibility calculations for object detection in parking facilities show that a minimum illuminance of approximately 0.2 fc (2 lux) is necessary for adequate visibility of concrete curbs or wheel stops outdoors at night. A minimum illuminance of approximately 0.5 fc (5 lux) is necessary inside a parking structure due to the higher background luminance and lower contrast of the concrete curb or wheel stop against the concrete floor.

9.1.2.3 Glare

Glare is an excessive amount of light reaching the eye in contrast to the amount of ambient light to which the eye was previously adapted. The effect of adapted luminance on glare is best illustrated by the fact that vehicle headlights can be very annoying at night, but hardly perceptible during daylight.

Glare is categorized in two ways: discomfort and disability. In the former case, there is discomfort, but the ability to see is retained. An example of discomfort glare is squinting your eyes on a bright sunny day, when ambient illuminance may be more than 10,000 footcandles. Disability glare occurs when the ability to see and function is affected, such as the temporary blindness that occurs after one passes an oncoming car at night with its high beams on.

There are actually two sources of glare. The first is direct glare, which is excessive light from the source directly entering the eye. The second is reflected glare. In some cases, both types of glare are present. Direct glare is controllable by:

- Shielding the light source from the observer.
- Decreasing the luminous intensity (lamp wattage) of the light source.
- Reducing the area of the light source.
- Increasing the background luminance around the source (for example, paint the ceilings and walls white).

Reflected glare is more difficult to control as it may be due to vehicles or objects that are not part of the parking structure itself. However, the designer must be aware of possible reflections from windows and sign surfaces. Paint surfaces with flat paints rather than gloss or semi-gloss paint.

Disability glare is not a problem in covered parking structures at night, as the lamp intensity typically does not exceed 200 watts. Disability glare is only a problem during the daytime, particularly on clear, sunny days. Bright sunlight through perimeter wall openings often obscures the visibility of signs placed on the line of sight directly in front of those openings. The veiling luminance from bright sunlight through perimeter window openings can also obscure the visibility of trip hazards when the patron's line of sight is toward the window opening. Where veiling luminance is a problem, one must remove the glare source or provide additional contrast (for example, internally illuminated signs) and/or provide enhanced illuminance of the target or object.

In addition, the driver's vision may be impaired in transitioning from bright sunlight to the darker interior at parking structure entrances. Gated parking equipment facilitates this transition by delaying the driver long enough for the driver's eyes to adapt to the darker interior of the parking structure. However, if free flow access is provided at the entrance, enhanced lighting (minimum of 50 fc) is required for at least 60 feet inside the parking structure portals during the daytime to facilitate the transition from light to dark, and to allow the eyes to adapt more gradually.

Most measurements of discomfort glare produced by single glare sources have been performed by determining the luminance *L* just necessary to cause discomfort as subjectively recorded by a group of people representative of the general population. Data from one investigation at low adaption luminances indicates that the borderline between comfort and discomfort (BCD) is described by the formula:

$L = 527F^{0.44}$ where F equals the background luminance in candela per square meter.

Since the reflectance of unpainted concrete is approximately 35%, the background luminance in a covered, concrete parking structure is approximately equal to the average illuminance in footcandles. Therefore, at an average illuminance of 5 footcandles, the background luminance is approximately 5 candelas per square meter (cd/m^2). The maximum luminous intensity of the glare source should then not exceed 1074 candelas per square meter.

The luminance of a luminaire is calculated by determining the luminous intensity in candela from the photometric test report at the vertical and horizontal angle to the eye of the observer, and dividing by the projected area of the luminous surface perpendicular to the line of sight of the observer. Typical luminance values are shown in Table 9-3.

The angle of view for the driver is shielded by the vehicle roof overhang at an angle of approximately 15 degrees above the horizontal line of sight, such that the glare zone is then between a 75 degree and 90 degree angle from a vertical line through the fixture (see Figure 9-5). Many garage luminaires are engineered using reflectors and refractors to reduce the luminous intensity in this glare zone.

Table 9-3.
Approximate Luminance of
Various Light Sources (cd/m^2)

Light Source	Luminance
60-watt incandescent lamp	30,000
8-foot, T12 bare fluorescent lamp	11,900
8-foot, T12 fluorescent lamp with wrap-around lens	4,400
100-watt HPS , Garage Luminaire	12,000 – 18,000
150-watt HPS, Garage Luminaire	20,000 – 30,000

If a bare lamp is wrapped with a prismatic lens, the area of the luminous surface (lens) is increased while the luminous intensity is the same for the same wattage lamp, less the light lost through the lens material. Therefore, the fixture luminance decreases substantially when a lens or refractor is used. However, the luminance values for 100 to 175-watt fixtures typically used in parking structures are still well above the threshold BCD luminance value. The upshot of this statement is that patrons will experience discomfort when viewing a typical parking structure fixture directly in their line of sight. It is then incumbent on the designer to locate the fixtures as far as possible from the driver's and pedestrian's direct line of sight (for example, do not locate light fixtures along the centerline of the drive aisle). In addition, it is important to shield the fixtures as much as possible without impacting the distribution of light from the fixture too severely. The structural elements in a typical parking structure generally serve this purpose (see Figure 9-5).

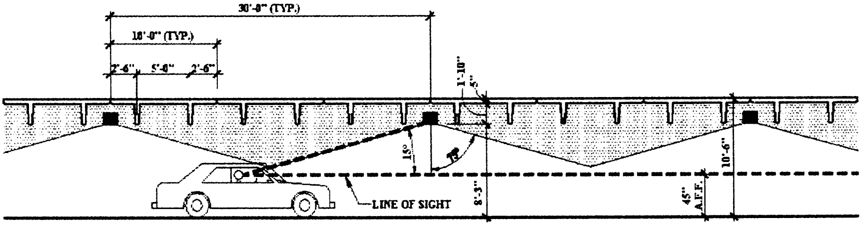


Figure 9-5. Defining the Visual Field

It should be noted that painting the ceiling and walls white increases the background luminance by a factor of approximately 2.5. The BCD luminance calculated from the above formula then increases to 1607 cd/m^2. This value is still well below the luminance of typical parking structure fixtures.

Another option is to consider indirect lighting of the interior. Indirect lighting systems utilize shielded fixtures with the light directed up at the ceiling. The interior space is then illuminated solely by reflectance off the ceiling. However, approximately 3 to 4 times as many fixtures are required for unpainted concrete surfaces, and approximately 2 times as many fixtures are required for white painted concrete as compared to direct lighting designs. Federal, state, and local energy limitations will likely preclude that type of lighting system in a parking structure. Cutoff light fixtures also reduce glare, but often do not provide adequate vertical illuminance at 5 feet and above for ambient illumination of signage and pedestrians when fixture mounting height is less than 10 feet.

9.2 LIGHTING DESIGN ISSUES

Issues that must be addressed in lighting design include selection of the lamp or light source, selection of the fixture, and placement of the fixture. Before those issues can be resolved, however, one must first set the design requirements for level of illumination.

9.2.1 Minimum Illumination Levels

The Illuminating Engineering Society of North America (IESNA) is the recognized technical authority for the illumination of indoor and outdoor environments. The IESNA has recommended minimum illuminance levels for proper visibility for over eighty years. The Subcommittee on Off-Roadway Facilities of the IESNA Roadway Lighting Committee is charged with setting standards for lighting of parking facilities, both surface lots and structures. The current recommended practice *RP-20 Lighting for Parking Facilities* was published initially in 1985 and significantly revised in 1998. The updated recommended practice for parking facility lighting is also included in the ninth edition of the IESNA *Lighting Handbook.* All of the discussion herein is based on the latest IESNA standards.

The IESNA minimum illuminance criteria for surface parking lots and roofs of parking structures are shown in Tables 9-4 and 9-5.

Table 9-4. Recommended Maintained Illuminance Values for Parking Lots

		Basic	Enhanced Security
Minimum Horizontal Illuminance	lux	2	5
	fc	0.2	0.5
Uniformity Ratio, Maximum to Minimum		20:1	15:1
Minimum Vertical Illuminance	lux	1	2.5
	fc	0.1	0.25

Table 9-5. Recommended Maintained Illuminance Values for Parking Garages

		Minimum Horizontal Lux	fc	Maximum/Minimum Horizontal Uniformity Ratio	Minimum Vertical Lux	fc
Basic		10	1.0	10:1	5	0.5
Ramps						
	Day	20	2.0	10:1	10	1.0
	Night	10	1.0	10:1	5	0.5
Entrance Areas						
	Day	500	50		250	25
	Night	10	1.0	10:1	5	0.5
Stairways		20	2.0		10	1.0

Source: IESNA RP 20-98 Lighting for Parking Facilities.

The IESNA RP-20-98 design criteria represent a significant departure from the 1985 recommended practice. The previous design criteria were based on average maintained illuminance. *Maintained* illuminance refers to the depreciated light level immediately prior to lamp replacement and fixture cleaning. As stated earlier, the average illuminance is the sum of the calculated illuminance at each point throughout the floor (maximum point spacing equals 6 feet) divided by the total number of points. The new standards are based upon the minimum maintained illuminance at any point in the structure or surface lot. Since visibility is based upon the minimum illuminance required for detection, it makes sense that the standard should be based upon minimum illuminance.

The 1985 standard specified an average maintained illuminance equal to, or greater, than 5 footcandles for parking structures. An upper limit on the average to minimum ratio was specified as 4:1. Therefore, the minimum illuminance would have to be at least 1.25 fc for an average illuminance of 5 fc. Since the current IES standard specifies a minimum illuminance of 1.0 footcandle, there is not an appreciable difference in the minimum illuminance criteria.

The human eye can see across two log-steps of brightness (for example, 1 cd/m^2 to 100 cd/m^2). Therefore, uniformity of the lighting is important in order to allow visibility of the dark areas as the eyes respond and adapt to the brightest areas in the field of view. Therefore, it makes sense that the uniformity is now expressed in terms of the maximum to minimum illuminance throughout the area of the facility as opposed to the average to minimum ratio used in the 1985 standard.

In addition, the 1998 standard has reduced the maintained vertical illuminance criteria to 50 percent of the maintained horizontal illuminance criteria on the floor, as opposed to 100 percent in the 1985 standard. Further,

the vertical illuminance is now determined at 5 feet above the pavement as opposed to 6 feet above the pavement in the 1985 standard.

The illuminance criteria in stairways has also been revised from an <u>average</u> maintained illuminance of 10, 15 or 20 footcandles depending upon the level of activity and characteristics of the users, to a <u>minimum</u> maintained illuminance criteria of 2 footcandles. This requirement is consistent with the minimum illuminance for safety (see Table 7-2) for low activity level and high hazard detection. Chapter 11 of the IESNA handbook indicates that stairways for industrial uses should have an average maintained illuminance in the range of 5 to 10 fc. Because of the relatively confined area of a typical enclosed stair (approximate dimensions of 10 feet by 20 feet), there typically is not a lot of variance in the illuminance throughout the space. The ratio of average illuminance to minimum illuminance is usually less than 2. An average illuminance in stairways of 5 footcandles is recommended. In high crime areas, an average of 10 footcandles is recommended.

In the past, IESNA did not allow the inclusion of surface reflectance in calculations of lighting. However, RP-20-98 allows for inclusion of the depreciated surface reflectance in the calculation. Even for unpainted concrete surfaces, inter-reflected light adds approximately 20 to 25% to the direct light for non-cutoff luminaires, primarily due to light reflected off the ceilings. Since cutoff luminaires do not have any uplight component, there is little, if any, benefit of increased illuminance due to reflectance for those fixtures. Reflectance of new concrete surfaces is usually about 40% but declines over time with the accumulation of dirt to 30% for walls and ceilings. The reflectance of concrete floors is typically about 20%. Concrete painted white will have a reflectance of 70 to 80%. Painting the walls and ceilings increases the illumination levels approximately 25 to 30%

compared to unpainted concrete, but the surface must be washed down annually to maintain the benefit.

The final issue to be discussed in reference to illumination levels is energy usage. In 1989 the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) in association with IESNA published a standard that specifies **maximum** power usage per unit of floor area. This standard was updated in 1999. The maximum lighting power density (LPD) in parking facilities is specified as 0.3 watts per square foot. Compliance with this standard is required on all projects that receive federal funding and in those jurisdictions that have adopted this publication in building codes or local ordinances. With the current efficiency of light sources, designing to both the IESNA lighting standards and the ASHRAE/IESNA energy standards effectively limits the average maintained illuminance at the pavement to an average of approximately 12 fc for direct lighting.

9.2.2 Level of Service in Lighting Design

Just as has been seen in other areas of parking design, there is more interest in customizing the lighting design for specific circumstances than in the past. While minimum light levels used to be employed in every facility without much question, today, many owners are asking for higher lighting levels than "minimum." These owners include not only those with a higher emphasis on user-friendliness (such as retail or airport), but also those who are at higher risk for security problems. The level of service approach is thus a useful concept for selection of lighting levels.

The level of service approach has been borrowed from traffic engineering practice where level of service (LOS) A is free flow and level of service F is gridlock.

Recommended gradation of the level of service with increasing light levels for general covered parking areas is presented in Table 9-6. The

Table 9-6. Level of Service Illuminance Ratings

LOS	Minimum Illuminance fc	Minimum Illuminance lux	Average Illuminance fc	Average Illuminance lux
A	4	40	10	100
B	3	30	8	80
C	2	20	6	60
D	1	10	4	40

IESNA basic illuminance criteria are absolute minimums, and therefore, are assigned the lowest acceptable level of service, LOS D.

The LOS A minimum illuminance criteria is based primarily upon visibility research that indicates that contrast detection and confident facial recognition are not improved significantly above a minimum illumination level of 4 footcandles. The LOS A average light level also considers the maximum lighting power density (LPD) limitations by the ASHRAE 90.1-1999 energy standards (0.3 watts per SF for parking garages). Minimum illuminance takes precedence over average illuminance in determining the LOS rating.

9.2.3 Lamp Selection

Several different lamp types are commonly used in parking facilities. These may be grouped into two broad categories: fluorescent and *high intensity discharge (HID)*. All of these lamps consist of a sealed arc tube with two electrodes. The tube is filled with a gas that is ionized by the passage of an electric arc through it.

HID lamps commonly used in parking facilities include mercury vapor (MV), metal halide (MH) and high-pressure sodium (HPS). The low-pressure sodium (LPS) lamps sometimes used in roadway lighting are not appropriate to the parking environment because of their extremely poor color rendition. One exception to that rule occurs in locations where there is a concern for sky glow or stray light emitted into the atmosphere. For example, stray light impairs the visibility for astronomers. Therefore, where observatories are located nearby, top tiers and surface lots may need to be illuminated with LPS, because this monochromatic light source can be easily filtered. The mercury vapor lamp, once considered the best alternative to HPS, has largely been replaced by MH lamps and/or improved versions of the fluorescent lamp. Therefore, MV lamps are not considered further.

The fluorescent lamp is familiar to most people as the long white tube used in offices and kitchens. The fluorescent lamp is actually a low-pressure mercury vapor lamp, with a phosphor coating. As an arc of electricity passes through the lamp, the mercury in the lamp vaporizes and emits ultraviolet radiation. The radiation activates the phosphor powder coating inside the lamp, allowing the radiation to become visible light. Fluorescent lamps have very good color rendition. Fluorescent lamps also start up within seconds—rather than minutes as with HID lamps—from both cold and hot starts, and are therefore preferred for emergency lighting. Manufacturers describe fluorescent lamps in terms of the diameter of the tube, utilizing a "T" designation followed by a number that indicates how many multiples of eighths of an inch for the diameter. For instance, a T8 fluorescent lamp is one-inch diameter, a T5 lamp is 5/8-inch diameter, and a T-12 lamp is 1½-inches in diameter.

The key issues in lamp selection are energy efficiency, (light output produced per watt of energy, also called efficacy), depreciation of light output with age (lamp lumen depreciation), lamp life (re-lamp maintenance costs), color rendering, and life cycle costs.

9.2.3.1 Energy Efficiency

Energy efficiency (also known as efficacy) is determined from the ratio of lumen output of the lamp to the watts of energy consumed. The higher the ratio, the better the efficiency. The energy consumed consists of the lamp watts plus the ballast watts. New advances in ballast technology have greatly reduced the energy requirements of lamp-ballast systems. Since 75 to 85 percent of the life cycle cost of the lighting system consists of energy costs, energy efficiency is the single-most important element in lamp selection. Table 9-7 indicates the initial lumen output and wattage for typical parking structure light sources:

Table 9-7. Initial Lamp Efficacy

Lamp	Total Watts	Initial Lumens	Lumens per Watt
150 W HPS	188	16,000	85
150W/PS MH	172[1]	15,000	87
175 W/PS MH	194[1]	17,500	90
4, T8 Fluor	113[2]	11,800	104

[1] Pulse-start metal halide lamp with 277V controlled current, reactor ballast. Source: Venture Lighting International

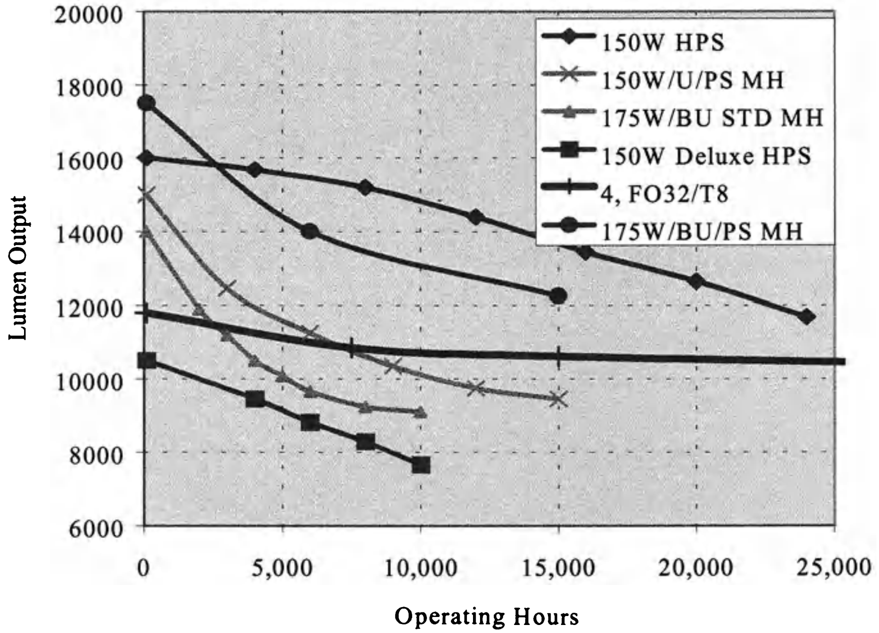
[2] Utilizes a four-lamp, high-frequency electronic ballast. Source: Osram-Sylvania Lighting.

Therefore, fluorescent lamps with electronic ballasts are the most efficient light source. Pulse-start, metal-halide lamps and high-pressure sodium lamps are relatively equal in terms of energy efficiency.

9.2.3.2 Light Loss Factors

The light output of all lamps diminishes with age. This factor is known as lamp lumen depreciation or LLD. Figure 9-6 illustrates the lumen depreciation for the lamps illustrated in the above table.

Figure 9-6. Lamp Lumen Depreciation



In addition, the light output is affected by the ballast used with the lamp in the production luminaires for your project. It is standard industry practice to perform the laboratory photometric test with a reference ballast specially constructed to have certain prescribed characteristics for use with electric discharge lamps. The reduction or increase in light output for the actual ballast in relation to the reference ballast is published by the ballast manufacturer and is known as the *ballast factor (BF)*. The ballast factor for MH and HPS lamps is typically 1.0. The ballast factor for fluorescent lamps may range from 0.7 to 1.2. Therefore, it is very important to know the ballast factor for fluorescent lamps, in particular. The lighting calculations must then consider the total light loss of the lamp-ballast system in determining the most efficient light source.

The IESNA RP20-98 publication specifies that the maintained illuminance calculations consider the light loss factors just prior to lamp replacement and fixture cleaning. Since few, if any, parking structure owners replace lamps before they burn out; the lamp lumen depreciation (LLD) should be determined at the end of the rated life of the lamp. The total light-loss factor (LLF) is then the product of the lamp lumen depreciation at 100% of the rated life, times the ballast factor.

The *design lumens* for calculating maintained illuminance and determining the energy efficiency of the lamp-ballast system is illustrated in Table 9-8:

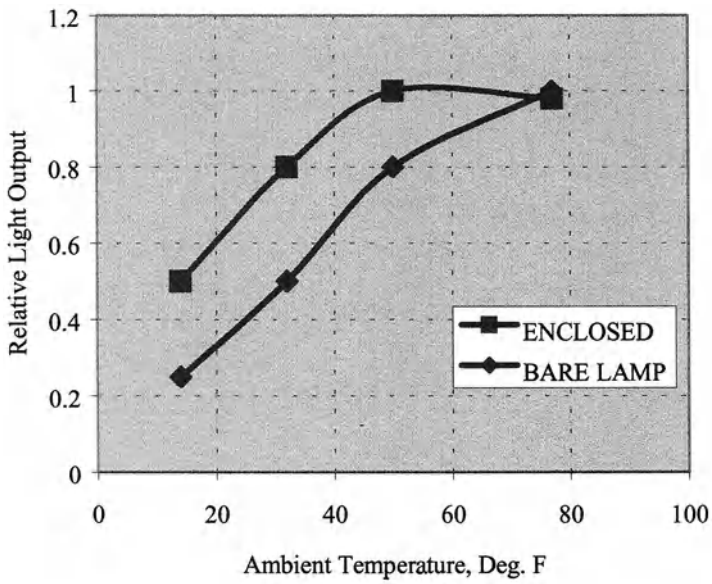
Table 9-8. Maintained Lighting System Characteristics

Lamp	Total Watts	Initial Lumens	LLD	BF	LLF	Design Lumens	Efficacy
150W HPS	188	16,000	0.73	1.0	0.73	11,680	62
150W/PS MH	172	15,000	0.62	1.0	0.62	9,300	54
175 W/PS MH	194	17,500	0.70	1.0	0.70	12,250	63
4, T8 Fluor	113	11,800	0.92	0.88	0.79	9,322	82

Therefore, in terms of the maintained light output, the fluorescent lighting system is the most energy-efficient. In terms of the illuminance values, the 150W HPS and 175W/PS MH light sources will provide equivalent illuminance for the same fixture layout. The 150W/PS MH and four, T8 Fluorescent systems will provide equivalent illuminance with each other, but the illuminance will be approximately 20 to 25% less than the 150W HPS or 175W/PS MH systems.

Although the fluorescent lighting system noted previously is the most energy-efficient, fluorescent lamps are subject to significant loss in light output at temperatures below 50°F. A 50% light loss occurs at 32°F (see Figure 9-7). Therefore, fluorescent lamps should not be used outdoors in winter climates where temperatures below 32°F are anticipated (see Table 9-9). Further, cold weather ballasts are required for temperatures below 60°F. Where temperature conditions frequently fall below 50°F, a wrap-around lens should be used to contain the heat generated by the lamps and protect the lamp from the wind. The light loss at 32°F for an enclosed fluorescent lamp is only 20%. In any event, a light loss factor due to temperature should be included in the design. While additional fluorescent fixtures may

Figure 9-7. T8 Fluorescent Light Output Vs. Temperature



be required at closer spacing to develop the equivalent illuminance to the MH or HPS systems, which are unaffected by temperature, the 35 to 40% lower wattage of the fluorescent system allows the addition of a significant number of fixtures and still save energy.

Another factor to consider in the illuminance calculation is the reduction of light output due to dirt and bug accumulation on the lenses as well as

Table 9-9. Mean Number of Days Annually with Minimum Temperature 32°F or Less

Flagstaff, AZ	209	Chicago, IL	131	Charlotte, NC	63
Phoenix, AZ	6	Indianapolis, IN	116	Oklahoma City, OK	78
Los Angeles, CA	0	Wichita, KS	109	Portland, OR	43
Fresno, CA	21	Louisville, KY	88	Eugene, OR	55
Sacramento, CA	16	New Orleans, LA	14	Charleston, SC	33
San Francisco, CA	2	Shreveport, LA	37	Nashville, TN	76
Denver, CO	155	Kansas City, MO	111	Dallas, TX	39
Jacksonville, FL	15	Jackson, MS	49	Houston, TX	19
Orlando, FL	2	Las Vegas, NV	30	Salt Lake City, UT	123
Atlanta, GA	52	Reno, NV	166	Richmond, VA	84
Savannah, GA	28	Albuquerque, NM	116	Seattle, WA	31
				Olympia, WA	86

Source: National Weather Service Climatological Data Center yellowing of the lens. However, this factor is common to all light sources and is not a factor in determining which light source to use. The Luminaire Dirt Depreciation (LDD) factor is typically 0.8 to 0.9 depending on the frequency of fixture cleaning. The total light-loss factor is then the product of the individual light-loss factors described above.

9.2.3.3 Lamp Life

The cost of re-lamping is typically 5 to 10% of the total life cycle cost of the lighting system. The re-lamping cost is a function of the lamp cost and lamp life (See Table 9-10).

Table 9-10. Lamp Life and Cost

Lamp	Lamp Cost	Lamp Life Hours (1)
150W HPS	\$15-\$20	28,000
150W/PS MH	\$20-\$25	15,000
175W/PS MH	\$22-\$28	15,000
4,T8 Fluor	\$2 each/ \$8 total	30,000

(1) Based upon a minimum of 10 hours per start.

Therefore, metal halide lamps will have the highest maintenance cost because of the relatively higher lamp cost and the fact that lamps will burn out twice as frequently as HPS or Fluorescent Systems. It should also be noted that pulse start MH lamps have 50% longer lamp life than standard MH lamps.

Further, the position of the lamp affects the life of MH lamps. A horizontal pulse start MH lamp will have approximately 75% of the lamp life of a vertical MH lamp (for example, base up or base down). In addition, the lumen output of a horizontal MH lamp is 10% less than a vertical MH lamp. HPS lamps are unaffected by the position of the lamp.

9.2.3.4 Color Rendering

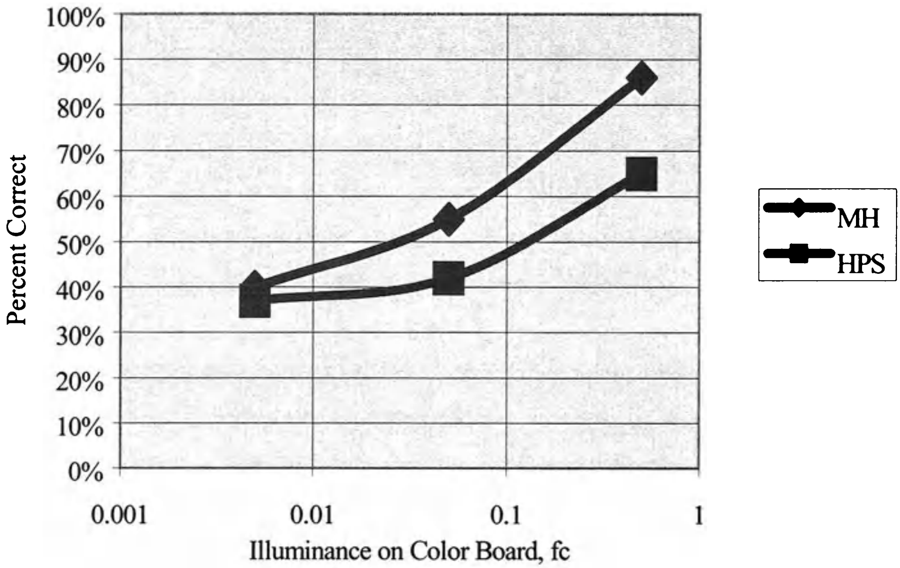
HPS lamps emit a yellowish light while MH and Fluorescent lamps emit white light. While some users would say the yellowish glow of HPS lighting adds warmth to the stark interior of a concrete parking structure, many studies have been performed that indicate brightness perception is enhanced with white light sources. In fact, approximately 30 to 40% more illuminance with HPS lighting is required to achieve the equivalent brightness perception of MH lighting.

One of the drawbacks to MH lamps is that the color is not consistent, even among lamps from the same manufacturer. The "white" light of a MH lamp may have bluish, pink, or green tones. This inconsistency not only affects color rendition, but also lumen output, which can vary as much as 20% from lamp to lamp.

Fluorescent lamps have the most consistent color-rendering properties. However, one can obtain fluorescent lamps with a particular color ranging from warm-white to cool-white.

Color discrimination is not particularly important in a parking facility, at least compared to the textile or food industries. Color-dependent tasks in a parking facility consist of identifying one's vehicle or identifying the color-coding of different floors. Figure 9-8 indicates the color-naming accuracy of HPS lighting versus MH lighting.

Figure 9-8. Color Naming Accuracy vs. Illuminance



Source: Mehra, 1999 and Rea, 1999

Experienced lighting designers consider that the color rendition of HPS lamps has gotten a "bad rap." According to Dr. Richard Corth:

> "The human visual system is extremely adaptable to changes in illumination and spectral composition. Further, chromatic adaptation can be extremely rapid depending on familiarity with the luminant. Thus, one is adapted, for example, to incandescent illumination

> immediately upon entering such an environment from daylight... It might be expected that as the public becomes more familiar with HPS, similar adaptation will occur. There is considerable anecdotal data indicating that this is already the case."

Even when color adaptation is not immediate as described above, the typical parking structure patron has adequate time to adapt to the light source before color recognition becomes a critical task.

Knowing that the color rendition is the single biggest problem with HPS, manufacturers are constantly working to improve the lamps. The color-corrected HPS lamp (Deluxe HPS) on the market at the time of this writing has lower efficiency and reduced lamp life (about 15,000 hours). The life cycle cost is no better than with MH lamps and therefore MH would be the current choice vis-a-vis the color-corrected HPS lamp. Various manufacturers report that they are "close" to producing a color-corrected HPS lamp without those deficiencies.

9.2.3.5 Life Cycle Cost

Life cycle costs (LCC) consist of the operating cost (energy cost), maintenance cost (relamping and fixture cleaning), and initial construction cost accumulated over the useful life of the luminaire, including an adjustment factor for inflation. The useful life of the lighting system is determined at the point where the luminaire gaskets have become brittle, the lenses have yellowed, and frequent ballast replacement has become necessary. The cost of repair then approaches the cost of replacement. The useful life is typically about 25 years. Alternate designs are often compared to determine the incremental LCC to provide LOS B lighting versus LOS C lighting.

The annual operating cost is determined by multiplying the total watts of the lamp-ballast system, times the number of luminaires, times the annual operating hours, times the energy cost charged by the utility. The total energy consumed by a luminaire consists of the lamp watts plus ballast watts. The ballast wattage for HID lamps is approximately 10 to 25% of the lamp wattage. The number of luminaires is a function of the design illuminance and the fixture spacing required to achieve that illuminance. The annual operating hours for the covered levels with all lights on for 24 hours per day, 7 days a week will be 8,760 hours. For light fixtures that are on only from dusk to dawn (e.g. roof fixtures), the annual operating hours will be approximately 4000 hours. Average utility costs vary from $0.06

per kilowatt-hour in Las Vegas to $0.12 per kWh in San Francisco. The U.S. average is approximately $0.09 per kWh at this writing.

The maintenance cost is calculated by first determining the number of lamps that expire annually, based upon the lamp life. The annual operating hours are divided by the lamp life to determine the percentage of lamps that will expire annually. Since the lamp life is determined as the point at which 50% of the lamps have expired, the number of fixtures should be multiplied by 50% and then multiplied by the percentage that will expire annually. One must then estimate the labor hours, labor cost, and lamp cost to replace the lamp and clean the fixture. That cost is then multiplied by the annual number of lamps that will expire.

The annual operating and maintenance costs are then accumulated over the useful life of the lighting system including an adjustment factor for inflation. The 25-year operation and maintenance costs are then added to the estimated initial construction cost to arrive at the total life cycle cost. A typical analysis is indicated in Table 9-11.

Table 9-11. Life Cycle Cost Analysis (Y2000 Dollars)

	Fluorescent FO32T8	High-Pressure Sodium 150W	Metal Halide 150W Pulse Start	Metal Halide 175W Pulse Start	Metal Halide 200W Pulse Start
Watts/lamp	32	150	150	175	200
Lamps/fixture	4	1	1	1	1
Longitudinal Spacing, Ft	40	40	40	40	40
Lateral Spacing, Ft	28	28	28	28	28
Mounting Height, Ft	8	8	8	8	8
Number of Luminaires	216	216	216	216	216
Floor Area, SF	195,492	195,492	195,492	195,492	195,492
Lamp + ballast watts per fixture	113	188	172	194	219
Lighting power density (watts/sq ft)	0.12	0.21	0.19	0.21	0.24
Rated Life (hours)	30,000	28,500	15,000	15,000	15,000
Initial lumens/lamp	2,950	16,000	15,000	17,500	21,000
Lamp lumen depreciation (LLD)	0.92	0.73	0.62	0.70	0.70
Dirt depreciation	0.90	0.90	0.90	0.90	0.90
Ballast factor	0.88	1	1	1	1
Temperature factor[a]	1	1	1	1	1
Total light loss factor[b]	0.73	0.66	0.56	0.63	0.63
Design lumens per fixture	8,598	10,560	8,400	11,025	13,230
Horizontal illumination[c,d]					
Average on Pavement (fc)	6.9	7.6	6.4	8.4	10.1
Minimum on Pavement (fc)	1.9	1.9	1.5	2.1	2.5
Uniformity (average:minimum)	4.7	4.0	4.0	4.0	4.0
Uniformity (max: min)	13.0	9.9	9.9	9.9	9.9
LOS	C	C	C-	C+	B-

Twenty-Five Year Life Cycle Cost[e]					
Life Cycle Energy Cost	$895,358	$1,489,623	$1,362,846	$1,537,164	$1,735,
Life Cycle Maintenance Cost	$79,303	$54,439	$113,929	$113,929	$113,9
Initial Cost	$158,160	$235,560	$216,960	$239,160	$264,2
Total Life Cycle Cost	$1,132,821	$1,779,622	$1,693,735	$1,890,253	$2,113,
Amortized Annual LCC Cost	$45,313	$71,185	$67,749	$75,610	$84,5
Total Cost indexed to HPS Cost	0.64	1.00	0.95	1.06	1.19
Initial Cost / Life Cycle Cost	14%	13%	13%	13%	12%
Energy cost / Life Cycle Cost	79%	84%	80%	81%	82%
Maintenance Cost / Life Cycle Cost	7%	3%	7%	6%	5%
Other Considerations					
Color temperature (Kelvins)[f]	4100	2100	4000	4000	4000
Color rendition index (CRI)[g]	82	22	65	65	65
Cold start time (minutes)	0.01-0.02	3-4	1-2	1-2	
Hot start time (minutes)	0.01-0.02	1-2	3-5	3-4	

[a]Assumes southern climate
[b]Depreciation factors taken at end of rated life.
[c]Non-cutoff fixtures assumed.
[d]For fluorescent fixture, nominal lumens and watts are peak values and may be lower depending on ambient temperature.
[e]Analysis assumes 24 hour per day operation, 365 days per year.
[f]Energy cost starting at $0.08 per kWh. Energy and maintenance costs inflated at 3% per year.
[g]CRI is an international number system which indicates the relative color rendering of the lamp; the higher the number the better.

9.2.3.6 Lamp Selection Summary

There is a growing trend in the lighting industry away from the yellowish light of HPS lamps and more toward "white" light sources. In the past, the efficiency and lamp life of MH and Fluorescent lamps were no match for the cost-effectiveness of HPS lamps. However, new technology resulting in improved, pulse-start MH lamps, enhanced phosphors for fluorescent lighting, and the advent of high-frequency electronic ballasts, has revolutionized the lighting industry. In the extreme south (Florida), the desert cities (Phoenix, Las Vegas, Palm Springs), and the California coast, fluorescent lamps are the light source of choice as they are 40 percent more energy-efficient than HPS or MH lighting. However, fluorescent light output is reduced severely in cold-weather environments (50 percent reduction in light output at 32 degrees F). Therefore, pulse-start MH lamps are the light source of choice for the remainder of the United States.

9.2.4 Fixture Selection

There are three basic fixture types available for HID parking structure lighting, which are known as the cutoff luminaire, the non-cutoff luminaire, and the semi-cutoff luminaire. The IES Lighting Handbook defines these fixtures as follows:

Cutoff	Intensity at 80° from nadir does not exceed 100 cd per 1000 lamp lumens (10%) nor at 90° from nadir does intensity exceed 25 cd per 1000 lamp lumens (2.5%) Note: Full cutoff luminaires limit the intensity to zero at or above 90° from nadir.
Semicutoff	Intensity at 80° from nadir does not exceed 200 cd per 1000 lamp lumens (20%).
Noncutoff	No intensity limitations

Further, the IES classifies the lighting pattern produced by the luminaire as follows:

Type I	Narrow, symmetric distribution, highest intensity between 10 and 20° from nadir.
Type II	Wider distribution than Type I, highest intensity between 25 and 35° from nadir.
Type III	Wide distribution, highest intensity between 25 and 35° from nadir.
Type IV	Widest Distribution. (Also known as Forward Throw).
Type V	Symmetrical; produces circular illuminance pattern
Type VS Or VQ	Produces an almost symmetrically square illuminance pattern

The above classifications were largely developed for roadway lighting where the term "wider" refers to the direction across the width of the street in front of the luminaire or in the forward direction. Type I, II, III and IV distributions are largely used at the perimeters of parking lots. Type V, VS and VQ are used at the interior of parking lots or on roofs of parking structures, and for the covered levels of parking structures.

The cutoff luminaire (see Figure 9-9) encloses the lamp in the housing with a flat lens or slightly convex lens on the bottom. The light distribution consists of a cone of light below the fixture with a cutoff angle of approximately 70 to 80° from a vertical line through the fixture. The fixture box with the internal reflector effectively hides the source of the light from the eye, eliminating direct glare for drivers. However, there can still be high fixture brightness when one walks under the fixture because of the light redirected downward by internal reflectors. Further, the spacing of these fixtures must be relatively close to achieve the recommended uniformity of lighting on the floor, and an acceptable uniformity at the plane of the driver's eye (approximately 45 inches above the pavement). This uniformity is critical because, a driver going from light to dark to light conditions (all at eye level) has great difficulty adjusting to the changes. Further it is very difficult to achieve the IESNA recommended vertical illuminance at 5 ft above the floor on covered parking levels due to low mounting height. Adequate ambient illumination of overhead signage is also very difficult with cutoff luminaires (minimum vertical

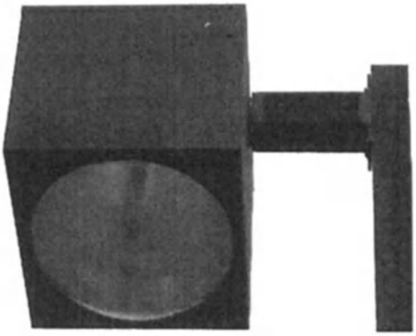


Figure 9-9. Cutoff Luminaire

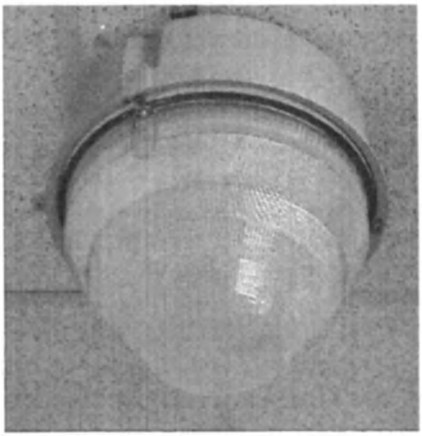


Figure 9-10. Non-cutoff Luminaire

illuminance of 1 fc is required for visibility of overhead signs at 7 to 8 feet above the floor).

The non-cutoff luminaire (see Figure 9-10) generally has the bulb mounted vertically below the housing and encloses the lamp with a wrap-around clear plastic or glass lens. An internal reflector and/or prismatic lens is used to redirect the light distribution away from the driver or limit the amount of light distributed between a 70 and 90° angle from a vertical line through the fixture. These fixtures create good three-dimensional uniformity of light and can easily meet the vertical illuminance standard. However, there is much greater potential for glare. Another disadvantage is that with the bulb exposed to view from the side, virtually every lamp can be seen individually at certain angles and perspective from the outside of the structure. This point source of brightness will increase the overall impression of light spill from the facility, which may be objectionable to neighboring uses. Additional shielding of the fixtures closest to perimeter wall openings may then be required (See Figure 9-11). A structure with cut-off fixtures will emit a gentle glow of light, but individual lamps will not be visible from a line of sight up to 15° above the horizon.

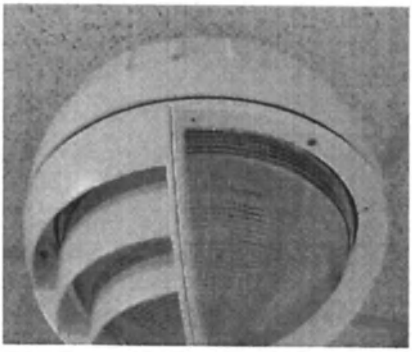


Figure 9-11 Shielded Luminaire

Figure 9-12 Semi-Cutoff Luminaire

Semi-cutoff fixtures (See Figure 9-12) are similar to a cutoff fixture in that the lamps are shielded; however, openings are provided in the upper portion of the housing to direct light upwards. Other variations use a shallow (2-3 inch deep) prismatic refractor at the bottom of the fixture to provide an "uplight" component. The uplight illuminates the ceiling, which eliminates the cavernous effect resulting from cutoff fixtures and increases vertical illuminance by reflecting light off the ceiling. This fixture reduces the amount of luminous surface area that is perpendicular to the line of sight and thus reduces the potential for glare. However, semi-cutoff fixtures may not produce adequate vertical illuminance at high elevations above the floor where the mounting height is less than 10 feet. Therefore, fixtures must be carefully selected and specified.

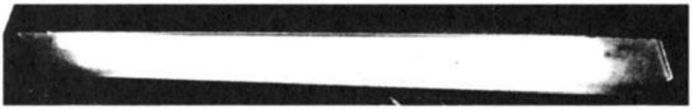


Figure 9-13. Fluorescent Fixture

Fluorescent tubes (Figure 9-13), where used for parking facilities, are generally mounted with bare tubes, although a wrap-around lens is recommended to protect the lamp from wind and cold weather, as well as breakage due to vandalism or vehicle antennae. The length of the tube should be mounted parallel to the aisle to reduce glare for drivers and pedestrians traversing the aisle. The glare of fluorescent fixtures is somewhat less than for comparable HID fixtures as the luminous intensity is distributed over a larger area compared to the typical point source of HID fixtures.

It is important that the light fixture be UL listed for damp locations at a minimum, and preferably for wet locations. This specification assures that the fixture will be gasketed adequately to prevent dust and bug infiltration in addition to preventing moisture infiltration. Tamper-proof hardware should be used to prevent vandalism.

Lenses should be impact-resistant. Polycarbonate lenses are not recommended, as they become more brittle with age until they ultimately are no stronger than high-impact acrylic. Further, polycarbonate lenses are more prone to yellowing and degradation, particularly when exposed to ultra-violet radiation. Polycarbonate lenses also have lower light-transmission characteristics than acrylic or glass. Since metal halide lamps produce ultra-violet radiation, UV stabilizers must be provided in plastic lenses with this lamp type, or a tempered-glass lens used.

9.2.5 Fixture Location

Fixture locations should be coordinated with structural system components so that potential beam and wall obstructions do not interfere with the light distribution from the fixture. For a cast-in-place, post-tensioned concrete parking structure, the beams will be spaced at 18 to 24 feet. For a precast concrete structure with double-tee floor units, the tee stems will be at a spacing of half the width of the double tee unit. Double tee widths may vary from 10 to 12 feet in the western U.S, up to 15 feet in some areas in the Eastern U.S. The precast tee stem spacing will then be in the range of 5 to 7.5 feet. In either post-tensioned or precast garages, the beams or tee stems are perpendicular to the drive aisle. The longitudinal spacing of luminaires should then be modular with the structural member spacing. The fixture spacing parallel to the drive aisle will be referred to as the longitudinal spacing. The fixture spacing across the drive aisle will be referred to as the lateral spacing.

The luminaires are typically mounted flush to the ceiling. For the typical floor-to-floor height of 10 feet in parking structures, the luminaire mounting height will be approximately 8'-6". Where beam or tee stem spacing is less than 10 feet, the luminaires should be pendant-mounted with the bottom of the luminaire flush with the bottom of the beam or tee stem to prevent obstruction of light. The mounting height in this instance will be approximately 7'-9". The building code requires a minimum overhead clearance of 7'-0". Handicapped accessible spaces must have an 8'-2" clearance. Increased floor heights are required on the accessible parking levels.

Experience indicates that the IESNA minimum illuminance criteria can be achieved with a maximum floor area of approximately 1440 sq. ft per luminaire for 150W HPS or 175W/pulse-start MH lamps in an appropriate fixture at a 8-foot mounting height. A maximum floor area of approximately 1200 sq. ft per luminaire is required for 150W, pulse-start MH fixtures or for an 8-foot long fluorescent fixture with four, 4-foot T8 lamps and one electronic ballast. These values are rules-of-thumb and must be verified by actual lighting calculations.

If the designer elects to place fixtures down the centerline of the drive aisle only, one luminaire must light the entire width of the parking module. A parking module consists of two rows of parking with a drive aisle between and is typically 52 to 62 feet wide. The required longitudinal fixture spacing is the maximum area per luminaire divided by the width of the area to be illuminated. For a 60-foot wide area, the maximum longitudinal spacing is 24 feet for a 175W MH fixture. In addition to creating a potential glare problem for the driver, this configuration is awkward, as the luminaire must distribute light evenly over a 24-foot by 60-foot area. Since most parking garage luminaires have a symmetric light distribution, adequate light distribution over an oblong area is difficult to achieve. Even luminaires with an asymmetric light distribution do not come close to a lighting pattern with a 3:1 aspect ratio.

It is more common that two rows of light fixtures are used in each parking module with each row placed at the quarter points of the parking module (i.e. mid-way between the drive aisle centerline and bumper wall at the front of the parking stall). For a 60-foot wide parking module, each row illuminates a width of 30 feet. The maximum longitudinal spacing for each row is then approximately 48 feet for a 150W HPS or 175W pulse-start MH fixture.

Note that the total number of fixtures will be the same with either the single row or double row configuration as the required longitudinal spacing of a single row is half the required longitudinal spacing for a double row. For luminaires with equivalent light output, this arrangement makes sense as the average illuminance is a function of the area per luminaire (footcandles equals lumens per square foot). It therefore makes little sense to use a single row of fixtures down the drive aisle centerline. The double row of fixtures will provide more uniform light distribution with less glare to the driver at the same cost of a single row of fixtures at the drive aisle centerline.

A variation on the side-by-side, double row configuration is to stagger the row on one side at half the longitudinal spacing with respect to the row on the opposite side of the drive aisle. In the case of a 20-foot beam spacing with light fixtures at a 40-foot longitudinal spacing, the staggered configuration results in one luminaire per beam coffer instead of two luminaires in every other beam coffer with the side-by-side configuration. With more ceiling soffits illuminated, the space will appear brighter.

A rule of thumb for parking lot lighting and roof lighting of parking structures is that the mounting height should equal half the distance from the fixture to the boundary of the area illuminated by that fixture. Since perimeter light poles on the roofs of parking structures are generally prohibited for aesthetic reasons and light trespass concerns, the poles are usually located on the first interior column line. This location is often 52 to 62 feet from the perimeter wall, thus requiring a 26 to 31-foot fixture mounting height. The spacing between poles is then approximately 4 times the mounting height (i.e. each fixture illuminates half the distance). Utilizing this rule of thumb with a single 400-watt HPS or pulse-start MH lamp will generally achieve a minimum maintained illuminance of 0.5 fc. If a minimum illuminance of 1.0 fc is desired, then two, 400W fixtures per pole are recommended. All luminaires should consist of cutoff fixtures with a symmetric (Type V) light distribution using a vertically oriented lamp. As stated before, these values are rules-of-thumb and must be verified by actual lighting calculations.

9.2.6 Other

As discussed here, light output is reduced over time due to accumulation of dirt and bugs in or on the lenses as well as some discoloration of the lens.

Annual cleaning is recommended in order to assure that the reduction in light output does not exceed 10%.

Attention to relamping is important to maintain the minimum illuminance in any discrete area for safety and security. Relamping costs are minimized by replacing older lamps all at once, before they actually burn out, rather than replacing a few burned-out lamps at a time. Further, the lamp life is defined as the point at which 50% of a large population of lamps have expired. Therefore, many lamps will burn beyond their rated life and continue to depreciate below the design illuminance. The lamps should be replaced when the horizontal illuminance directly under the fixture is below a predetermined value based upon the lighting calculations. Semi-annual surveys with a light meter should be performed to determine which lamps should be replaced in order to maintain the fixtures with adequate functioning lamps.

Energy use will be reduced by controlling perimeter light fixtures during the day when adequate natural sunlight infiltration occurs. Sensors should be placed at strategic locations to detect the amount of daylight infiltration and turn off appropriate fixtures automatically. Roof fixtures should also be controlled by photocells to turn on only when appropriate. Timers and segregated circuits may also be used to reduce the light levels during periods of low activity (for example, 1:00 a.m. – 6:00 a.m.). Even when the parking facility will be closed down at certain hours, it is recommended that a certain minimum number of fixtures remain on overnight for security.

As discussed in this chapter, painting of ceilings, beams, and walls will greatly enhance brightness perception, will reduce potential discomfort glare, and will increase the illuminance through increased reflectance by approximately 25 percent. Maintenance of the painted surfaces is, however, a concern. It is important to use a breathable, acrylic-based paint or stain. Moisture trapped or migrating through the concrete can cause the paint to peel. A breathable material will allow water vapor to escape. The acrylic base provides for good bonding characteristics. It is also important to prepare the surface properly before application, to remove form oils, concrete laitance, etc., that may compromise bonding of the material to the concrete. The right product, applied properly, will last 10 to 15 years before repainting is required. Periodic (1-2 years) pressure-washing of the surfaces is recommended.

9.3 SUMMARY

The objective of any lighting design is to meet or exceed the minimum visibility requirements for security and safety, while creating an environment that will make patrons feel at ease. The psychological perception of the user as to whether the space is brightly lighted is often more important to user comfort than the light levels alone.

How much lighting is enough? The industry standards recommend minimum illuminance criteria for the safe movement of vehicle traffic and pedestrians while recognizing the need to deter criminal activity and meet energy constraints. There is not adequate information available to determine the potential decrease in crime, property damage, or personal injuries at enhanced light levels. Certainly, there are psychological and perceptual advantages to increased light levels. Therefore, the determination of the illumination criteria for any project is largely subjective, based on the experience of the owner and the designer. In order to aid in that process, levels of service for lighting levels have been developed.

Lamp and fixture selection is governed by many parameters, not the least of which is the structural system in the facility. Lighting design must also consider glare and color rendition, as well as life cycle costs. In general, white light sources, such as metal halide or fluorescent, are preferred. Fixtures that reduce the lighting intensity in the glare zone while providing adequate three-dimensional distribution of light are preferred.

One of the chief interrelationships in parking design is between lighting and signage/graphics. With a fundamental understanding of lighting and visibility in parking facilities, Chapter 10 will discuss signage design.

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Chapter 10

SIGNAGE

Mary S. Smith

In Chapter 3, wayfinding concerns and considerations were addressed. The ideal wayfinding design is one that requires no signage. Since that ideal is simply impossible to achieve, signage design is an integral part in the development of a parking facility. It is important to remember, however, that signage should reinforce natural means of wayfinding. The first exposure could very well be the last if the parker does not feel comfortable using the structure. Owners, if a designer ever says to you, "We'll take care of that with signage," a red warning flag has just been raised. Signage should never be required to correct design failures or mistakes, especially at the design stage. It can compensate for compromises that are necessary to balance competing objectives in the design process. In retrofit situations, signage can also reduce, but rarely eliminate, problems resulting from poor natural wayfinding.

For definition purposes, signage is the system of signs providing directions, identification warnings, and information to the user of a parking facility. Graphics are the means by which the message is presented on the sign. Environmental graphics are the integration of wayfinding messages into the physical design, including wall treatments, flags, banners, etc.

Signage is a means of communication with the driver and/or pedestrian, especially one using the facility for the first time. To be effective, the signage in parking facilities must be clear, concise, and simple. The driver

A. P. Chrest et al., *Parking Structures*

has no time to read the Preamble to the Constitution or even Lincoln's Gettysburg Address as he or she moves through the facility. While the creative designer may itch to make an architectural statement, "plain" is far better than "fancy," particularly for traffic direction.

It is obvious there are many questions that go through the driver's mind as he or she travels the facility looking for a "good" parking space. The driver must remain alert for pedestrians, other vehicles, structural elements, parking control equipment, and directional information that may be present in the facility. Often structure (i.e., beams and columns) or other vehicles may obstruct much of this information.

There are equally as many concerns for the pedestrian finding his or her way through a facility. In addition to being alert to vehicles, structural elements, and visual obstructions while wayfinding, pedestrians are often concerned about security and may thus be hurrying.

It is therefore important to separately address the unique wayfinding requirements for vehicular and pedestrian modes of travel through the facility. The experienced graphic designer does this by establishing hierarchies of information to be communicated.

10.1 WHAT MUST BE COMMUNICATED?

The essential information required to guide the user through the facility falls into four basic categories:

- Traffic information, which assists drivers by providing directions at points of decisions (One Way, Right Turn Only, Park, Exit, etc.).
- Pedestrian information, which helps the user find such destinations as elevators and stairs, and helps in recollecting the parking location.
- Regulatory information, which identifies areas such as reserved, compact or accessible parking spaces, or which prohibits or restricts entry/exit or vertical clearance limitations.
- General information, such as parking rates, hours of operation, etc.
- Each parking facility has its own characteristic set of requirements.

These requirements present specific questions concerning the needs and concerns of the users to be answered during the design of the signage, including:

- What are the points where information is needed?
- What information is needed?
- How should this information be presented?

- Will there be a high percentage of first-time users in the facility, or do the same people use it every day?
- Is the patron under stress or hurrying to get to his or her destination, such as at a hospital or airport facility?
- Are there special sign requirements for accessible parking or bilingual patrons?
- Is the layout of the facility complex (multiple decision points, large number of bays)?
- Are there choices in traffic patterns that must be presented to drivers such as directions to parking near the entrance of an anchor tenant or exits to different streets?
- Is there a relationship between structures, such as pedestrian connections at several levels that may lead to different destinations?
- How many levels of delineation of parking spaces are required for recollection of the parking location: parking space, aisle, zone, floor, structure, destination, and entry portal?
- Are there restricted areas or special needs for security?
- Are there special requirements for introductions related to the PARCS system, pay-on-foot operations?

The airport, transportation terminal, arena and stadium are types of facilities that have a high percentage of first-time visitors. These patrons are in a hurry to board a plane, or locate their seats before the event starts. Hospitals and retail businesses are very sensitive to customers' choice of patronage; making the parking system "user friendly" is of critical importance. In facilities serving these uses, the driver needs specific directional information in the proper sequence at each point of decision. Pedestrian information must also be well placed, easily read, and conveniently seen. Signs for these types of facilities should stand out clearly.

The facility serving a large office building usually requires less signage. The user is usually under less stress. A structure serving primarily monthly or contract parkers requires fewer signs because the user becomes familiar with the structure quickly and thereafter drives through the facility by habit. Conversely, it is more likely that a complicated design such as a double-threaded helix has been employed, affecting signage needs. The signage in such cases may serve more of a regulatory role. The monthly parker does need to remember where the vehicle is parked each day.

- Some general rules for sign design and location are as follows:
- All signage should have a general organizing principle that is consistently evident in the system.

- Directional signage for both pedestrians and vehicles must be continuous (i.e., repeated at each point of choice) until the destination is reached.
- Signs should be placed in consistent and therefore predictable locations.
- A sign should be placed at every point where a driver or pedestrian must make a decision.
- Signs may be located at a point where all users/traffic turns in the same direction even though there is no decision needed. In general, such signs serve as reassurance to first-time or irregular users who are unfamiliar with the path of travel.
- In general, overhead traffic signage should be placed just prior to the turn.
- Traffic signage should always be placed centered over the driving aisle, except that a standard "STOP" sign may be most effective in the standard traffic engineering mounting—i.e., on a post 5 ft. above the pavement.
- When there is no end-bay parking, a sign placed on the end bumper wall of the facility, even if slightly below eye level, is often more effective than one placed overhead before the turn, especially when located on down-bound routes (see Section 10.2.1).
- Regulatory and pedestrian information signage is usually placed at or over the parking stalls. Avoid placing pedestrian signage in the expected location for traffic signage.
- Location signage in parking areas is most effective overhead (in the parking zone) if the facility is post-tensioned and if there are not too many other signs present. Otherwise, column faces can be used. It is generally easier and more economical to paint and stencil location information on the column or beam face. Reflective messages are not required for location signage.
- Identification and location signage at stairs and elevators is often most effective on the door itself, and can be painted and stenciled directly on the door.

10.2 GRAPHICS

An important aspect of signage is the graphics. Effective signage programs combine aesthetics with information. Choice of color; typeface;

character size, weight, and spacing; and the use of uppercase and lowercase text all influence *readability.*[1] The arrangement of text and symbols must be visually distinct. They must not contradict their basic meaning or intent, so as not to confuse the user. The background is equally important: backgrounds that are too small or too large for the type size can greatly detract from the effectiveness of the sign. Equally important is to coordinate the design of each sign with its environment.

10.2.1 Environmental Issues

Environmental factors affect signage perception and readability, such as the quality, intensity, and color of light falling on the sign; the possibility of glare from a fixture directly in front of sign; light from behind the sign; sight lines (or conversely, obstructions) between the user and the signs; and the visual clutter in the sign's surroundings.[2] Many of these factors may not be within the designer's control, yet the designer must recognize these factors and design the signage to work effectively in the environment.

Coordinating lighting with signage is one of the most critical and most often neglected elements. Visual acuity and speed of recognition improve as illumination levels increase. Conversely, excessive lighting reduces legibility by creating glare. Halation may also occur with light-colored letters on a dark background. These letters appear "heavy" and blurred (see section 10.2.2).

The ambient or general lighting has a twofold impact. First, of course, is the illumination of the sign itself. Second is the fact that the eye adjusts to ambient light levels. The minimum ambient light level required for non-illuminated signs in interior, lighted spaces is about 25 footcandles (fc).[2] However, outdoors at night, signs can be viewed in as little as 2 fc. As discussed in Chapter 9, the parking industry has traditionally only considered lighting at pavement level in design. While 5 to 10 fc (average) may be maintained at the pavement, there generally has been far less at eye level and above.

Post-tensioned structure lighting designed to the Illuminating Engineers Society of North America (IESNA) standard (see Chapter 9) will generally have an adequate number of light fixtures in each bay to ensure that signage placed on beam faces will be properly illuminated. The placement of fixtures over the parking spaces and signs over the aisle avoids over-illumination and glare from light sources in front of signs. A sign that has been placed directly in front of a light source, either natural or artificial, is often unreadable. Circumstances in which this situation can occur include signs placed on an overhead beam on the perimeter, and signs that must be suspended in turning bays. If the location of the sign can't be changed, additional lighting can be placed in front of the sign to compensate for the excessive illumination behind it.

In precast structures, the frequency of the tee stems directly impacts the lighting/signage relationship. The tee stem limits the dispersion of the uplight component, if any; placing the sign in the same coffer and immediately behind the light fixture will often result in over-illumination; placing the sign several coffers away from the fixture can place it in the shadows. There is substantially more visual clutter in precast structures as well. Generally, it is advisable to suspend the sign below the bottom of the tee stem to assure visibility. The additional clearance required below tee stems to accommodate signage is a major factor in the recommendation of different floor-to-floor heights in the level-of-service (LOS) design parameters (see Chapter 3). The same posted clearance height should be maintained in a precast deck as in a post-tensioned one. For example, the LOS C floor-to-floor height in a post-tensioned structure would have a 7'-8" straight vertical clearance to the bottom of the beam and a 7'-6" posted vehicular clearance. The LOS C precast deck would have a clearance of 8'-10" to the bottom of tees and but also have 7'-8" posted clearance. Therefore, the signs can be hung so that the full letter is below the bottom of the tee stem, while still keeping the sign several inches above the posted clearance. (See further discussion of sign mounting in 10.3.)

Structural elements are generally among the most limiting factors on sign visibility in parking facilities. (See Figure 10-1)

In the parking environment signs must be read from a distance of 75 ft. to be minimally effective. This is based on a perception-reaction time of 5 sec and 10 mph; 100 ft. is a much more desirable standard. Care must be taken that signs not become visible only after it is too late for the driver to make and implement a decision.

Motorists view signs from an approximate height of 45 in. (per IESNA[3]), pedestrians from 5 to 6 ft. Signs mounted on structural elements can be at an acute angle to the normal line of vision. As seen in Figure 10-1, beams limit the distance from which a traffic sign may be read in a post-tensioned structure. Using the floor-to-floor heights and floor slope gradations for level of service, the distance from which a sign mounted on the beam face can be read on a level floor is calculated for beam spacings from 15 ft. to 30 ft. This column would also apply to signs placed on a beam face over a sloped parking area or ramp, and viewed from that slope. The impact of increased floor-to-floor height and beam spacing are both clearly demonstrated in Table 10-1. Except for the unusual combination of a 15-ft. beam span and LOS D floor-to-floor heights, signs attached to beam faces will be visible from at least 75 ft., with visibility extending nearly 200 ft. for the combination of 30-ft. beam spacing and LOS A floor-to-floor heights. However, when a sign is placed on a beam face over the level end bay after a down slope, the visible distance is sharply reduced. This condition is most critical at the exit of the parking facility, at the bottom of the main down ramp, where traffic is given a choice of exiting straight ahead or turning in the end bay for re-entry. The sign is rendered ineffective by reason of the fact that the driver probably sees it too late to have the sign play any role in decision making. The remedy is to place the sign further in from the end, at the hinge point in the floor slope. Conversely, a sign placed in the level end bays at the top of an up slope is visible from more than 250 ft. away.

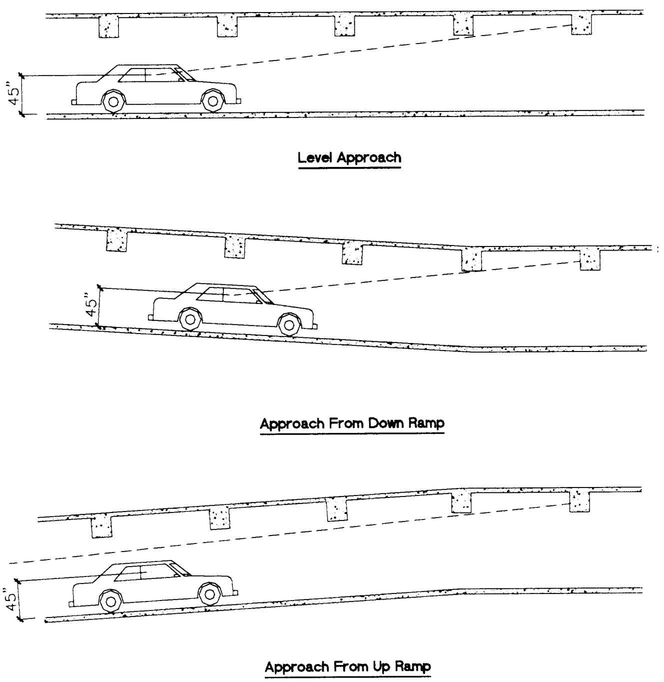


Figure 10-1. Structural members and floor slope impact distance from which signs can be read

Table 1. Sign Visibility Distances

		Approach to Sign		
Beam Span	LOS	Level	Down	Up
Post-tensioned structure				>250'
15	D	54'	28'	
	C	67'	37'	
	B	81'	46'	
	A	95'	56'	
20	D	73'	33'	
	C	92'	43'	
	B	110'	54'	
	A	129'	67'	
25	D	93'	37'	
	C	116'	48'	
	B	140'	61'	
	A	164'	75'	
30	D	112'	39'	
	C	141'	52'	
	B	170'	66'	
	A	198'	81'	
Precast structure, signs above bottom of tee stems				
4	D	37'	25'	71'
	C	44'	31'	79'
	B	51'	37'	87'
	A	59'	43'	93'
5	D	47'	29'	120'
	C	56'	36'	129'
	B	66'	43'	135'
	A	75'	51'	141'

Signs held above the bottom of the tee are generally not visible at 75 ft. If the signs are suspended below the bottom of the tee stem in a precast structure as previously recommended, the visibility will be more than adequate. The concern in that case remains that the sign is adequately lighted.

Sight obstructions must be avoided when considering sign placement. Architectural features and parked vehicles should not obscure sight lines. Other visual obstructions might include columns, shear walls, and piping. The latter can be a severe problem in flat slab structures, where many elements are competing for the same space.

Visual clutter around and behind the sign can distract from the readability of a sign. Increasing the amount of background around sign messages (negative space) will help to compensate for visual clutter. It is important to balance the contrast between the letters, sign background, and surrounding elements. Copy and background should have a minimum difference in reflectivity of 75%[2]; this criterion exceeds the recommendation in ADAAG (see Chapter 7), which is a minimum difference of 70%. A black background with white text provides a brightness differential of 96%. An orange background and white text provides only 68%. White copy on a dark background—preferably black— has been found to be one of the most universally effective combinations, as shown in Figure 10-2. The dark background draws the eye to the sign because of its contrast with concrete surfaces and the relatively monochromatic setting inside parking facilities. If unforeseen shadowing occurs, the message will still stand out. Also, when glare occurs, there is less loss of message with white reflective letters on a dark background. There is no need to have the background be reflective. In fact, the contrast is heightened when white reflective colors are used against

Figure 10-2. White copy of black background is very effective in parking structures. Photo courtesy Standard Parking Corporation, US Patent No. 4,874,937

a flat black background. Also, there is less likelihood of glare with a flat background. In the outdoors, the reverse is true; a white sign is the most conspicuous against the visual landscape. A black panel must be more than twice as large to be equally conspicuous at 250 yd. [2]

Colored light such as that from high-pressure sodium fixtures can affect legibility if it reduces the color contrast between the copy and the background. There will often be a difference in reflectivity values under high-pressure sodium light that may affect selection of colors. Again, white copy on black background avoids this problem. In situations where visual clutter or other visibility constraints exist, illuminated signs may be the best solution. In addition to the traditional backlit illuminated sign, fiber optic and LED signs are now viable alternatives. (Figure 10-3)

10.2.2 Letter Forms

Typeface must be selected based on legibility. Legibility is primarily affected by the choice of typeface, the thickness and contrast of strokes, and the height. Letter height and typeface style are of equal importance in making a sign legible. The most simple and commonly used type style is Helvetica Medium. The relationship of stroke width versus height avoids many problems resulting from halation with the light letter on a dark background. The differential can appear up to 10% larger than it actually is. The balance found in the Helvetica Medium takes advantage of this effect without sacrificing legibility.

Figure 10-3. Fiber optic signs can compensate for over-illumination behind the sign. Photo courtesy Daktronics, Inc.

Where themeing or architectural tone makes Helvetica Medium less desirable, other sans serif fonts, such as Univers, Futura, or Gil Sans are acceptable (see Figure 10-4).

Helvetica Medium

Futura

ABCDEFG
abcdefghi
1234567

Univers

ABCDEFG
abcdefghi
1234567

Gil Sans

Figure 10-4. San serif alphabets are the preferred choices for parking structure signage.

Simple serif fonts such as Times Roman or Goudy are possible; however slight increases in letter heights are recommended as the ratio between upper case and lower case letter form are greater than with sans serif fonts.

Lower case letters are 10% to 12% more readable,[2] and lowercase with initial caps occupies 30% to 35% less space; therefore lower case with initial upper case is preferred. All-uppercase may then be used for special emphasis, such as STOP. The nominal letter height with upper-and lowercase is the cap height. The height of the cap or uppercase letter is one-third larger than the height of the lowercase letter.

Letters are visible at a distance of about 50 ft. per inch of cap height. Given the additional constraints of parking structures, a minimum of 1 in. height for every 30 ft. of distance is recommended for pedestrian signs.[2] For drivers traveling at of 10 mph, such as in parking bays, a ratio of 1 in. for 20 ft. is more appropriate. Letter height on signage for express ramps and roadways should be calculated in accordance with the following formula[4]:

$$H = \frac{(N + 6)V}{100} + \frac{S}{10}$$

where H = cap height in inches, N =number of messages, V = vehicle speed in mph, and S = lateral sign distance.

This rule is not intended to imply that the letter size on each sign should be customized to the distance from which it can be read. As the recommended range of visibility is 75 to 250 ft. in parking facilities, a 6 in. cap on a 12 in. high sign is strongly recommended for traffic signs in parking bays. It provides a balance of legibility at an acceptable distance with an effective amount of background. Sizing letters under 6 in. on the premise that the sign need not be read more than 75 ft. away is wasting the opportunity to give the driver more than a minimum amount of time to recognize and read the sign. Over-sizing either letter or background is merely distracting in a traffic situation.

Pedestrian signs can use smaller letters because both recognition and reaction time are much longer. Pedestrian destination signage can often be visible for the full length of the structure. Eight-inch letters are then appropriate. Where more immediate directional information is provided, 4 in. is a good choice, especially when longer place names must be communicated. Conversely, oversize signs and letters for location indicators emphasize the importance of remembering.

Borders and circles around copy make the sign more difficult to read and should be avoided, especially with the visual clutter inherent in parking facilities. However, a different background color or border creating a "target" for arrows or pictograms, in particular, may improve legibility. It separates the directional message from the text message, and helps to establish the information hierarchies on a single sign.

Spacing of letters and length of message are the last considerations in the area of copy design. The distance from the left edge of the sign to the first letter or symbol should be equal to the cap height. Standard letter spacing should always be used, unless sign length is very restricted. Length restrictions most often occur when signs must be located between tee stems in precast structures. With the recommended Helvetica Medium typeface, the message will be approximately 0.75 times the cap height times the number of letters and spaces.[2] Additional space should be provided between two separate messages on the same line; a minimum space of two times the cap height is recommended.

No more than 30 characters per line is recommended.[2] Messages should be kept as short and concise as possible. "Park" and "Exit" are most frequently used to guide the driver through the facility. Some consultants prefer to use the word "Out," reserving "Exit" for pedestrians.[5] Avoid excessively wordy messages such as "To Additional Parking." Once the driver is conditioned to seeing Park and Exit at every decision point along the path of travel, don't throw in a new message such as "All Traffic." Similarly, remain consistent with directional information. If a sign states "To Regional Eye Institute" don't change to "R.E.I." down stream. Two lines of copy on a pedestrian sign is acceptable, but should be avoided for traffic signs unless there is extra reaction time. "Do Not Enter" is used to warn a driver not to enter; "Wrong Way" is employed where the driver is looking into the area. Both signs can be used in sequence to reinforce the message.

10.2.3 Arrows and Symbols

Research on visibility of arrows has not pointed to a "best" design. [2] Certainly, an overly stylized or "fussy" arrow should be avoided. The simple block arrow in Figure 10-5 is a good complement to the recommended Helvetica Medium typeface.

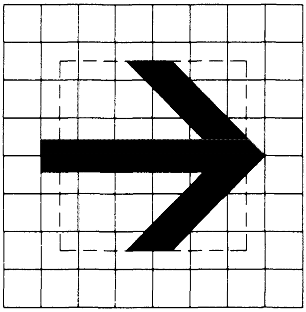


Figure 10-5. A simple block arrow is recommended for parking structure signage

Theoretically, arrows may point in virtually any direction; however, in practice they should be limited to the eight visually distinct directions represented by 45-degree increments. The conventions of the Federal Highway Administration's Manual on Uniform Control Traffic Devices (MUTCD)[6] should be used. In general, left and right turns employ horizontal arrows. Some in the industry customize the arrow for up and down slopes. For example, if the driver is to turn right and go up a ramp, an arrow pointing right and up at 45 degrees is used. This sign may take a little longer to recognize and understand, especially if there are multiple messages and arrow directions in the field of vision. The 45-degree arrow is probably most beneficial when there is a lack of vision around the corner to see that there is a ramp.

When the intended message is "straight ahead" or "this way," the arrow should point up. A downward-pointing arrow says "this lane," and is most appropriately used when there are multiple lanes from which to choose, such as separate monthly and cash lanes at the exit.

The combination of symbols and words is the most effective means of communication.[6] Only when the symbol alone is universally understood should pictograms totally replace words (see Figure 10-6). The use of international pictograms also bridges language barriers, eliminating the need for text messages to be displayed in multiple languages in bilingual situations. An excellent reference for standard pictograms is *The International Pictograms Standard*[7]. Their images can be downloaded from www.pictrograms.com. As society at large increasingly communicates through pictograms, the universality of symbols will increase and become usable in parking facilities.

Figure 10-6. Commonly used pictograms are effective communication tools

The arrangement of copy and particularly of arrows should reinforce the message. Left arrows should generally begin with the arrow flush left on the sign; messages with right arrows should generally be placed to the right with the arrow flush right. When messages with both left and right arrows are placed on a sign, there should be a good visual separation and distance between the two. Up arrows are generally placed to the left of the messages. Since down arrows are used for special emphasis, down arrows are often repeated on both sides of the message.

10.2.4 Colors and Themeing

Color can be an important component to a signing program. In the words of colleague Don Monahan,[2] "It can enliven parking structures and public spaces that would otherwise be very dull." Colors for pedestrian signs might be distinctively different from traffic signs for better recognition by the user. Conversely, many years ago we decided it might be a good idea to use the background colors in MUTCD, with the bright green seen on highway signs for all "park" signs and fire engine red for all "exit" signs. We abandoned the idea after the first installation, because it was simply too visually distracting. There is a simple elegance to the white letter on a black sign.

The owner or architect may have a preference for a certain background color — to match window framing or special accents in the architecture. At the same time color must be carefully used. As previously discussed, there must be adequate difference in reflectivity between copy and sign background as well as contrast between the background and the adjacent construction. For example, burgundy letters on a strong gray background may be quite attractive for interior signage in an office tower, but would be a major mistake in the adjacent parking facility.

It has been a favorite tactic of the industry for many years to color-code parking levels. Used forcefully and liberally in conjunction with floor numbers and, if needed, letters for sections, colors can help patrons identify the parking location. However, there are very real limitations to the use of color as a major contributor to wayfinding. The use of "trendy" colors such as teal and aqua certainly adds to the atmosphere or sense of being in a new, different space from the traditional parking garage. However, color-coding one floor with teal and the next with aqua will add little but cost to wayfinding. According to Monahan[2] "Most people can only distinguish and remember six different colors, not including black and white—red, yellow, blue, green, orange, and brown." If more or other than those six colors are needed, a significant loss of effectiveness occurs. Further, while there may be certain logic in using "warm" colors (red, yellow, orange) in one structure and cool colors (blues and greens) in another, 99% of users will never notice or appreciate such subtle logic.

Another constraint on color-coding is that 5% of males and 0.8% of females are color-blind. In one case, a parking structure with at least 10 floors was color-coded with bands of color on each column and the elevator lobby on each floor boldly painted in the color. Nowhere was there a sign "Remember—purple." The elevator floor buttons were matched to the colors, but with no numbering or words on the adjacent panel. Picking out the difference between blue and purple among the buttons was hard enough, even if you did remember purple correctly. The color-blind person, however, had no hope of getting back to the right floor.

Too many symbols/colors/patterns can actually detract from wayfinding. Don't expect the patron to figure out that the 4 ft. by 8 ft. graphic of a lobster with a pair of cherries 6 in. high in one corner is supposed to communicate that this is the red floor. The same set of memory aids must be repeated at every location. It does little good to theme a floor with lobsters if the panel in the elevator cab doesn't have the same graphic next to the elevator button.

Conversely, themeing that ties together elements and reinforces them with unusual visual elements can be very powerful in wayfinding. A parking operator in Chicago, Standard Parking Corporation, has successfully themed a number of structures, with music playing in the lobby to further reinforce the theme. An award-winning parking structure for Northwestern University has each floor named after a rival university with the school's colors and mascot on each floor and the fight song playing in the lobby while you wait for the elevator. Directories of each floor are provided in the lobby for reference upon return. This touch is far more helpful than just putting a floor number or color next to the elevator button. If you aren't quite sure where you have parked, you can scan the directory to jog your memory. "All you have to do is remember one of the four things: the number, the music concept, the visual concept, and possibly color," according to designer Craig Simon.[8] The concept is so successful that Standard has patented the idea (see Figure 10-7).

When there are multiple parking structures serving a single use, it may be helpful to keep the floors in each structure within an overall theme. However, be careful that the connection is universally obvious. Subtlety is usually wasted, and ambiguities should be avoided. If one of the two structures serving a building had floors named for fruits and the other had vegetables, would you know which structure the tomato floor is in?

Figure 10-7. The lobby directory for a parking facility with the musical floor reminder system. Photo courtesy Standard Parking, US Patent No. 4,874,937

10.3 CONSTRUCTION DETAILS

The preferred sign material traditionally is 0.080″ aluminium sheet. Recycled post-consumer plastic composites are also becoming more common. Plastic composites eliminate any metal reaction between aluminum and concrete, and are not as likely to be stolen as aluminum signs (which are stolen to be sold for recycling). However, the use of plastic composites requires more attention to adhesion of reflective sheets and/or cut vinyl letters. Plywood, Duraply, and tempered hardboard should be avoided because of warping, checking, delamination of plies and the like, and the lack of a consistent working surface for application of copy.

There are two common methods for applying the copy. Again, the traditional process is a reverse technique where the entire sign is covered with white reflective sheeting and then the background is silkscreened over the top, allowing the letters and symbols to show through. There are four basic grades of reflectivity sheeting, in ascending order of cost; Engineer, High Intensity, Visual Impact Performance, and Diamond grade. Engineer grade is the usual choice for parking since most of the signs are weather protected. However, where extra reflectivity is desired, High Intensity would be the choice. It holds its reflectivity very well and is three times brighter than Engineer grade; however, the sheets cost about four times as much as Engineer grade. The inks may be either transparent, which results in a reflective background, or opaque, which results in a flat background. Our experience has found that the flat or satin background reduces the possibility of glare blanking out the message. Opaque inks are also a little more durable.

Recent advancements in both reflective materials and production techniques have made laser-cut reflective letters a preferred solution. Die-cut letters have slightly lower reflectivity and are prone to curling and cracking if not properly applied. Proper specification of die-cut letters is thus critical. Pranksters occasionally pick letters off and/or rearrange messages. A clear overlay is available that prevents curling and peeling of die-cut letters and makes the sign more durable and graffiti resistant.

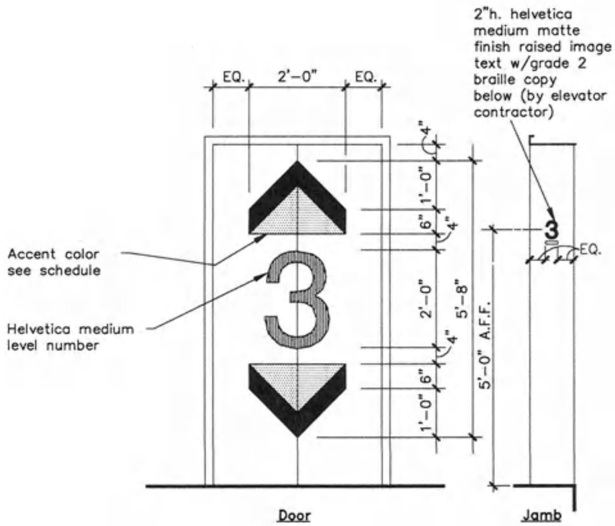
Internally illuminated signs have generally been too expensive to use for parking facility traffic signage. The traditional internally illuminated sign has letters cut into the sign face with a translucent second sheet, behind which is mounted a fluorescent light tube.

Neon has occasionally been used effectively, particularly as part of the parking location/themeing system.

Advances in fiber optic and light emitting diodes (LED) technology make those desirable options where changeable messages or special emphasis is required. These devices have very low maintenance and operating costs.

One of the most cost-effective means of designating floor locations is to paint the elevator door with the floor color and then apply a super graphic (see Figure 10-8). When not painted directly on the construction, signs on stair/elevator walls can be back- or reverse-painted on Lexan to prevent vandalism. Any damage can be readily cleaned and restored.

Framework for signs is usually painted or galvanized steel tubing. Make sure to specify the painting of saw-cut ends and drilled holes in prepainted tubing prior to final installation to prevent rusting. Inserts, fasteners, etc. should be rust-resistant and tamperproof. Avoid aluminum tubing because special consideration must be given to the electrolytic action between concrete and aluminum. The "softness" of aluminum also leads to crushing and distortion of the tube sections (see Figure 10-9).



Notes:
1. Raised image text w/braille copy to conform to requirements of american with disabilities act.
2. Provide sign at each elevator door & each elevator jamb at each tier.
3. Omit top 'arrow' at top tier & omit 'bottom' arrow at ground tier.

Figure 10-8. Supergraphics on elevator doors are effective location reminders

Exterior signage must be designed in concert with the owner and architect. Some of the choices include the following:

- Individual cast or cut letters 9 in. to 12 in, high over the entrance and exit lanes are an attractive and economical alternative. Be sure that there is adequate contrast between the building façade and the letter. A smooth surface may be needed in a heavily textured panel. This change in texture can be developed architecturally to emphasize the entrance/exit. Lighting from behind, over, or under the letters must be coordinated with the electrical engineer.
- Illuminated signs may be placed over the entrances/exits. These signs are especially effective when built into a canopy or larger architectural feature that emphasizes the entry point (see Figure 10-10). Prefabricated illuminated boxes can also be placed either flat or perpendicular to the façade. Unless carefully designed, the boxes tend to look a little "artificial" or "attached" rather than integrated into the façade design.

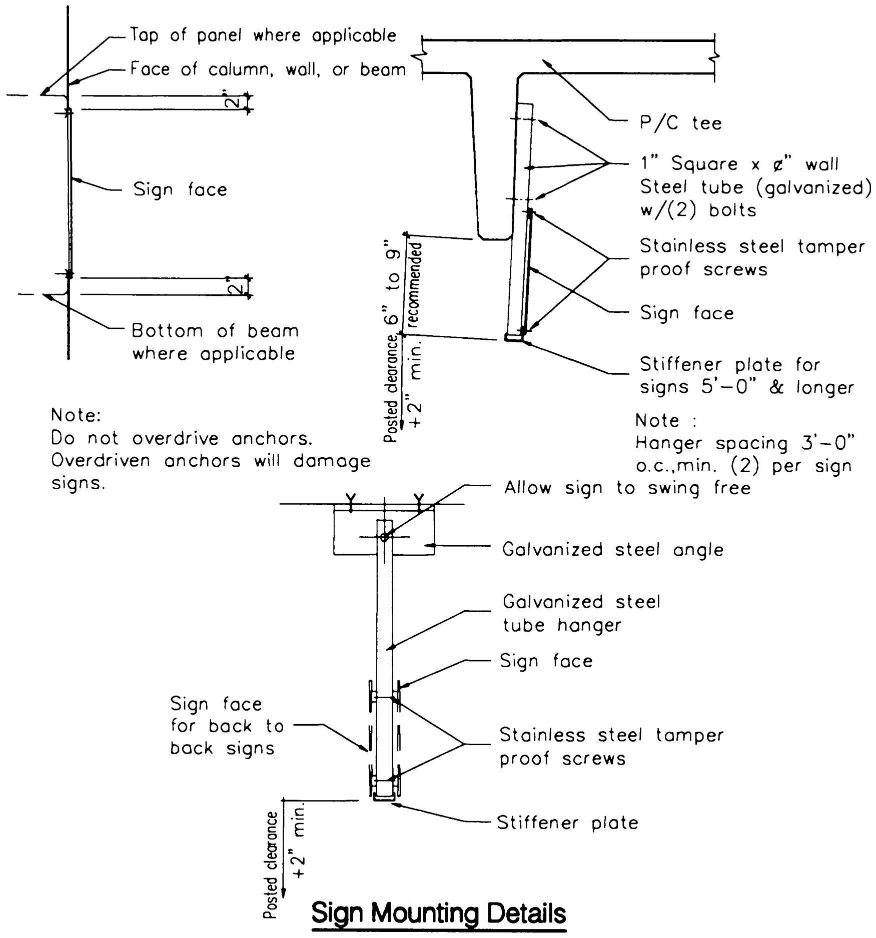


Figure 10-9. Typical sign mounting details

Figure 10-10. Marquee style signs are especially effective in urban settings. Photo courtesy of Standard Parking Corporation

One concern with any relatively flat sign attached to the face of the building is that it may not be readable by drivers in the street if the facility is pulled tight to a narrow sidewalk. Illuminated kiosks at the sidewalks are among the most effective signage tools, but they can be relatively expensive. It is also critical to be sure that a kiosk sign does not block the driver's vision while entering or exiting.

It is very important to have a clearance bar at the posted vehicular clearance height. Most experienced designers use a PVC tube suspended from the façade beam with reflective, die-cut letters (see Figure 10-11).

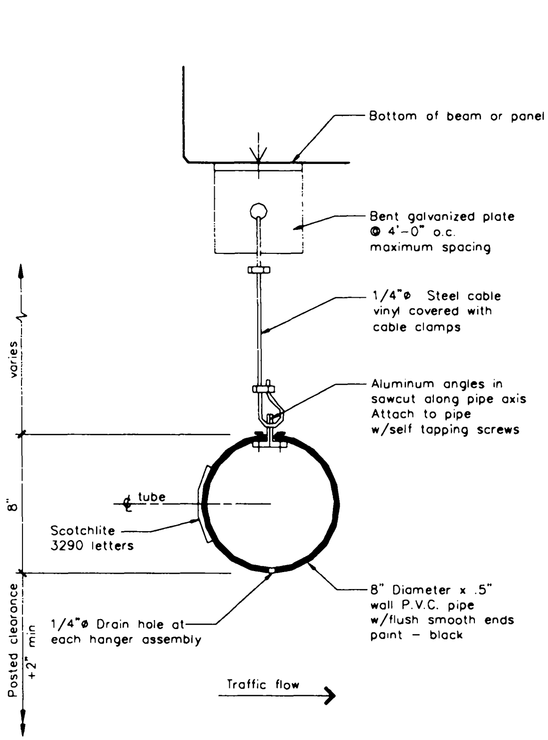


Figure 10-11. Clearance bars are placed at every vehicular entrance and point of change in vehicular clearance

10.4 FLOOR ARROWS AND STALL STRIPING

Although a different contractor will usually provide floor arrows and stall striping, they are part of the system communicating directions to the user and therefore merit discussion here. In general it is desirable to design pavement markings in conformance with MUTCD or state/local requirements. One of the first questions is what color should be used for floor arrows and striping. MUTCD specifies that white paint be used for markings delineating traffic flowing in the same direction and that yellow paint be used between lanes traveling in opposite directions, which implies a warning. Crisp, white paint shows well against the concrete in a new facility. However, over time dirt tends to obscure the paint and yellow seems to be more visible under "average conditions". Either white or yellow is quite acceptable from a visibility standpoint; the choice generally comes down to a personal preference of the designer.

A number of paint choices are available for pavement markings. A major change in the formulation of pavement markings occurred when the Environmental Protection Agency (EPA) regulations limited the use of solvents in paints. All of the paints listed have been formulated to pass EPA's current standard. However, several states have more stringent standards, which effectively limit the choice to water-based paints.

Acrylic thermoplastic and polyester are generally accepted substitutes in those states. Chlorinated rubber paints provide a good balance of durability for the money, and are the traditional choice for parking facilities. Chlorinated rubber, although it meets the current EPA standard, raises environmental concerns when flakes, which are considered carcinogens, are carried off by storm water. It is expected that chlorinated rubber paints will be outlawed in the near future. Water-based paints have the poorest durability and performance. The best performance/durability comes with acrylic thermoplastic paints. However, they are difficult to apply; the paint must be heated to 400° before application. A study by the EPA found that polyester paints have the lowest life cycle cost, when such parameters as paint cost, labor and application costs, and expected marking durability are considered. Polyester paints are also the most environmentally safe.

The reflectivity of highway paints is often enhanced with the application of glass beads to the paint. Glass beads act as retroreflective lenses that reflect the rays of auto headlights back to the driver. They increase safety and night visibility. Beads are most effective when mixed with the paint and sprayed in a single application; in such cases they increase the paint life. Most parking stripers object to this type of application because it reduces the life of the striping equipment. They prefer to spray the beads from a second nozzle or hand-broadcast beads as a top coat. However, beads applied as a top coat wear off, often in less than a year, and are probably not cost-effective. Therefore glass beads should only be specified if required to be mixed with the paint before application. In parking applications, use of either the most expensive paint and/or glass beads may increase the cost of striping, but in the context of the total construction cost, the increment is negligible.

It should be noted that pavement marking paints might bond poorly to green concrete, owing to hydration as concrete cures and/or curing/sealer applications. The first application of striping will probably have a shorter life than subsequent applications.

Double-line or hairpin striping continues to be preferred by most consultants as encouraging better alignment of vehicles in parking stalls. The cost differential is small compared to the benefits in helping parkers get aligned properly in a stall (see Figure 10-12). Studies[9] have shown that it is better to keep stripe length shorter than the intended stall length, encouraging drivers to pull further into the stall.

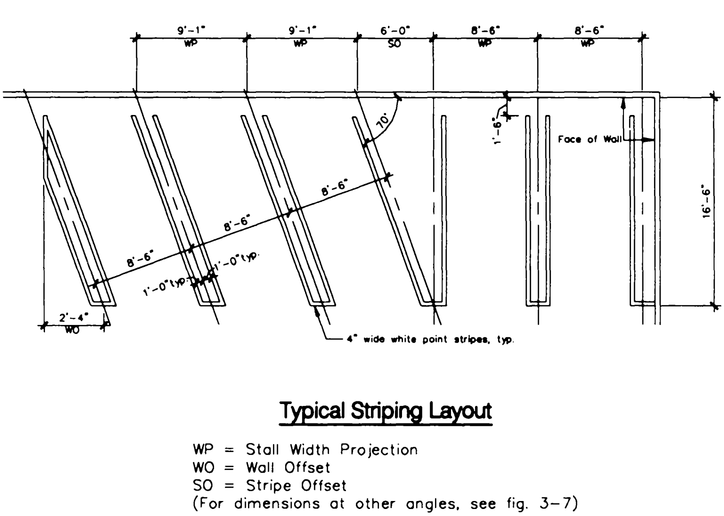


Figure 10-12. Double-line striping detail

Floor arrows should be located centered in the drive aisle just in advance of every turn whether or not a sign is provided. The location of floor arrows is shown on the same drawings as the striping. Be careful not to include arrows that are helpful to a layman looking at a drawing but that are not intended for painting (see Figure 10-13).

Special sign requirements under ADA are addressed in Chapter 11. It is instructive to note however, that some states require the use of blue paint in pavement markings for accessible stalls. The preferred method is to paint a large blue square in the middle of the stall or to paint the entire stall between the lines blue and then to paint a handicap logo in white. Less effective is merely painting the stripes and/or cross-hatching blue.

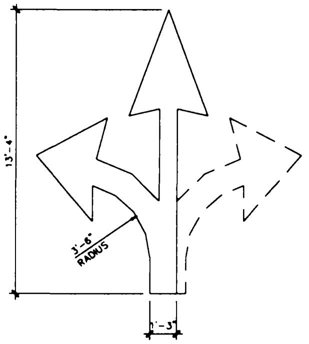


Figure 10-13. Standard floor arrow

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Chapter 11

ACCESSIBLE PARKING DESIGN

Mary S. Smith

11.1 INTRODUCTION TO ADA

In July of 1990, President George Bush signed into law the Americans with Disabilities Act (ADA); one of the most sweeping and far-reaching pieces of civil rights legislation ever passed by the United States Congress. ADA has five titles:

Title I - Employment covers elements related to employment persons with disabilities, including requirements to make reasonable accommodations such as modifying work stations and equipment.

Title II - Public Services

Part A- State and Local Government Services requires that local governmental entities, which include schools, state universities, county hospitals, etc., must operate each service, program or activity so that, when viewed in entirety, it is readily accessible to and usable by persons with disabilities. This title also requires that newly constructed buildings owned by (or on behalf of) entities covered by Title II must be accessible. Alterations to existing buildings must be done in an accessible manner.

Part B - Transportation covers requirements for accessibility of transportation facilities.

A. P. Chrest et al., *Parking Structures*

Title III - Public Accommodations covers requirements for accessibility of those areas of existing privately-owned buildings where the public may go to receive goods and services. It also has distinct requirements for accessibility of new buildings and alterations of existing buildings that are places of public accommodations or commercial facilities.

Title IV - Telecommunications covers telephone companies and phone systems.

Title V - Miscellaneous explains enforcement procedures, fines, etc.

You may note that the Federal Government is absent from the above listing, and indeed it was intentional. Most buildings constructed or altered with federal funds are required to comply with the Architectural Barriers Act of 1968. Recipients of federal financial assistance have similar obligations to ADA under Section 504 of the Rehabilitation Act of 1973. ADA essentially extended similar obligations to state and local governments not in some way covered under the two older acts, as well as private entities. Residential uses are covered by the Fair Housing Act. Private clubs are exempted when they qualify for exemption under Title II of the Civil Rights Act of 1964. There is really only one other type of non-residential building owner that is exempted from ADA, and that is religious entities. Note that the exemption is restricted to buildings directly associated with the practice of religion including churches, synagogues, and convents but not hospitals, for example, even if directly owned and controlled by religious orders. Further, a nonreligious entity, such as a day care center, must ensure that the facilities it rents from a church are accessible or rent space elsewhere.

Perhaps the most important thing to remember about ADA is that it is a **civil rights law**. The Department of Justice is charged with enforcing the act, and individuals who feel they have been discriminated against can sue the property owner. The guidelines for building and facility design are **not** a building code, subject to state or local approval and variances. (Of course, if a state or local government has a conflicting standard, the higher of the two standards applies.) Even when local officials approve a design as compliant, a federal judge can later decide that it was not compliant and award damages to a plaintiff.

Parking is considered to be a critical element to accessibility. To paraphrase the words of an official of the Access Board at one industry conference, if the individual with disabilities can't drive to and park at a building, there is no sense in requiring the owner to make the building accessible. Actions do often speak louder than words: the very first case brought into Federal Court that resulted in a civil penalty under Title III of ADA was for failure to make parking accessible.

11.1.1 Terms and Acronyms

One of the first things that must be addressed in discussion of ADA is all the terms and acronyms that are required to communicate the requirements of ADA in a reasonably succinct fashion. Note that the term "handicapped" is no longer operative. In all of the 300 pages of the *Federal Register* devoted to Title II and Title III rules and regulations, the term "handicapped" is not used once. The correct term is "persons with disabilities."

When an element is designed to be readily usable by persons with disabilities, it is accessible. An access aisle is not the driving aisle in a parking facility, but rather an accessible pedestrian space between elements, such as parking spaces, seats, or desks. An accessible route is a continuous unobstructed route connecting accessible elements. A ramp is not a sloped driving path providing vertical circulation in a parking facility, but rather a walking surface that has a running slope greater than 1:20 (5.0%).

Whenever Congress passes a law, an agency is specifically designated to issue "rules" that establish standards and procedures for implementation of the act. For ADA, several different agencies were charged with rule making. The three primary documents that affect building design under ADA were issued on July 26, 1991. The first is the *Americans with Disabilities Act Accessibilities Guidelines* [1] (ADAAG). It was issued by the Architectural and Transportation Barriers Compliance Board (Access Board) to ensure that buildings and facilities covered by the law are accessible. The Department of Justice (DOJ) also issued its Title II Rule[2] and Title III Rule[3] on that date.

ADAAG is modeled on an older federal standard, the *Uniform Federal Accessibility Standards* (UFAS). This document was issued in 1982 by the Access Board as a consolidated standard for compliance with ABA. Technically design guidelines for ABA compliance are issued by the Department of Defense, the General Services Administration, the Department of Housing and Urban Development, and the US Postal Service. UFAS was then adopted by the individual agencies in their "rules." UFAS is also referenced as the standard by applicable agencies for compliance with the Rehabilitation Act of 1973. Multi-family housing is covered by yet another statute, the Fair Housing Act, but UFAS did not cover requirements thereto. ADAAG is essentially a revisiting, updating, and extension of UFAS. The Access Board will, from time to time, issue clarifications of

ADAAG. For example, in February 1994, the Access Board issued Bulletin #6, addressing parking.

Initially, state and local governments were given the option of complying with ADAAG or UFAS. At the time ADAAG was issued, the Access Board stated that it intended to adopt modifications to ADAAG applicable to governmental buildings and that DOJ would then adopt a rule mandating that Title II entities comply with ADAAG rather than UFAS. On June 20, 1994, the Access Board issued those modifications.[4] In that rule, the board stated that it will use ADAAG as the accessibility guidelines for federal and federally-funded buildings, under the 1968 and 1973 acts. However, at the time of this writing, the DOJ has not yet even issued proposed rules (that must be published for comment before final rules can be issued) spelling out how and when state and local governments must switch to ADAAG, nor have most of the individual Federal agencies adopted ADAAG. Therefore, the new Title II amendments to ADAAG are denoted an "Interim Final Rule." Technically, no one is **required** to follow the new rule; however, the board strongly recommends that all entities do so. In general, the 1994 rule addresses issues never covered under either UFAS or ADAAG (i.e., courthouses) and as such represents the best available information on how to design those facilities so that they are accessible. Willfully choosing to follow UFAS because it is less restrictive than ADAAG is risky. Making a "good faith" effort to comply with ADA means that you should comply with the best available reference, which is ADAAG.

From a parking perspective, the most critical section of the Title II modifications to ADAAG is 14.0 Public Rights-of-Way, which greatly clarifies design standards for those areas. In particular, there is a section governing on-street parking that sheds light on the board's thinking about parking in general. Also, when parking structure construction requires reconstruction of sidewalks, curbs and other construction in the public right-of-way, what "comes out" has to be "put back" in accordance with these standards.

On November 16, 1999, the Access Board issued a draft of a comprehensive revision to ADAAG for public comment, hereinafter called ADAAG 2000. Among other things, this revision consolidates the requirements under ADA and those under the Architectural Barriers Act of 1968 (ABA.) Although the various agencies noted above are still legally responsible for issuing standards, they have now gotten together and created a single standard for compliance with both ADA and ABA. It is presumed that other agencies will also adopt this standard, at least with appropriate modifications to the specific requirements of the applicable statute. In sum, with the issuance of this document as a final rule, probably before the end of

2000, UFAS will disappear and almost all Federal accessibility rules will employ ADAAG 2000.

The proposed revision was also undertaken with the goals of:

- Improving the format and usability of ADAAG
- Reconciling differences between ADAAG and national consensus standards, including model building codes and industry standards;
- Updating ADAAG to reflect technological developments and to continue to meet the needs with persons with disabilities; and
- Coordinating these and future ADAAG revisions with national standards and model building codes; among other things, ADAAG has been reorganized to follow the same organization and section numbering standard as ANSI A117.1 to the extent possible.

The revisions were principally developed by an Advisory Committee, which worked over a two-year period. The Board, as the ultimate issuing authority, made all final decisions and indeed declined to adopt Advisory Committee recommendations in a number of cases. The section numbers of the new document are referenced by "2000-section" (e.g., 2000-308.1.1) while sections in the current ADAAG are noted as ADAAG 4.1.3.

Most of the requirements in the 1994 Interim Final Rule are incorporated into ADAAG 2000 **except** the Public Rights-of-Way section. A separate advisory committee is currently reviewing and revising these requirements. ADAAG 2000 does have new requirements for residential housing.

A word of warning: every attempt has been made to quote directly from and adequately support and reference all of the design guidelines herein. The material from this chapter is organized to present all of the information relevant to an issue together, rather than in the sequence it is presented in each succeeding federal document. The author, as co-chair of a committee on Accessibility for the Parking Consultants Council (PCC) of the National Parking Association (NPA), met with staff members of the Access Board and DOJ on several occasions to discuss issues relating to the design of parking, and to develop a model code for accessible parking requirements as permitted under the law. While the staff members of the Access Board and the DOJ gave us their best advice and opinions, this chapter must be viewed as the opinions of the author based on the available information.

An individual can not begin to understand ADAAG without reading the Supplementary Information that is published with each rule in the *Federal Register*. The complete documents are available free of charge from the Access Board and the Department of Justice. An excellent additional reference is CALDAG[5]. While specifically designed to present the State of California requirements, it is careful to explain any variation from ADAAG. CALDAG has substantially more figures and illumination of grey areas than ADAAG and therefore is quite valuable to any designer.

11.1.2 Existing Buildings

It is extremely important to note that Titles I, II, and III have distinct and different requirements, especially in regard to existing buildings. Title I says that **existing** areas of buildings that are used only by employees must only be modified when an employee with a disability needs such modifications. Table 11-1 compares the major differences between Titles II and III regarding existing facilities. Title II states that programs and services must be accessible to the public unless it would be an **undue burden**. If that requires physical changes or removal of barriers in buildings, so be it. However, if governmental units can make a program or service accessible by relocating it to a part of the facility that is accessible, that's fine too. Title III requires that existing physical barriers to accessibility in areas of a building where the public may go to receive goods and services must be removed if **readily achievable** (Title III Rule 36.304(a)). According to DOJ, "Congress intended the undue burden standard of Title II to be significantly higher than the readily achievable standard of Title III" (Title II Rule, Supplementary Information Section 35.150). Thus while the state/local government has more flexibility to make a program or service accessible, it has a greater obligation to make existing programs and services accessible.

Table 11-1. Comparison of rules for existing buildings

	Title II	Title III
Who	All public entities/all programs & services	Public accommodations
What	Programs & services must be readily accessible. Physical barriers must be removed only if necessary for accessibility to a program	Remove physical barriers where readily achievable or provide alternative means for providing goods and services.
Where	All facilities where programs and services are delivered. (Work Areas covered under Title I)	The areas of a building where the public receives goods or services (Work Areas covered under Title I)
Exceptions/ considerations	Undue burden Fundamental change in program	Cost Financial resources Impact of operation
When	Three years from Jan. 26, 1992 > 50 employees July 26, 1992 <50 employees	Ongoing
Standard	UFAS or ADAAG until DO ADAAG 2000 is finalized	ADAAG

Bulletin #6 addressed one frequently asked question regarding existing parking:

> Are accessible spaces required in existing parking lots and facilities? ADAAG establishes minimum requirements for new construction or alterations. However, existing facilities not being altered may be subject to requirements for access. Title III of the ADA, which covers the private sector, requires the removal of barriers in places of public accommodation where it is "readily achievable" to do so. This requirement is addressed by regulations issued by the Department of Justice. Under these regulations, barrier removal must comply with ADAAG requirements to the extent that is readily achievable to do so. For example, if, when restriping a parking lot to provide accessible spaces it is not readily achievable to provide the full number of accessible spaces required by ADAAG, a lesser number may be provided. The requirement to remove barriers, however, remains a continuing obligation; what is not readily achievable at one point may become readily achievable in the future.

That last sentence is extremely important. Public accommodations are expected to remove barriers in small, affordable steps, but to continue to make improvements until all possible improvements have been made. This literally open-ended requirement could mean years. Title II entities were given a specific date by which all programs and services must be made accessible (see Table 11-1).

11.1.3 Alterations

An alteration is defined in ADAAG 3.4 as:

> An alteration is a change to a building or facility made by, on behalf of, or for the use of a public accommodation or commercial facility, that affects or could affect the usability of a building. Alterations include, but are not limited to, remodeling, renovation, rehabilitation, reconstruction, and historic restoration. Normal maintenance, re-roofing, painting or wallpapering, or changes to the mechanical and electrical systems are not alterations unless they affect the usability of the building or facility.

"Restoration," as generally defined in the parking industry, is a very broad term that includes anything from limited areas of crack and spall repair to extensive removal and replacement of concrete in floor surfaces. Application of traffic topping and sealers and minor spall repairs are all normal maintenance, equivalent to reroofing, and as such would not be considered alterations. However, a project involving extensive slab removal and replacement would be considered reconstruction or rehabilitation. Likewise, resurfacing and/or changes to the functional layout of a surface lot are alterations.

All sections relating to accessibility in alterations are not repeated here. A two-line summary might be as follows: Whatever is taken out, must be put back accessible unless it is technically infeasible (ADAAG, 4.1.6(1)). In addition, improvements to the path of travel to the area being altered must be made, up to a cost equal to 20% of the project budget (Title III, Rule 36.403(f)). Note that the path of travel improvements is not subject to a specific cost limitations under ABA.

An example of putting something back accessible would be if a nonconforming curb at an elevator tower were removed during an alteration, a curb ramp fully meeting ADAAG should be put back in.

The path of travel requirement in ADAAG is qualified by a provision that it need only be improved if the area being altered is a primary function. As parking is the primary function in a parking structure, then major rehabilitation of a parking area will usually trigger a need to make improvements to the path of travel.

Table 11-2. Comparison of rules for alterations

	Title II	Title III
Who	All public entities	Public accommodations & commercial facilities
What	• Altered elements/spaces must be readily accessible to maximum extent feasible • Path of travel (silent)	• Same • Path of travel to areas of primary functions must be made accessible
Limitations for altered areas	• ADAAG: same as Title III • PAS silent	• Unless technically infeasible
Limitations for path of travel	Only if cost of alternation >50% of full fair market value of building (UFAS)	Must spend up to 20% of cost of all alterations on path of travel

Table 11-2 summarizes the requirements for alterations under Titles II and III. An alteration is one area where there is a substantial difference between the requirements of UFAS and ADAAG. UFAS requires that what is taken out must be put back accessible; however, funds only need to be expended on the path of travel to that area if the cost of the alterations is equal to more than 50% of the market value of the building. For example, under ADAAG, a $1 million restoration project requiring extensive slab removal and replacement of the roof floor slab on a parking facility that has a market value of $5 million would be required to include up to $200,000 more in improvements to the path of travel to the roof. This facility has only three levels and now has no elevator; it would be required to add the elevator in the restoration project even if there are no accessible parking spaces on the roof (see section 11.2.11), presuming that could be accomplished for $200,000. Under UFAS, no additional expenditure for an elevator would be required because the restoration project is less than 50% of the full market value of the structure.

Parking access and revenue control devices, including prefabricated cashier booths, are considered part of the electrical/mechanical equipment of the building, and replacement of such equipment is not an alteration unless changes in number, location, or layout of lanes are contemplated. Conversely, if the islands are being removed and rebuilt, then the cashier booth must be made accessible (see 11.2.12) unless it is technically infeasible to do so.

In parking facilities, routine maintenance and repair are also necessary to prevent extensive deterioration of floor surfaces and to maintain the structural integrity of the facility, which is analogous to maintaining and repairing roofing or paint that provides protection to the underlying surface or occupied space below. These maintenance items can include, but are not limited to: crack and joint repairs; patching; resealing; application of traffic toppings or membranes; and restriping parking areas. Such preventive maintenance is not considered an alteration under ADAAG. Resealing and restriping a parking lot is likewise maintenance, so long as the striping layout is unchanged.

Bulletin #6 confirmed the interpretation that resealing/restriping is normal maintenance but resurfacing/reconstruction is an alteration:

> **Is the restriping or resurfacing of a lot considered an alteration?** According to the definition of alteration, normal maintenance is not considered an alteration unless the usability of the lot is affected. For example, if a lot is to be resurfaced or its plan reconfigured, accessible spaces must be provided as part of the alteration. However, work that is primarily maintenance, such as repainting existing striping, may not trigger a requirement for accessible spaces. Although the work undertaken may not be technically considered an alteration, accessible spaces should be provided where the work, by its nature, makes the addition of such spaces possible.

It should be noted that restriping to add and/or relocate accessible spaces will be required in existing parking facilities that are associated with public accommodations, under the requirement to remove barriers. If restriping to add, locate, stripe, and sign accessible spaces in conformance with these guidelines has not been previously accomplished, making such improvements while resealing and restriping would in many cases be considered "readily achievable" and thus would be required as part of such projects.

Bulletin #6 continues:

> **Are accessible spaces required in alterations?** In alterations, the minimum number is based on the total number of spaces altered in each lot, although it is recommended that the full number of spaces required for new construction be provided where the opportunity to do so exists within the planned scope of work. Accessible spaces are required in each altered lot. However, accessible spaces can—and should—be located closest to accessible entrances even where such locations lie outside the altered area or lot.

A DOJ representative pointed out in a meeting with the PCC that the logic here is related to the fact that an alteration project presents increased opportunity to make accessibility improvements and therefore carries increased responsibility to do so. Therefore, if the three-level deck in the previous examples has 750 spaces (250 on each level,) and none are now accessible, the minimum number of accessible spaces that have to be available in the facility after the alteration is seven (based on 250 spaces on the roof). However, if it is at all possible, the total number of accessible spaces in the facility should be increased to 15, two of which need to be van-accessible (see 11.2.1).

Bulletin #6 addresses the issue of what improvements are required in an alteration. Note that Bulletin #6 was written at the time that ADAAG was primarily oriented to Title III.

> **Is full compliance with ADAAG required in alterations?** In alterations, applicable ADAAG requirements must be met except where it is "technically infeasible" to do so. For example, if the resurfacing of a lot does not include regrading, it may be technically infeasible to meet the maximum 1:50 surface slope requirement for accessible parking spaces and access aisles due to existing site constraints. Similarly, if providing the number of accessible parking spaces specified by ADAAG would reduce the number of parking spaces in an altered lot below the minimum number required by a local zoning or land use code it may be technically infeasible to fully meet the ADAAG scoping requirement for accessible parking. For instance, if five accessible parking spaces are required, but the parking lot can only accommodate four accessible spaces and still meet the local code requirement for the total number of parking spaces, then four accessible parking spaces must be provided.

> However, many zoning adjustment boards are willing to grant limited waivers on the total number of required spaces if accessible spaces are provided.

Similarly, it is probably "technically infeasible" to provide the additional clearance for van-accessible stalls in existing parking structures with lesser clearance. However, the two van-accessible stalls must still be provided. Only the very specific portion of the requirements that is technically infeasible can be waived.

11.1.4 New Construction

Table 11-3 compares the requirements for new construction under Titles II and III. Basically, they are very much the same at the level of the DOJ rules. However, there are a number of differences based on the evolution of UFAS to ADAAG. There was very little changed between UFAS and ADAAG, but a number of new requirements were added to the latter. The most difficult one for parking relates to the vertical clearance requirements for van-accessible spaces, which have a significant impact on parking structure design. The draft. ADAAG-2000 standard, however, would eliminate this loop-hole by eliminating UFAS; van-accessible spaces will be required in all designs.

Table 11-3. Comparison of rules for new construction

	Title II	Title III
Who	All public entities	Public accommodations & commercial facilities
What	All elements/space must be readily accessible	Same
Limitations	ADAAG: same as Title III; UFAS: silent	Unless structurally impracticable (very narrowly defined)

11.2 PARKING DESIGN UNDER ADAAG

The Access Board defined accessible parking in Bulletin #6 as follows:

> Accessible parking requires that sufficient space be provided alongside the vehicle so that persons using mobility aids, including wheelchairs, can transfer and maneuver to and from the vehicle.

> Accessible parking also involves the appropriate designation and location of spaces and their connection to an accessible route.

The following sections present the more critical issues relating to designing accessible parking under ADAAG. No attempt has been made to present the requirements of state and local codes that exceed the ADAAG requirements and therefore supersede them. The difference in requirements of UFAS is also not further discussed because that issue will become moot when DOJ mandates the transition to ADAAG.

11.2.1 Required Number of Accessible Spaces

ADAAG 4.1.3(5)(a) states the basic requirement for number of accessible spaces as follows:

> If parking spaces are provided for self-parking by employees or visitors, or both, then accessible spaces complying with 4.6 shall be provided in conformance with the table below. Spaces required by the table need not be provided in the particular facility. They may be provided in a different location if equivalent or greater accessibility, in terms of distance from an accessible entrance, cost and convenience is ensured.

See Table 7-1 for the required number of accessible spaces.

In new construction, the total number of spaces provided in a parking lot determines the minimum number of accessible spaces. If there is more than one lot, the minimum is determined lot-by-lot, not by the total number of spaces provided.

Table 11-4. Required Number of Accessible Stalls

Total Parking in Lot	Required Minimum Number of Accessible Spaces
1 – 25	1
26 – 50	2
51 – 75	3
76 – 100	4
101 – 150	5
151 – 200	6
201 – 300	7
301 – 400	8
401 –500	9
501 –1000	2% of total
1001 and over	20 plus 1 for each 100 over 1000

Total Parking in Lot	Required Minimum Number of Accessible Spaces
Accessible Spaces	
1 – 8	1
9 – 16	2
17 – 24	3
25 – 32	4
33 and over	1 additional van-accessible space for every 8 accessible spaces

The operative phrase here is "new construction." The PCC attempted to get an interpretation that would allow the required number of spaces to be based on the entire supply of parking serving a building or complex of related buildings (such as a hospital, university, or shopping center) rather than the sum of the required number of spaces calculated lot by lot. Bulletin #6 definitively rejected the proposed PCC interpretation. ADAAG requires that accessible spaces be added based on the parking capacity of each new facility, without regard to capacities or accessible spaces elsewhere on a site/campus. Thus, a university with thousands of spaces scattered in numerous facilities would still have to add 20 accessible spaces with the construction of a new 1000-space facility, rather than considering the facility as an incremental 1000 spaces to the system and thus only requiring 10 accessible spaces.

The request to allow a site-wide determination of required number of accessible spaces has been resubmitted as part of the comments on ADAAG 2000 submitted by the Parking Consultants Council.

The Access Board and DOJ representatives stated that it might be reasonable for a private institution to bring the number of accessible spaces in existing facilities up to the number required if the system is taken in aggregate, and to concentrate its "readily achievable" improvements on making those spaces as compliant with ADAAG as possible. Note further that this applies only to existing visitor or general-purpose parking. A Title III entity will be required to add accessible parking to facilities that are restricted to employees only if and when an employee with a disability needs a stall, under the provisions of Title I of ADA. Certainly, it makes sense to have a reasonable number of accessible stalls based on the current needs of disabled employees, but there is no requirement for either public or private entities to add accessible stalls to existing employee parking facilities under ADA unless the lot is otherwise being altered or an employee specifically needs the improvements.

However, when the entity serves and/or employs an unusually high number of persons with disabilities and the table values clearly result in insufficient accessible spaces, the "reasonable accommodation" of Title I, the accessible programs and services requirements of Title II and the readily achievable requirements of Title III will likely require the institution to add accessible spaces over and above the otherwise required number.

It should also be noted that the Access Board uses the term "lot" rather than "facility." The PCC had requested the term "facility" be used to encompass parking structures as well as surface lots and/or to clarify the interpretation of "lot," but the Access Board apparently declined to do so. The definition of "lot" can become an issue in situations where large lots are divided by nonparking access aisles/roadways or fire lanes, planting strips, etc. The classic example would be the large parking lot shopping center. When questioned about such situations, the representatives of the Access Board stated that "lot" should be interpreted "in accordance with typical design industry practice." We posed several examples to them in order to query their thoughts on reasonableness of certain interpretations. *Remember that these conversations with Access Board and DOJ staff are to be considered "best available" interpretations, not official clarifications of the Access Board.* In general, if one can freely circulate from one section to another, without going back out onto a public street, the entire facility can be considered one lot. However, where parking areas are separated and access is controlled so that one cannot circulate freely from one area to the other, it is probable they will be considered separate lots. The PCC has requested that a definition of lot be added to ADAAG 2000.

Conversely there is a possibility that parking structures that are broken into several parking areas with separate entrances, exits, and internal circulation systems could be considered multiple lots, with the number of spaces required in each area determined on a "lot-by-lot" basis.

As will be discussed in more detail later in this chapter, it is sometimes appropriate to provide the accessible spaces required in one facility in another location with better accessibility. This topic gets especially complicated if new facilities are constructed on existing lots. For example, a 1000-space structure is to be built on a lot that previously had 400 spaces. In previous accessibility planning, eight accessible spaces were provided elsewhere. Twenty accessible spaces are required for the new structure but eight already exist; therefore 12 accessible spaces should be added to the parking system.

Note that spaces converted to accessible under the relocation provision must fully comply with new construction standards in terms of width, layout, floor slopes, the accessible route to the building entrance, etc. There will be no "readily achievable" limit on the reasonableness of the cost to convert closer spaces to accessible ones.

It should also be noted that the reference to cost in 4.1.2(5)(a) concerns the cost of parking to the user, not the cost of constructing the accessible spaces. Accessible parking cannot be relocated from a free or low-cost facility to one with a higher fee, thereby forcing a person with a disability to pay the higher fee. A person with a disability can either be given the same choices (distance/convenience versus price) or can be allowed to park in the closer facility at the same rate as charged in the more distant facility.

Nothing in the guidelines or the ADA requires that the disabled shall be afforded free parking when other parkers must pay.

11.2.2 Employee and Contract Parking

As previously noted, neither public nor private entities must add accessible spaces to employee parking lots until or unless the area is being altered or an employee needs an accessible space.

In response to requests for clarification from members of the National Parking Association who had major concerns about the loss of revenue in parking lots that are entirely leased to monthly parkers (none of whom require a disabled space), Bulletin #6 contained the following clarification:

> **Must accessible spaces be provided in lots where parking is assigned to individual employees or to paying customers?** ADAAG does not distinguish between lots or garages with assigned spaces and those without. Thus, in lots or garages comprised only of spaces that are leased or assigned to employees, accessible spaces are required. However, in such situations, policies regarding the use of accessible spaces may be feasible so long as they do not discriminate against persons with disabilities. For example, in lots reserved for employees only, accessible spaces may be used by persons without disabilities when they are not needed by employees with disabilities.

This interpretation is one of the most significant in Bulletin #6. Note that it is written for new construction but would be equally applicable to existing and altered lots. In new lots or facilities reserved for employees, the required number of spaces must be designed to be fully accessible. However, they need not be marked or signed as accessible, and any employee can use them, until or unless a disabled employee needs the accessible stall. This interpretation applies to both new and existing parking facilities. Therefore, unnecessary disabled stalls need not sit vacant in employee-only facilities. Bulletin #6 further indicated and a DOJ representative confirmed that this interpretation would apply to a parking facility entirely leased to monthly parkers by a commercial parking operator. The operator need not provide preference to the disabled on a waiting list; however, it cannot skip over the disabled person at the top of the waiting list because it can't or won't convert a space to accessible. It must be noted that the entity that chooses not to identify and reserve the spaces as accessible must commit to bear whatever expense is necessary to convert the spaces to fully accessible under ADAAG when needed by a disabled parker. Figure 11-1 provides an example of how an area designed to provide accessible parking spaces might be constructed and used as nonaccessible spaces until needed as accessible. Note that curb ramps and the separate accessible route are already in place; the only cost of converting the spaces to accessible is adding signage. The pavement markings (including cross hatching of the access aisles) and the bollards (to discourage use of the van access aisle) are optional but are strongly recommended, particularly when parkers have been able to park in those spaces in the past.

It should also be noted that students cannot be treated as employees under ADA and therefore student parking at colleges and universities would have to be treated as public parking. However, where student parking is provided entirely in lots reserved for permit holders, the institution would only have to reserve accessible spaces as required for the needs of a student with disabilities.

11. 2.3 Medical Facilities

ADAAG 4.1.2(5)(d) provides special requirements for the number of accessible spaces at certain medical facilities:

> At facilities providing medical care and other services for persons with mobility impairments, parking spaces complying with 4.6 shall be provided in accordance with 4.1.2 (5)(a) except as follows:
>
> (i) Outpatient units and facilities: 10 percent of total number of parking spaces provided serving each such outpatient unit or facility.
>
> (ii) Units and facilities that specialize in treatment or services for persons with mobility impairments: 20 percent of the total number of parking spaces provided serving each such unit or facility.

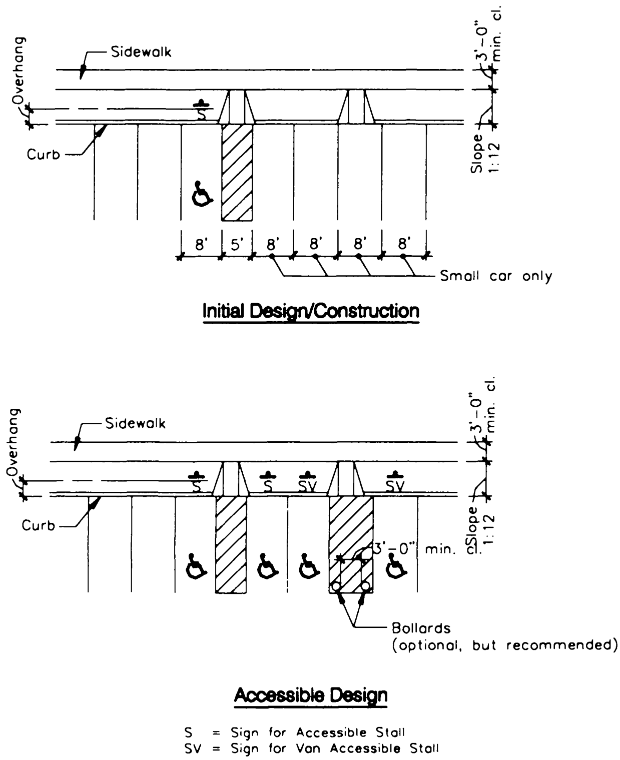


Figure 11-1. Design of employee spaces for future conversion to accessible

Bulletin #6 further clarified the application of these requirements:

Medical Care and Other Services for Persons with Mobility Impairments.

A greater number of accessible parking spaces is required at facilities providing medical care and other services for persons with mobility impairments. The term "mobility impairments" is intended to include:

- conditions requiring the use or assistance of a brace, cane, crutch, prosthetic device, wheelchair or other mobility aid;
- arthritic, neurological, or orthopedic conditions that severely limit one's ability to walk;

- respiratory diseases and other conditions that may require the use of portable oxygen; or
- cardiac conditions that impose significant functional limitations.

At outpatient facilities, 10% of the parking spaces must be accessible. Facilities that specialize in medical treatment and other services for persons with mobility impairment are required to have 20% of parking spaces accessible. Other facilities (including medical care facilities) that do not provide outpatient services or specialized service for persons with mobility impairments are subject only to the general scoping requirement in the table in ADAAG 4.1.2(5)(a).

The question that immediately arose upon the issuance of ADAAG was whether or not doctor's offices, independent clinics, and immediate-care facilities would be considered outpatient facilities. Bulletin #6 continues with a clarification of the term "outpatient facility".

What is an outpatient facility? An outpatient facility is part of a medical care facility, such as a hospital's clinic or ambulatory care center that provides regular and continuing medical treatment to patients without overnight stay. As defined in the guidelines, medical care facilities are facilities in which the period of stay may exceed 24 hours and physical or medical treatment or care is provided where persons may need assistance in responding to an emergency. Under these guidelines, the term "outpatient facility" does not include doctors' offices, independent clinics, or other facilities not located in medical care facilities.

While the PCC had previously obtained the clarification that doctors' offices are not covered by "outpatient," the exclusion of independent clinics is a significant interpretation. The Bulletin #6 definition of outpatient tends to limit it to services provided at hospitals. Freestanding "immediate care" and "surgicenters" that have no facilities for overnight stays (even if owned by a hospital) thus are not considered outpatient services unless located on a hospital campus. We have further clarified with the Access Board that facilities provided by teaching medical centers for doctors on the faculty to examine and prescribe treatment (as they would in a private practice) may be considered to be doctor's offices rather than outpatient services.

ADAAG 2000 contains language formalizing the clarifications given in Bulletin #6, by adding the following change in language and an advisory:

208.2.1 Hospital Outpatient Facilities. Ten percent of patient and visitor parking spaces provided to serve hospital outpatient facilities shall be accessible.

> **Advisory 208.2.1**: The term "outpatient facility" is not defined in this document but is intended to cover facilities or units that provide regular and continuing medical treatment without an overnight stay, and that are located in hospitals. Doctor's offices, independent clinics or other facilities not located in hospitals are not considered hospital outpatient facilities for the purposes of this document.

Bulletin #6 then clarifies the definition of specialized rehabilitation facilities:

> **Facilities and Units Specializing in Treatment or Services for Persons with Mobility Impairments.** Facilities or units that specialize in treatment or other services for persons with mobility impairments, including vocational rehabilitation and physical therapy, must have 20% of parking spaces accessible. These are facilities in which the treatment or service specifically serves persons with mobility impairments, such as spinal cord injury treatment centers, prosthetic and orthotic retail establishments, and vocational rehabilitation centers for persons with mobility impairments. This requirement does not apply to facilities providing, but not specializing in, services or treatment for persons with mobility impairments, such as general rehabilitative counseling or therapy centers. In determining whether a facility is subject to this requirement, both the nature of the services or treatment provided and the population they serve should be carefully considered.

In one of the most important clarifications of Bulletin #6, the following was stated:

> **Do the 10% and 20% requirements apply to employee parking spaces as well?** The higher percentages required for outpatient facilities or those facilities specializing in treatment and services for persons with mobility impairments are intended primarily for visitor and patient parking. If there are separate lots for visitors or patients and employees, the 10% or 20% requirement may be applied only to the visitor/patient lot while accessible parking could be provided in the employee lot according to the general scoping requirement in the chart. If a lot serves both visitors and patients and employees, 10% or 20% of the spaces intended for use by visitors or patients must be accessible.

This clarification makes compliance with the 10%/20% requirement much easier. Bulletin #6 continues:

> **If a hospital with an outpatient unit is served generally by one lot, must 10% of all spaces be accessible?** At medical care facilities

> where parking does not specifically serve an outpatient unit, only a portion of the lot would need to comply with the 10% scoping requirement. A local zoning code that requires a minimum number of parking spaces according to occupancy type and square footage may be an appropriate guide in assessing the number of spaces in the lot that "belong" to the outpatient unit. These spaces would be held to the 10% requirement while the rest of the lot would be subject to the general scoping requirement in the chart. Those accessible spaces required for the outpatient unit should be located at the accessible entrance serving the unit. This method may also be used in applying the 20% requirement to hospitals or other facilities where only a portion or unit provides specialized treatment or services for persons with mobility impairments.

The Access Board representatives stated that in the absence of a local zoning standard for required number of spaces for outpatient use, a parking study conducted in accordance with generally accepted practices (such as those outlined in the PCC publication *Parking Studies*[6]) could also be used to determine the proportion of the facility that is subject to the 10%/20% requirement.

A clarification that the 20% ratio for rehab units is also applicable only to visitor and patient parking is provided in section 208.2.2 of ADAAG 2000.

Table 11-5 presents sample calculations for the required number of spaces for a hospital with multiple parking facilities. The following is a comparison of requirements at a typical hospital that has multiple lots, separated by non-owned property or public right-of-ways, with that required for a new hospital, designed with a single large parking facility. (Incidentally, the data is for a real, existing hospital that prefers to remain nameless!)

This real hospital is supposed to have 55 accessible parking spaces. Because the employee lots are as far away as two blocks, it is obvious that they should relocate those accessible spaces to location(s) nearest to the accessible employee entrance(s), and provide the visitor spaces closest to those entrances. However, if the hospital builds a single, large parking structure of 1525 spaces, it would only need 30 accessible spaces. An excessive number of accessible spaces standing vacant only further encourages the arrogant types to illegally park in the disabled stalls, if not the access aisles. It simply doesn't make sense to require this hospital to provide 55 spaces distributed to the three or four lots closest to the accessible entrances to the building. Colleges and universities have even more complex systems and are required to provide far more spaces than are reasonably required. Indeed, most will work with individual disabled students and employee to assure parking and accessibility to the appropriate buildings and therefore have little need for an excessive cushion due to a fragmented supply.

Table 11-5. Minimum Accessible Parking Space

Lot	Total Spaces	Multiple Lots	Single Structure
Outpatient Lot	31	4	5
Emergency Lot	19	2	(50*10%, rounded up)
Visitor Lot A	164	6	25
Visitor Lot B	38	2	
Physician Lot	28	2	(20 + (525-50)*1%,
Employee Lot C	11	1	Rounded up)
Employee Lot D	29	2	
Employee Lot E	52	3	
Employee Lot F	31	2	
Employee Lot G	87	4	
Employee Lot H	40	2	
Employee Lot I	106	5	
Employee Lot J	41	2	
Employee Lot K	53	3	
Employee Lot L	515	6	
Dr. Office Building Visitors	46	2	
Dr. Office Building Employees	247	7	
TOTAL	1538	55	30

The number of accessible spaces should be calculated first for the parking provided to patients and visitors of outpatient units and units specializing in the treatment of mobility impairments, and then Table 11-4 shall be used to determine the required number of accessible spaces for the remainder of the parking provided.

11.2.4 Van Accessible Spaces

ADAAG 4.1.2(5)(b) requires that some of the accessible spaces b specially designed for the use of persons employing vans for persona transportation:

> One in every eight accessible spaces, but not less than one, shall be served by an access aisle 96 in. (2440 mm) wide minimum and shall be designated "van accessible" as required by 4.6.4. The vertical clearance at such spaces shall comply with 4.6.5. All such spaces may be grouped on one level of a parking structure.

> EXCEPTION: Provision of all required parking spaces in conformance with "Universal Parking Design" (see appendix A4.6.3) is permitted.

The ADAAG 2000 provisions are substantially the same except the exception for Universal Parking Design has been dropped.

The 96-in.-requirement translates to an 8-ft. access aisle rather than the 5-ft. access aisle as required for the remainder of the accessible spaces. (See Section 11.2.8 for layout of accessible spaces.) In addition, ADAAG 4.6.6 specifies a special clearance requirement of 8'-2" at van-accessible spaces:

> At parking spaces complying with 4.1.2(5)(b), provide minimum vertical clearance of 98 in. (2490 mm) at the parking space and along at least one vehicle access route to such spaces from site entrance(s) and exit(s).

Special consideration must be made to provide this clearance at all elements in the vehicular path of travel, including structure at hinge points, lighting fixtures, and conduit, drain lines and other projections and appurtenances that protrude into the path of travel.

ADAAG Appendix A4.6.3 further illuminates the requirements:

> The increasing use of vans with side-mounted lifts or ramps by persons with disabilities has necessitated some revisions in specifications for parking spaces and adjacent access aisles. The typical accessible parking space is 96 in. (2440 mm) wide with an adjacent 60 in. (1525 mm) access aisle. However, this aisle does not permit lifts or ramps to be deployed and still leave room for a person using a wheelchair or other mobility aid to exit the lift platform or ramp. In tests conducted with actual lift/van/wheelchair combinations, (under a Board-sponsored Accessible Parking and Loading Zones Project) researchers found that a space and aisle width totalling almost 204 in. (518 mm) was needed to deploy a lift and exit conveniently. The "van accessible" parking space required by these guidelines provides a 96 in. (2440 mm) wide space with a 96 in. (2440 mm) adjacent access aisle that is just wide enough to maneuver and exit from a side mounted lift. If a 96 in. (2440 mm) access aisle is placed between two spaces, two "van accessible" spaces are created. Alternatively, if the wide access aisle is provided at the end of a row (an area often unused), it may be possible to provide the wide access aisle without an additional space. A sign is needed to alert van users to the presence of the wider aisle, but the space is not intended to be restricted only to vans.

The "revision" mentioned above is in reference to the fact that UFAS does not require van access spaces. During the preliminary rule making, some had argued that all spaces should be van-accessible; the PCC, among others, supported language similar to that now in ADAAG.

An interesting change to ADAAG 2000 is that the requirement for the "van accessible" sign is dropped. According to the preamble, this change is because it created the very confusion discussed above, i.e., whether the space is reserved for vans or not.

As an alternative to providing van accessible spaces as detailed above, ADAAG allows the Universal Parking Space Design:

> An alternative to the provision of a percentage of spaces with a wide aisle and the associated need to include additional signage, is the use of what has been called the "universal" parking space design. Under this design, all accessible spaces are 132 in. (3350 mm) wide with a 60 in. (1525 mm) access aisle. One advantage to this design is that no additional signage is needed because all spaces can accommodate a van with a side mounted lift or ramp. Also, there is no competition between cars and vans for spaces since all spaces can accommodate either. Furthermore, the wider space permits vehicles to park to one side or the other within the 132 in. (3350 mm) space to allow persons to exit and enter the vehicle on either the driver or passenger side, although, in some cases, this would require exiting or entering without a marked access aisle.

Bulletin #6 reinforced the concept of Universal Parking Spaces as follows:

> **Universal Parking Spaces.** As an alternative to providing both accessible and van-accessible spaces, "universal" parking spaces may be provided. Universal parking does not require the specific designation of van spaces since each accessible space can accommodate either a car or van. This design features wider parking spaces that are at least 11 feet wide with standard access aisles at least 5 feet wide. The wider space allows users to park to one side or the other of the space, which may ease transfer and travel from the vehicle, especially when an access aisle is provided on only one side of the space.

Clearly, you are not supposed to use Universal Parking Design only for van-accessible spaces; the intent is to use it for all accessible spaces. However, because it is essentially an upgrading of all accessible spaces to van-accessible requirements, it requires significantly more area and thus is little used except where local requirements mandate Universal Parking Design. Further, using Universal Parking Design requires that all accessible spaces have the 8'-2" vertical clearance for van-accessible parking (see Figure 11-2). It is unclear why ADAAG 2000 dropped the provision of Universal Parking Design, as a number of states and localities have adopted it or a variation thereof.

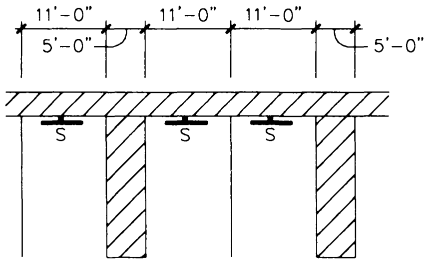


Figure 11-2. Universal parking design

Bulletin #6 provided the following commentary, which, while not particularly distinct or clarified from ADAAG, does reinforce the requirements as follows:

> **Accessible Van Parking Spaces.** The growing use of vans by persons with mobility impairments has led to a requirement for some accessible spaces that accommodate van users. Most often, vans are equipped with a lift or ramp at a side door. According to research sponsored by the Access Board, almost 17 feet in width is needed for the convenient deployment and use of a van-mounted lift. ADAAG requires the access aisle serving a van space to be at least 8 feet wide, as is the parking space itself, for a combined minimum width of 16 feet. Since accessible spaces may share an access aisle, a single eight-foot aisle can serve two van spaces without additional space impact.

This presumes that 90 degree parking is always provided. With angled parking, only the aisle with the access stall on the passenger side should be considered van accessible.

Some folks persist in trying to manipulate ADAAG requirements, such as the term "1 in 8," which is **not** a percentage factor. If nine accessible spaces are required, two must be van-accessible, and so forth. To eliminate all possibility of misinterpretation, the Access Board provided a table for van accessible spaces in Bulletin #6. The Bulletin #6 table is summarized in Table 11-4 previously presented.

> **Minimum Number of Van-Accessible Spaces.** One of every eight spaces is required to have an eight foot aisle to accommodate van users. Where spaces share access aisles, it is recommended that both spaces served by the 8 foot aisle be designated as "van-accessible."

Bulletin #6 goes on to address a frequently asked question:

> **Must van-accessible spaces be restricted to van use?** The required "van-accessible" designation, which should be located beneath the international symbol of accessibility, is intended to be informative, not restrictive, in identifying those spaces that are better suited for van use. It should not be interpreted as restricting the use of spaces to vans only. Additional signage may be provided recommending that cars not be parked in van-accessible spaces unless no other accessible parking space is available. This distinction could be particularly helpful in those lots where only one accessible space is required, since ADAAG requires that space to be van-accessible.

We recently encountered a design of a new structure that had severe restrictions on the development of the site. The project architect was able to design accessible parking meeting all requirements, except he was having extreme difficulty achieving the additional height requirements for van-accessible parking. The parking facility would serve a large outpatient clinic at an urban hospital, triggering the 10% accessible rule. In fact, the hospital is part of a state university and technically can choose to follow UFAS, which doesn't require any van-accessible stalls. However, because the facility serves an ambulatory care center, the hospital administration wanted it to be designed to ADAAG. The overall required capacity of 500 spaces could not be achieved within the zoning height limitations while providing 50 accessible spaces of which seven are van accessible with 8'-2" clearance. Under the provision that allows van-accessible parking to be provided in another location where equal or greater accessibility is provided, the architect was proposing that all van-accessible parking be valet-parked at no charge in an adjacent existing reserved parking area that had the required clear height. The van parking pick-up/drop-off would be closer and more easily accessible to the outpatient clinic. However, this denies the van driver the right to self-park when all other users can self-park. Many individuals don't like to turn their vehicle over to an attendant for valet parking. We suggested the design provide two self-park van-accessible spaces in the area proposed for valet pick-up and drop-off (which was easily accomplished) and valet park any additional vans at no additional cost to the parker.

11.2.5 Valet Parking

ADAAG addresses the unique differences between self-parking and valet parking in 4.1.2(5)(e):

> **Valet parking**: Valet parking facilities shall provide a passenger loading zone complying with 4.6.6 located on an accessible route to the entrance of the facility. Paragraphs 5(a), 5(b) and 5(d) of this section do not apply to valet parking facilities.

The requirements are further clarified in the Appendix A4.1.2(5)(e) Valet Parking.

> Valet parking is not always usable by individuals with disabilities. For instance, an individual may use a type of vehicle controls that render the regular controls inoperable or the driver's seat in a van may be removed. In these situations, another person cannot park the vehicle. It is recommended that some self-parking spaces be provided at valet parking facilities for individuals whose vehicles cannot be parked by another person and that such spaces are located on an accessible route to the entrance of the facility.

It should be noted that the term valet parking covers any facility wherein the parker surrenders the car to be parked by an attendant. Bulletin #6 provides further clarification:

> **Are accessible spaces required where valet parking is provided?** Parking facilities that provide valet parking only are not required to provide accessible spaces but must have an accessible passenger loading zone that is connected to a facility entrance by an accessible route. However, it is strongly recommended that some accessible parking be provided even if valet parking is available. Some vehicles may be specially adapted with hand controls only or lack a driver's seat and may not be operable by an attendant. In addition, accessible spaces must be provided if valet service is not available during all hours of operation for users who must sometimes retrieve or park their own vehicles.

While the above addresses most of the valet parking issues, one frequent problem was not covered: lots that are operated partially valet and partially self-park. Based on the other Bulletin #6 clarifications and interpretations (such as that for the calculation of spaces for medical facilities) as well as conversations with Access Board and DOJ staff, a reasonable determination of the maximum number of spaces that are self-parked at any one time can be used to calculate the number of accessible parking spaces required.

Another potential issue is whether or not an operator can valet-park the vehicles of persons with disabilities in lieu of providing accessible spaces. This arrangement might be considered a reasonable accommodation of accessible parking in certain circumstances where the provision of accessible parking is severely constrained by existing site conditions. For example, an existing garage has no parking at the grade level, and no elevator is provided to the two supported levels. It would not be "readily achievable" to provide accessible parking and valet parking would be the most viable solution. However, the person with disabilities cannot be charged an additional fee for valet parking when no self-park accessible parking is provided. For new construction, if all other spaces are self-park, than self-park accessible spaces must be provided.

In ADAAG 2000, the exemption for valet parking is completely dropped, apparently due to the fact that persons with disabilities found uneven accessibility of parking in such facilities. The PCC has requested a compromise requiring a number of self-park accessible spaces equal to the required number of van accessible spaces.

11.2.6 Passenger Loading Zones

ADAAG has distinct requirements for passenger loading zones, starting with 4.1.2(5)(c)

If passenger loading zones are provided, then at least one passenger loading zone shall comply with 4.6.6.

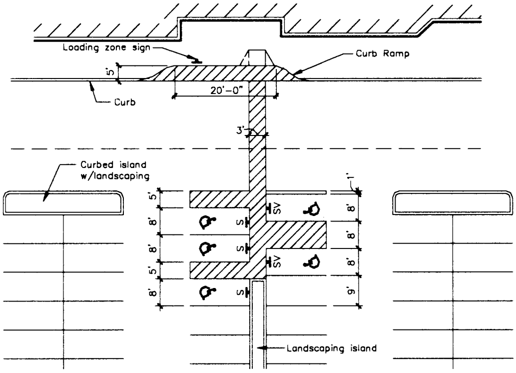
This in turn, ADAAG 4.6.6 requires:

> Passenger loading zones shall provide an access aisle at least 60 in. (1525 mm) wide and 20 ft. (240 in.) (6100 mm) long adjacent and parallel to the vehicle pull-up space. If there are curbs between the access aisle and the vehicle pull-up space, then a curb ramp complying with 4.7 shall be provided. Vehicle standing spaces and access aisles shall be level with surface slopes not exceeding 1:50 (2%) in all directions.

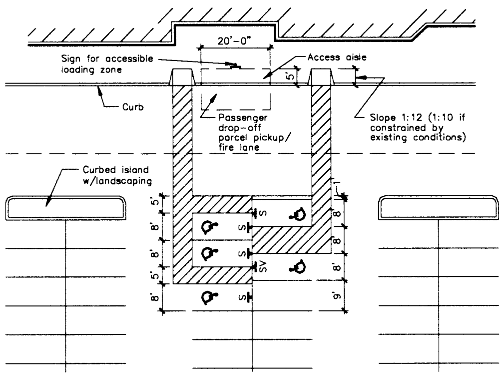
Newly constructed passenger loading zones under ADAAG 1991 may discharge to a curb as indicated above; however, it is strongly preferred that the curb and sidewalk be gently sloped down to blend with the pavement elevation (see Figure 11-3). Note that improvements to an existing passenger loading zone can be made to bring it into reasonable compliance without meeting the full requirements for new construction.

Bulletin #6 adds:

Passenger Loading Zones. An accessible passenger loading zone is required only where passenger loading zones are specifically designed for passenger loading and unloading. Areas not so designed are not subject to this requirement even if, as a practical matter, some drivers may use them for this purpose. Both the pull-up space and adjacent access aisle are required to be level with surface slopes no greater than 2% in any direction. Since the 2% slope requirement applies to the entire aisle surface, curb ramps should be located next to -- not within -- the aisle, preferably at both ends. Further, there can be no obstructions, such as planters or street furniture, in the access aisle area.



New Construction



Existing Conditions
With Site Constraints

Figure 11-3. Comparison of solutions for new construction and existing facilities

ADAAG 4.6.5 covers the required vertical clearance at passenger loading zones:

> Provide minimum vertical clearance of 114 in. (2895 mm) at accessible passenger loading zones and along at least one vehicle access route to such areas from site entrance(s) and exit(s).

One problem that has occurred is misunderstanding about the differences between accessible parking and passenger loading zones. In more than one case, a local building official has argued that all accessible parking spaces are passenger loading zones and thus must have the 9'-6" clearance. Clearly, this was not the intent of Access Board, since it specified a clearance of 8'-2" for van-accessible stalls. Bulletin #6 further addresses this issue:

> **Why does the vertical clearance for parking differ from that required for passenger loading zones?** Because vans used for accessible transit and paratransit may have higher roofs than those owned and used by most individuals, the minimum vertical clearance required for passenger loading zones (114 inches) is higher than the one specified for van-accessible spaces (98 inches).

Among the most significant changes proposed for ADAAG 2000 are the changes to passenger loading zones. It is proposed that one loading zone per 100 ft. of continuous loading be provided; this is of extreme concern to those involved in site planning, especially for uses such as shopping centers and airports, and particularly in light of modification to the design of the loading zone found in 2000-503. The access aisle will no longer be able to sit at the top of the curb, but rather must be flush with the vehicle standing zone. The detail further shows a "set-back" of the curb to achieve the 5 ft. wide loading zone. (As shown for new construction in Figure 11-3) With the 45-degree angle of the "set-back" as shown in ADAAG 2000, the actual overall length of curb is 30 ft., and thus, almost one of every four loading spaces is effectively required to be accessible. Where larger para-transit and full size coaches use the loading zone, it can be as many as one of every three loading spaces.

The first issue is the number of such spaces. Certainly one per three or four is too many; no other scoping requirement in ADAAG is so high. Of course the distance from the accessible loading zone to the accessible entrance needs to be considered. However, one loading zone in the middle of 100 ft. curb at a strip shopping means that the maximum walking distance to a door is not going to be much over 50 ft.; disabled parkers will almost certainly traverse much greater distances. Conversely where an individual is required to wait at a specific loading point, such as at a designated rental car company spot at an airport arrivals curb, each one effectively needs to be an accessible loading zone. However, that type of vehicle is required to provide accessible service and therefore should have a lift specifically designed to be accessible either from the pavement or the top of a curb, and a "bump-in" is not required. Therefore, the PCC has recommend the following requirement in the final version of ADAAG 2000:

> 209.1. General. Where a passenger loading zone(s) is provided at or near an accessible entrance, the loading zone closest to the entrance to the building or facility shall comply with 503. Where a continuous

> curb serves multiple accessible entrances, such as at a shopping center or airport terminal, at least one loading zone for every five such entrances, with a minimum of one for every 200 ft. of continuous curb, shall be accessible.
>
> EXCEPTION: Where a continuous curb loading zone is reserved for the use of public or commercial transit, paratransit, shuttle and other multi-passenger transportation vehicles, otherwise required to have a wheel-chair lift that is usable both from the pavement or top of curb, and where separate accessible passenger loading zones in compliance with Section 209 and 503 are provided for those arriving by private vehicle, this section does not apply.
>
> 503.3 Access Aisle. Access aisle shall connect directly to an accessible route, including a curb ramp as required.

A final issue relates to the specific design of the access aisle. The provision of the angled ends will appear to many users to mean that the vehicle is to be pulled into the access aisle closer to the curb. However, an overall length of 30 ft. is not adequate to pull in and out smoothly, and therefore people will attempt to parallel park in the access aisle. It is our understanding that the reason for the "set-back" of the curb is to provide the access aisle at the same elevation as the driving surface, so that a passenger can more easily transfer from a private car to a wheel chair. Therefore the PCC strongly recommended that the ends be at 90 degrees and that the access aisle be marked by crosshatching so that it be communicated that the aisle is not intended as a parallel parking stall. Also, there does not appear to be a requirement to provide a curb ramp from the access aisle to the top of curb. While logic says there should be one, the "yahoos" of the world will argue that one 20 ft. down the way is close enough and expect someone in a wheel chair to roll back out into vehicular traffic to reach it. We strongly recommended that where curbs exist around the perimeter of the access aisle, a curb ramp must be connected directly to the access aisle.

11.2.7 Location of Spaces

ADAAG 4.6.2 addresses the location of accessible spaces:

> Accessible parking spaces serving a particular building shall be located on the shortest accessible route of travel from adjacent parking to an accessible entrance. In parking facilities that do not serve a particular building, accessible parking shall be located on the shortest accessible route of travel to an accessible pedestrian entrance of the parking facility. In buildings with multiple accessible

entrances with adjacent parking, accessible parking shall be dispersed and located closest to the accessible entrances.

Bulletin #6 further clarifies one of the frequent issues of contention:

> **Must accessible spaces be provided in each lot or on each level of parking garages?** Accessible spaces can be provided in other lots or locations, or, in the case of parking garages, on one level only when equal or greater access is provided in terms of proximity to an accessible entrance, cost, and convenience. For example, accessible spaces required for outlying parking lots may be located in a parking lot closer to an accessible entrance. The minimum number of spaces must still be determined separately for each lot even if the spaces are to be provided in other lots or locations. Accessible spaces may be grouped on one level of a parking garage in order to achieve greater access. However, where parking levels serve different building entrances, accessible spaces should be dispersed so that convenient access is provided to each entrance.

In sum, accessible spaces can be grouped on one level of a parking garage or in one parking lot in order to achieve greater access. Further, accessible parking spaces need not be distributed to every floor of a parking structure or every lot on a campus, simply because that gives a person with disabilities equal access to all portions of the facility.

Parking is one of the areas in ADAAG where persons with mobility impairments are given preferential, not equal, treatment. Distance, convenience, and safety are the "standards of care" in locating the accessible spaces. Ideally, accessible parking spaces should be placed at the level(s) with direct accessible entrances and closest to those entrances if the facility serves building(s) on the same site, or if a freestanding facility serving multiple uses, the level with direct accessible exits to the public sidewalk. Among other things, this placement provides an accessible means of egress in the event of emergency. However, other requirements of ADAAG may dictate that accessible spaces be distributed to every floor. These requirements include providing the accessible spaces on level floor surfaces, providing an accessible route that does not pass behind a string of parked vehicles and providing the shortest possible travel distance.

Normally, accessible parking should be moved from remote parking. For example, a university building a new perimeter lot of say 500 spaces (nine accessible spaces required) can convert non-accessible stalls (as required to provide nine accessible ones) in existing parking facilities closer to the accessible entrances of the building(s). However, if a shuttle service from remote parking provides more convenient access to buildings than the proposed accessible lot location, the accessible parking should be provided at the remote lot and the shuttle service should be accessible.

Bulletin # 6 also addresses specific location issues related to van accessible spaces.

> Since this clearance may affect the design of multi-level parking structures, van-accessible spaces may be grouped on one level of the structure; providing van-accessible spaces outside parking structures should not be considered as an alternative if equivalent convenience is not provided. Moreover, placement of accessible spaces outside a parking structure may be considered discriminatory if it is not part of an integrated setting and if the same amenities of interior parking, such as weather protection, security, and convenience, are not provided.

This discussion specifically addresses the often-proposed avoidance of the required van clearance in structures by placing the van-accessible spaces in an adjacent surface lot. The Access Board essentially says that this usually does not provide equivalent or better accessibility and thus is not permissible. In weighing the balance between distance, safety, and convenience, climate may be a major factor. Because of the time it takes for a person using a wheelchair to exit a van or transfer to a wheelchair from a car, there is a particular concern with relocating accessible spaces from a structure to a surface lot. Climate protection during this unloading process may be more beneficial than a short path of travel. Because lifts are associated with vans, it is thus more critical to have the van-accessible spaces under cover in the structure if possible. Of course, this then triggers the requirement for 8'-2" clearance. If the surface lot is otherwise more accessible, i.e., much closer, it might be acceptable if a canopy or covering is provided at the accessible spaces. However, relocating all accessible spaces, including the van-accessible spaces, from a remote surface lot to one adjacent to the building would be permissible, because weather is a problem in either location.

The language of various sections of ADAAG puts a high priority on locating accessible spaces as close as possible to the accessible entrances of the associated buildings. Note that the portion of the route traversed via elevator is considered to be "zero" travel distance. The Access Board considered adopting a specific maximum distance within which accessible spaces must be located. However, it did not mandate a specific maximum distance (see also A4.3.1 of ADAAG for a discussion of path of travel distance). For reference, the Canadian accessibility guideline mandates a maximum distance of 83 ft.; some other guidelines have maximum distances of 100 to 200 ft. A maximum distance of 100 ft. is recommended by the

PCC where feasible. However, the recommendation of a certain distance is not a license to provide the spaces anywhere within 100 ft. The spaces must still be the closest to the accessible entrance.

Convenience may also be a factor in determining an appropriate travel distance. Examples of how the distance/convenience/safety balance must be weighed are as follows:

Example 1: An employee-only parking facility is to be built at a walking distance of more than 500 ft. from the pedestrian entrance of the parking structure to a hospital. Adjacent to the hospital entrance is a surface parking lot, in which the accessible parking spaces can be placed within a walking distance of less than 50 ft. In this case, the accessible parking spaces otherwise required in the parking structure should be placed in the surface lot, so as to minimize the distance of the accessible route.

Example 2: In the same circumstances as example 1, except that the travel distance is 100 ft. and there is a steep site slope along the path of travel. To achieve an accessible route, extensive ramping with several rest areas will be necessary. Again, placing the spaces in the surface lot is preferable.

Example 3: In the same circumstances as example 1, the owner elects to construct a pedestrian bridge from the parking structure to the hospital. In this case, the convenience of the protected bridge provides a better level of accessibility than the shorter path from the surface lot. Thus, the accessible spaces should be in the structure.

However, nothing in the guidelines should be construed as requiring a pedestrian bridge in such circumstances. There are alternative means of providing a reasonable degree of weather protection, such as locating the accessible spaces under a canopy.

The spaces are to be located so that the greatest degree of accessibility is achieved and the shortest possible path of travel in the pedestrian mode results. For example, a parking facility may have a small area created by the ramping system that provides an ideal location for accessible spaces. This area is highly convenient but out of the path of high vehicular traffic volumes, as seen in Figure 11-4. Locating the accessible spaces in sight of the cashier or security station may also discourage violation of the spaces by persons without disabled parking permits. Thus locating all accessible spaces at grade level and without passing directly behind parked vehicles is often the most desirable solution.

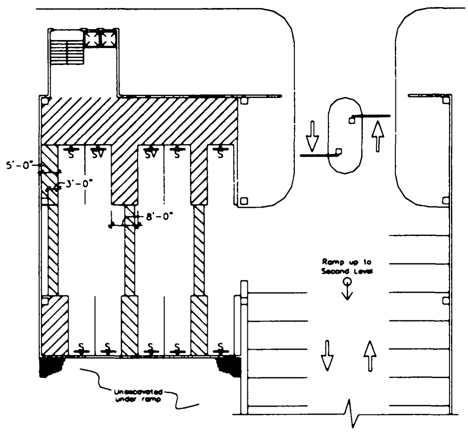


Figure 11-4. Accessible parking in dedicated bay

11.2.8 Layout of Accessible Spaces

ADAAG section 4.6.3 is one of the most frequently misinterpreted, and most often violated, sections relating to parking:

> Accessible parking spaces shall be at least 96 in. (2440 mm) wide. Parking access aisles shall be part of an accessible route to the building or facility entrance and shall comply with 4.3. Two accessible parking spaces may share a common access aisle. Parked vehicle overhangs shall not reduce the clear width of an accessible route. Parking spaces and access aisles shall be level with surface slopes not exceeding 1:50 (2%) in all directions.

The required width of the access aisle was specified with the required number of accessible spaces in 4.1.2 (5) (a):

> Except as provided in (b), access aisles adjacent to accessible spaces shall be 60 in. (1525 mm) wide minimum.

The reference to paragraph (b) is to the required 8 ft. width of access aisles for van-accessible spaces.

An essential consideration of any design is having the access aisle level with the parking space. Since a person with a disability using a lift or ramp must maneuver within the access aisle, the aisle cannot include a ramp or sloped area. The access aisle must be connected to an accessible route to the appropriate accessible entrance of a building or facility. The parking access aisle must either blend with the accessible route or have a curb ramp complying with 4.7. Such a curb ramp opening must be located within the access aisle boundaries, not within the parking space boundaries. Figure 11-5 presents "dos and don'ts" for detailing access aisles and curb ramps. Curb ramps in access aisles seem to be a particular pet peeve of the Access Board, as indicated in conversations with staff and hinted in Bulletin #6.

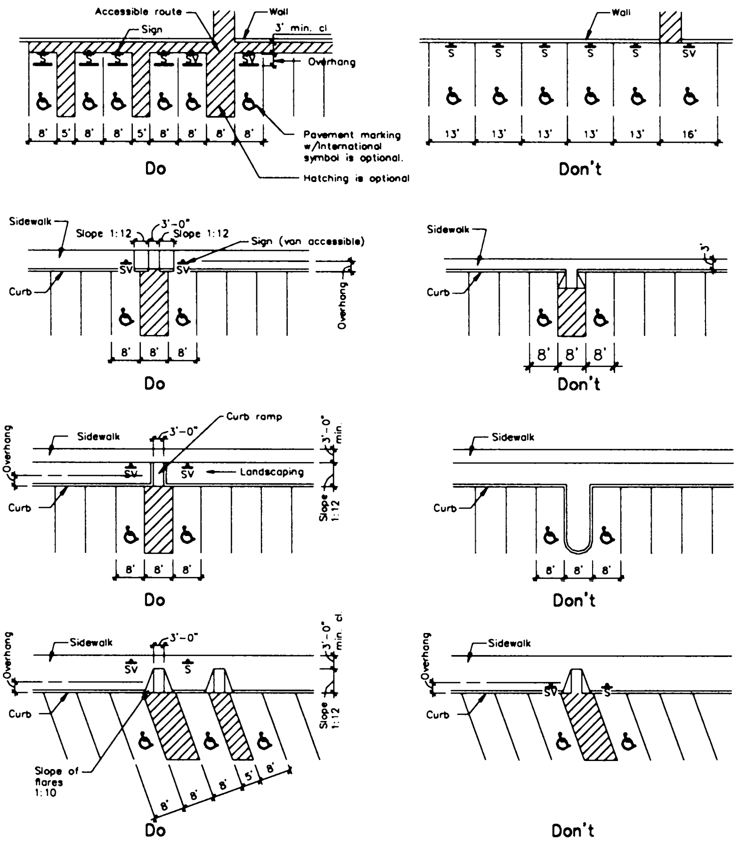


Figure 11-5. Dos and don'ts for accessible parking layout

Can curb ramps be provided within the access aisle? The maneuvering necessary to enter or exit vehicles and to transfer to and from wheelchairs requires that all accessible spaces, access aisles, and passenger loading zones be level, with slopes no greater than 2% in any direction. This does not apply to an entire parking lot or level of a parking structure but does include connecting accessible routes that cannot have cross slopes greater than 2%. For safe transfer,

> access aisles must be level for their full length. Thus, curb ramps, including built-up ramps, are not permitted within the area -- the full length and width -- of access aisles serving either parking spaces or passenger loading zones. Curb ramp openings must be located at the boundary of the access aisle, not the parking space, so that a parked vehicle does not block the ramp. In addition, the required size of access aisles and width of the accessible route cannot be reduced by planters, curbs, or wheel stops.

The PCC has previously received a clarification that allows the curb ramp to begin at the curb face when vehicles overhang a curb, as shown in Figure 11-5.

Accessible stalls may not be designed as parallel parking stalls discharging to a curbed sidewalk. It is extremely difficult for a person with a disability that requires the use of crutches or a wheelchair to get out of a vehicle parked close to a curb. If parallel parking is to be used, the stall must be pulled away at least 5 ft. from the curb face, to provide an overall width of 13 ft. The interim guidelines for on-street parking specifically require a similar access aisle at the street elevation, rather than discharging to a sidewalk.

Vehicle overhang must not intrude into either the access aisle or accessible routes. While the typical vehicle overhang is 2'-6" or less, a few vehicles have front overhangs of as much as 3 ft., and if a vehicle is backed into the stall, the overhang may be much greater. Since the guidelines essentially require a sign at each stall, the sign post can be reinforced to serve as a vehicle stop. Setting the post 3 ft. from a curb or wheel stop may save wear and tear on the post while still preventing intrusion into the accessible route.

According to the ADAAG Supplementary Information in the *Federal Register* of July 26, 1991, access aisles shall be demarcated; a single wide space is not acceptable. Although not required by ADAAG or other guidelines for pavement markings such as the *Manual on Uniform Traffic Control Devices,* it is generally advisable to cross-hatch the access aisle, the accessible route (if it uses a vehicular route), and any marked crosswalks, to improve visibility to all drivers and pedestrians in the facility.

Another contentious issue for the parking industry has been the sharing of access aisles. There is no specific requirement in ADAAG that the access aisle be on one side or the other of the parking space; indeed, ADAAG states that access aisles may be shared and provides a detail with a shared access aisle. However, the detail shows 90 degree parking into which vehicles can pull either forward or back to keep the access aisle on the side needed by the person with disability.

Bulletin #6 addressed this issue:

> **Is "front-in" only parking prohibited by ADAAG?** Accessible spaces are required to be served by an access aisle that can be placed on either side of the parking space. Drivers may pull in or back in to perpendicular parking spaces depending on which side of the space is served by an access aisle and whether a person with a disability wishes to exit the vehicle from the driver's or the passenger's side. Accessible spaces that drivers can only pull into do not afford the same level of flexibility. ADAAG does not specifically address or prohibit "front-in" only parking. Thus, it is recommended that where such parking is provided, accessible spaces be designed so as to allow "back-in" parking also or that access aisles be provided to serve each side of a space. With respect to van-accessible spaces, it is recommended that the access aisle be provided on the passenger side of spaces since van side doors and side-mounted lifts are typically located on the passenger side.

During the early meetings with the Access Board staff, the PCC presented drawings of angled stalls sharing the access aisle, and were told that it was acceptable, because disabled drivers can use the stall with the aisle to the left, while those who need passenger-side access will use that to the right. It was agreed that van-accessible stalls must always have the access aisle on the passenger side when "front in" only parking is provided. The Access Board used the term "recommended" in Bulletin #6, which seem to indicate that they would continue to accept shared access aisles with angled parking. However, in the Title II modifications to ADAAG, they addressed the issue head-on. Section 14.2.6(1)(b)(ii) allows shared access aisles with perpendicular parking, but paragraph (iii) does not allow the same for angled parking. The discussion in Appendix A14.2.6(1) clearly states the Access Board position:

> Parallel and perpendicular accessible spaces allow a driver to locate the access aisle on either the passenger side or driver side as necessary for transfer and therefore may share access aisle. Because angled spaces are approached only from one direction, a driver cannot always select a space with an access aisle that will accommodate the desired transfer. Therefore, angled parking spaces may not share an access aisle.

Technically, this paragraph only applies to on-street parking and, further, is not yet law, pending the completion of DOJ rule making. The Access Board does plan (and has reserved the right) to issue supplemental rules modifying ADAAG at certain intervals. In 1994, when this was published, it seemed likely that it was the Board's intent to add the language prohibiting shared access aisles for angled parking to the requirements for off-street parking at some future date.

It is interesting however, that no additional language regarding location and/or sharing of access aisles has been added to ADAAG 2000. Since they wrote the language for Section 14, of the 1994 Interim Rule for Public Right of Ways, we expected to find it included in ADAAG 2000 but it is not there. Therefore, one can only conclude that on further reflection, the Access Board has decided not to mandate design of stalls so that the access aisle is accessible from either side of the vehicle.

In parking structures, it is frequently difficult to lay out accessible parking without some intrusion of columns or other appurtenances into parts of the access aisle. At the same time, there are inherently "dead zones" wherein intrusions can be accommodated. Also while the access aisle must be 5 ft. wide (8 ft. for van spaces) in the area of door opening, the width of the junction with the accessible route need only be 3 ft. There is no requirement for length of the accessible parking stall in ADAAG. Angled parking further complicates the situation. To ensure that the access aisle is functional in situations in question, the designer should draw a design vehicle parked in the stall and check to be sure car doors will open into the access aisle. According to data from the Motor Vehicle Manufacturer's Association, the vehicle doors will be located no closer to either end of a vehicle than 3'-0". (In most cases the dimension is about 4 ft. for front clearance to doors and up to 6 ft. for clearance from the rear of the car.)

ADAAG 2000 however, would appear to eliminate any encroachments, by specifically requiring the access aisle to extend "the full length of the parking space", apparently leaving the nominal length of the parking space to local zoning officials.

11.2.9 Accessible Route to Destination

The accessible route is the path of travel from the accessible stall (and specifically from the access aisle) to an accessible entrance of the building(s) served by the parking. ADAAG 4.1.2 requires:

> Accessible sites and exterior facilities shall meet the following minimum requirements:
>
> (1) At least one accessible route complying with 4.3 shall be provided within the boundary of the site from public transportation stops, accessible parking spaces, passenger loading zones if provided, and public streets or sidewalks, to an accessible building entrance.

(2) At least one accessible route complying with 4.3 shall connect accessible buildings, accessible facilities, accessible elements, and accessible spaces that are on the same site.

(3) All objects that protrude from surfaces or posts into circulation paths shall comply with 4.4.

(4) Ground surfaces along accessible routes and in accessible spaces shall comply with 4.5.

We have not reprinted all of the applicable references. However, several issues need to be addressed in any discussion of accessible routes related to parking. First an accessible route may have a running slope of 5% and a cross slope of 2%. These requirements are stated in more definitive units of 1:20 and 1:50 slope, respectively. This is another area where the mathematical result cannot be rounded. A slope of 1:19 is no longer an accessible route but an accessible ramp, with requirements for level landings, handrails, etc.

As long as the parking floor does not exceed 5.0% slope in the main direction of travel and 2.0% cross-slope, the parking floor can meet the requirements for an accessible route. A contentious and frequently ignored issue relating to parking layout is whether or not the accessible route from an accessible stall can pass behind parked vehicles. Bulletin #6 provides this clarification:

Is the accessible route leading from accessible spaces prohibited from being located behind other spaces? Access aisles must connect to an accessible route leading to an accessible entrance of a facility. ADAAG Fig. 9, which illustrates an access aisle shared by two accessible spaces, does not require a specific configuration for the connecting accessible route. However, it is strongly recommended that the accessible route not require travel behind other parking spaces since persons who use wheelchairs are not easily visible to drivers. Where this is not possible, the accessible route should run behind accessible parking spaces only.

The critical phrase is "strongly recommended." The Access Board has stated that each design should take into consideration and balance "distance, safety, and convenience." It does not mandate certain things like maximum walking distances or separated accessible routes because it does not want to eliminate what might otherwise be the preferable design.

One objection to the requirement for a separate accessible route is that it is very difficult and occasionally very expensive to achieve in facilities with a large number of accessible spaces. Figure 11-6 gives two examples of layouts. The first has separate walkways while the second does not. The walking distance in the one with separated walkways is 50% greater than the other layout, which may account for the fact that no one uses them!

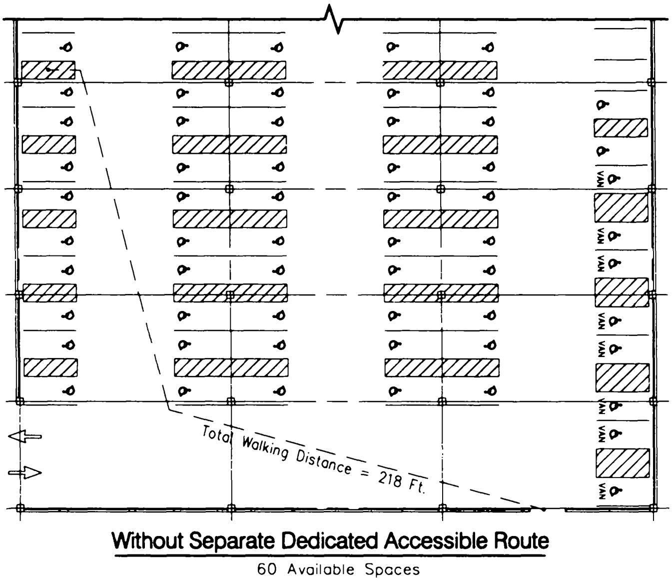
Conversely, the ADAAG definition of "accessible route" clearly indicates that crosswalks across vehicular routes may be part of the accessible route. ANSI requires that crosswalks in the accessible route be marked; the definition of "marked crossing" in ADAAG likewise implies that crosswalks should be striped. A number of individuals have argued that the accessible route in parking facilities should never use or cross vehicular routes.

While it is preferable that the access aisle connects to the accessible route at the front of the stall and that vehicular routes not be crossed, this is simply not possible in many circumstances. In many cases such as shopping centers and day care centers, the local code or design considerations require that a fire lane and/or drop-off be provided adjacent to the building. The perimeter of the lot, where accessible spaces might be placed with a dedicated accessible route, may be at a far greater distance from the building entrances. A dedicated accessible route may often be coordinated with landscaping islands and parking geometrics in new construction, but it may not be "readily achievable" in an existing center or "technically feasible" in an alteration. As another example, a rehabilitation hospital with 200 visitor/patient parking spaces would be required to provide 40 accessible parking spaces. It would in such a case be virtually impossible to provide a dedicated accessible route at the front of all of the accessible stalls. Crossing the vehicular route is clearly preferable.

Structural constraints in parking facilities also make it difficult to provide a dedicated access route in a configuration similar to those in Figure 11-6. The need to provide a relatively level floor surface at the accessible spaces also complicates the design.

It is interesting that ADAAG 2000 specifically adds language not only allowing vehicular routes, including parking aisles, to be part of an accessible route, but stating that where possible, the accessible route should be the one used by all pedestrians. Moreover, it did not add any language, or even an advisory discussing the issue of the path of travel passing behind parked cars. Therefore, it appears that the Access Board does not intend to require separated, accessible routes.

There are a number of solutions to maximize the convenience and safety of the accessible spaces. For example, if the access aisle also serves as the circulation path into the elevator tower, accessible spaces can be provided at each level. If a few additional spaces are required on some or all of the levels, reducing the angle of parking by 15 to 20 degrees will permit development of a separated accessible route (per Figure 11-6).



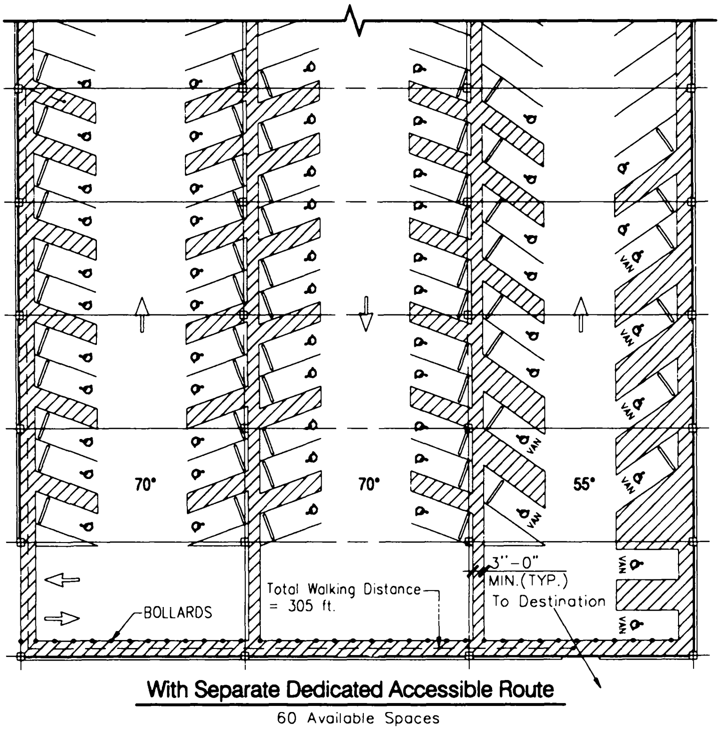


Figure 11-6. Layout of accessible parking with a separated accessible route in a parking structure

With the increasing size of parking structures, and the number of accessible spaces in such large facilities, it may be impossible to locate accessible spaces in a cluster around the elevator towers, and a string of spaces at one or more levels may be required to meet the required number of spaces.

One of the most controversial requirements of ADAAG, detectable warnings, has been suspended. As noted in Bulletin #6:

> The Access Board has voted to temporarily suspend the requirement for detectable warnings on curb ramps and at hazardous vehicular areas and reflecting pools until July 1996 pending the completion of further research.

The detectable warning requirement was officially suspended at the November 10, 1993, meeting of the Access Board. A bulletin that clarifies the requirements and specifications for detectable warnings is available from the Access Board

11.2.10 Signage

The signage requirements of ADAAG are designed to allow visually impaired persons to achieve at least a minimum degree of freedom to move about independently. Some have argued that it is ridiculous to require a Braille sign in a parking facility when at least one member of the party must have good enough sight to pass a driving test. However, there are circumstances where a visually impaired person might separate from the rest of the party in the parking area and have to return to the vehicle alone later. Therefore, ADAAG does require that signs in parking facilities meet the same requirements as those for buildings. Signage of parking facilities is subject to the general requirements of ADAAG 4.1.2(7):

> Signs that designate permanent rooms and spaces shall comply with 4.30.1, 4.30.4, 4.30.5, and 4.30.6. Other signs that provide direction to or information about, functional spaces of the building shall comply with 4.30.1, 4.30.2, 4.30.3, and 4.30.5. Elements and spaces of accessible facilities that shall be identified by the International Symbol of Accessibility and which shall comply with 4.3.0.7 are:
>
> (a) Parking spaces designated as reserved for individuals with disabilities;
>
> (b) Accessible passenger loading zones;

(c) Accessible entrances when not all are accessible (inaccessible entrances shall have directional signage to indicate the route to the nearest accessible entrance);

(d) Accessible toilet and bathing facilities when not all are accessible.

ADAAG section 4.6.4 further clarifies signage requirements for parking spaces:

> Accessible parking spaces shall be designated as reserved by a sign showing the symbol of accessibility (see 4.30.7). Spaces complying with 4.1.2(5)(b) shall have an additional sign "Van-Accessible" mounted below the symbol of accessibility. Such signs shall be located so a vehicle parked in the space cannot obscure them.

Again, it is noted that the draft ADAAG 2000 drops the requirement for special designation of the van accessible spaces. It remains to be seen whether van signs will be in or out of the final rule.

As discussed in Chapter 6, signs designed to provide direction to drivers and pedestrians within parking areas will routinely exceed the requirements of 4.30.1, 4.30.2, 4.30.3, and 4.30.5, which apply to signs providing direction, and those requirements are therefore not reprinted herein. It is advisable that these signs comply, to a reasonable extent, with the requirements of the *Manual on Uniform Traffic Control Devices* (see Chapter 10), particularly in the use of international symbols and shapes. Compliance will aid visibility to the moderately visually impaired.

Another type of signage commonly found in parking areas is location indicators that help the parker remember where the vehicle is parked. Because there is no standardized location and mounting of location indicator signs, it is not appropriate or necessary to put raised and Braille letters on those signs when mounted in parking areas.

The guidelines will require careful attention to the design (particularly to section 4.30.4, requiring raised and Braille letters) and location of signs "designating permanent rooms and spaces." Typically the only such signs in parking facilities are those identifying the entrances to stair/elevator towers and code-required exit signs, both of which "designate permanent rooms and spaces." The need for the visually impaired to stop, find, and "feel" the sign designating the stair/elevator tower entrance may require provision of a larger area protected from vehicle intrusion than has traditionally been provided at the entrances to these towers. It should also be remembered that ADAAG requires that a sign with raised and Braille letters for the visually impaired be mounted below all code-required exit signs.

Regarding the signage of accessible parking spaces, ADAAG requires that each parking stall be marked with a sign that will not be obscured by a vehicle parked in the stall. Bulletin #6 states:

> **Must a sign be provided at each accessible parking space?** While ADAAG requires parking spaces to be designated by the access symbol, it does not specifically require the designation of each space. Alternatives to signs at each space are allowed so long as spaces reserved for use by persons with disabilities are clearly designated and distinguished from other parking spaces.

Neither one nor two signs with arrows indicating a long string of accessible stalls nor pavement markings alone are acceptable. Although not required by ADAAG, it is desirable to add a sign indicating the fine for violation under the symbol for accessibility, as this notice increases voluntary compliance.

As discussed above, ADAAG does not provide a specific guideline for mounting height of signs at accessible parking spaces. As stated in Bulletin #6:

> **At what location and height is signage to be mounted?** ADAAG does not include a specific location or minimum height for signs but requires them to be placed so as not to be "obscured" by a car or van parked in the space. Access symbols provided on the surface of the space do not meet this requirement. Posted signage is typically placed in front of the space but signs can also be mounted on walls or other elements that are in close proximity to the space. Since many local codes address the height of exterior signage, a minimum mounting height is not specified in ADAAG.

ADAAG does require that signage designating permanent rooms and spaces are centered 5 ft. above the finished floor. Some have argued that the bottom of the sign must be 80 in. above the ground if mounted on a signpost to meet the protruding object requirements. However, section 4.4.1 specifically allows that objects mounted on posts may overhang 12 in. maximum in any direction between 27 in. and 80 in. above the ground, so long as the accessible route is not reduced below 36 in. width. Thus a 24 in. wide sign designating accessible parking spaces may be mounted centered on a post at a height of 5 ft. or so. UBC requires that the sign be centered 3 ft. to 5 ft. above the pavement. The State of California requires that the bottom of the sign be 6'-8" above the pavement if it protrudes into a circulation path, but allows signs on walls or posts not protruding to be mounted with their bottoms 3 ft. above the pavement. It should be noted that none of these requirements will ensure that the sign is visible when a van is parked in the stall. Such visibility can only be accomplished by placing the sign to the side with an arrow toward the stall or in the access aisle. Since the access aisle must be at least 5 ft. wide, while the curb ramp or other connection to the accessible route need only be 3 ft. wide, the sign may reasonably be put to one side of the access aisle, i.e., toward the center of the combination of stall and access aisle.

ADAAG 2000 does address this issue by requiring that the signs designating the accessible parking spaces be mounted with 60 in. to the bottom of the sign, and dropping the requirement that the sign not be obscured by a vehicle parked in the stall.

Bulletin #6 also states:

> **What are requirements for the size and color of signs?** ADAAG requires accessible spaces to be designated by the international symbol of accessibility but does not address the color or size of parking signs, which may be regulated by local code. The "van-accessible" designation is subject to requirements for informational signage found in ADAAG 4.30 and must comply with the specifications for character proportion (4.30.2), height (4.30.3), and sign finish and contrast (4.30.5).

Finally, Bulletin #6 addresses specifications for striping:

> **Does ADAAG contain specifications for the striping of parking spaces or the designation of accessible spaces on the surface of the parking space?** ADAAG does not specify the method or color in which accessible spaces are striped nor does it require placement of the access symbol on the surface of parking spaces. Local codes, not ADAAG, may contain requirements for the striping of spaces, including color, and any surface decals or designations.

11.2.11 Accessibility of Remainder of Facility

An important concept to understand is that even when all accessible spaces are located on the grade level, the rest of the building must meet applicable sections of ADAAG. For example, all doors and hardware must meet ADAAG. Elevators must meet ADAAG. This requirement is based on the premise that persons needing some of those features may not qualify for a disabled parking permit or may not have it with them.

Some have argued that parking structures are "exterior facilities," not "buildings," as defined in ADAAG, and thus none of the items scoped in section 4.1.3 (Accessible Buildings: New Construction) are applicable to parking structures. This position seemed to be reinforced by the following language in the ADAAG Supplementary Information (4.1.3(9)), page 35240 of the *Federal Register* July 26, 1991:

> The scoping provisions of 4.1.3(9) do not apply to exterior facilities covered by 4.1.2. For example, parking lots and open parking structures are only covered by 4.1.2 and are not required to comply with the scoping provisions of 4.1.3(9) for areas of rescue assistance.

However when we asked the ATBCB staff to clarify the classification of open parking garages as exterior facilities not subject to all of the scoping in 4.1.3, the staff stated that they never intended to exempt parking structures from all requirements in 4.1.3 and that parking structures are clearly buildings subject to 4.1.3.

ADAAG 2000 eliminates this grey area once and for all by simply eliminating any mention of exterior facilities.

ADAAG A4.1.3(5) requires that:

> One passenger elevator complying with 4.10 shall serve each level, including mezzanines, in all multi-story buildings and facilities unless exempted below. If more than one elevator is provided, each full passenger elevator shall comply with 4.10.
>
> EXCEPTION 1: Elevators are not required in facilities that are less than three stories or that have less than 3000 square feet per story unless the building is a shopping center, a shopping mall, or the professional office of a health care provider, or another type of facility as determined by the Attorney General. The elevator exemption set forth in this paragraph does not obviate or limit in any way the obligation to comply with the other accessibility requirements established in section 4.1.3. For example, floors above or below the accessible ground floor must meet the requirements of this section except for elevator service. If toilet or bathing facilities are provided on a level not served by an elevator, then toilet or bathing facilities must be provided on the accessible ground floor. In new construction if a building or facility is eligible for this exemption but a full passenger elevator is nonetheless planned, that elevator shall meet the requirements of 4.10 and shall serve each level in the building. A full passenger elevator that provides service from a garage to only one level of a building or facility is not required to serve other levels.

As a multistory self-park structure would never have less than 3000 sq. ft. per floor, that clause is considered moot. Two-level parking structures owned by private entities may thus be constructed without an elevator. However, Title II specifically states that all buildings owned by public entities with more than one story shall be served by an elevator (Title II Rule: 35.151(c)). Again, the elevator must be provided even if all accessible spaces are on the grade level.

If all of the floor(s) of the parking facility have a direct accessible means of egress (either at grade or via an accessible bridge or tunnel to an adjacent accessible building floor served by an elevator), no elevator is required. (This exception is based on 4.1.3(5), EXCEPTION 3, which states that accessible ramps may be used in lieu of elevators.)

Another of the extremely significant changes in ADAAG 2000 is that the above language is modified to require an accessible route between floors of a multi-story building meeting the same criteria as above, rather than elevator. This change clearly would allow a parking ramp of 5.0% or less to be used as the accessible route, without triggering a need for an elevator. However, it is strongly recommended that if this ramping is done, the accessible parking spaces be placed nearest to and on the level of accessible pedestrian entrances, so that someone with a mobility impairment doesn't routinely have to roll a couple hundred feet down a parking ramp for each story without an elevator. The PCC has submitted proposed modifications to ADAAG 2000 to clarify these issues.

A4.1.3(8) provides scoping for accessible entrances to buildings. It is important to remember that the public entrance(s) to a parking structure as defined in ADAAG would be the access point(s) to the facility used for normal pedestrian entering. For the purposes of this guideline, points of vehicular entry and exit to parking facilities are not considered entrances.

The requirements are somewhat complex and must be carefully reviewed. The two principal requirements are that at least 50% of the public entrances must be accessible and the number of accessible entrances may not be less than the number of exits required by building code, except if that would cause more public entrances than otherwise planned. The latter will frequently occur in parking facility design because it is common to have only one public entrance and several code-required emergency exits. This may simply be because there is only one logical route to the building(s) served or because of security concerns. In higher security risk situations, the public access may be restricted to one public entrance, with the exit stair towers enclosed and panic alarmed at all points of entry to the tower, for use only in emergencies. Thus, the grade level access to each code-required stair is often not "public entrance" to a parking facility.

Note that ADAAG 2000 will drop the provision for accessible entrances equaling the number of required exits. This is partially because the Board has adopted the accessible means of egress provisions of ANSI A117.1 and therefore addressed that part of the concern that originally led to the requirement.

In general, public entrances must be accessible if they are associated with accessible routes (from accessible parking spaces). In parking facilities, elevator towers are almost always associated with a public entrance (at grade, a pedestrian bridge or a tunnel or combinations thereof); therefore, the requirement of 4.1.3(8)(a) is to have 50% of the public entrances accessible and the accessible parking spaces should be grouped at those public entrances that are accessible. However, it is generally preferable to make all public entrances to elevator lobbies accessible.

ADAAG 4.1.3(9) Means of Egress requires that "Areas of Rescue Assistance" should be provided at all code-required exits in parking structures, even when there are no accessible parking spaces in the vicinity, because it is possible that on occasion a vehicle transporting a person with disabilities may not have a permit to park in the reserved accessible spaces. This situation could be for a variety of reasons, but most often because a friend or relative who does not qualify for a permit is transporting the person. The frequency of this happening is low, the amount of time spent in a parking area is short, and the risk of fires is demonstrably quite low, making it reasonable to conclude that the probability of a disabled person being present in an area without accessible parking spaces when a fire occurs is quite small.

In open parking structures, any smoke will dissipate rapidly as an individual moves away from the immediate vicinity of the fire. Thus, there is essentially no threat to life safety unless the individual is injured in an explosion, in which case there is no benefit to the area of rescue assistance. ADAAG recognizes that sprinklers render areas of rescue assistance unnecessary. The Access Board in its preamble indicated that it does not believe that areas of rescue assistance are required in open parking structures as previously discussed. Furthermore, there is one very good--indeed life safety--reason for providing open stairs in open parking structures: security. It would be counterproductive to require an enclosed area of rescue assistance adjacent to an open stair.

In order to clarify design guidelines for parking facilities, Bulletin #6 categorically stated: "Another important design consideration is that accessible parking spaces should always be located in close proximity to an accessible means of egress."

As previously discussed, the preferred method to meet this requirement is to locate accessible spaces at the grade level. Where this location is not possible the stair must be designed as an accessible means of egress. While the area of rescue assistance is not required to be enclosed, the other elements specified in 4.3.10 must be followed. These elements are primarily designed to facilitate evacuation of disabled persons by rescue personnel.

ADAAG 2000 has substantially modified requirements in this area to bring ADAAG into close coordination with ANSI A117.1. Specifically, the term area of rescue assistance has been changed to area of refuge as used in ANSI, and open parking structures are specifically not required to have areas of refuge assistance. Further discussion of the requirements for accessible means of egress are provided in Chapter 5, Building Codes.

11.2.12 Cashier Booths and Office Space

4.1.1(3) Areas Used Only by Employees as Work Areas states:

> Areas that are used only as work areas shall be designed and constructed so that individuals with disabilities may approach, enter, and exit the areas. These guidelines do not require that any areas used only as work areas be constructed to permit maneuvering within the work area or be constructed or equipped (i.e., with racks or shelves) to be accessible.

Appendix A4.1.1(3) goes on to state:

> Where there are a series of individual work stations of the same type (e.g., laboratories, service counters, ticket booths), 5%, but not less than one, of each type of work station should be constructed so that an individual with disabilities can maneuver within the work stations. Rooms housing individual offices in a typical office building must meet the requirements of the guidelines concerning doors, accessible routes, etc. but do not need to allow for maneuvering space around individual desks. Modifications required to permit maneuvering within the work area may be accomplished as a reasonable accommodation to individual employees with disabilities under Title I of the ADA. Considerations should also be given to placing shelves in employee work areas at a convenient height for accessibility or installing commercially available shelving that is adjustable so that reasonable accommodations can be made in the future.

If work stations are made accessible they should comply with the applicable provisions of 4.2 through 4.35.

There are essentially two distinct issues of accessibility to workstations--getting to the workstation, and maneuvering within the workstation. Regarding the first issue, the requirement of section 4.1.1(3) may be translated as: an accessible route must be provided to and through the door to every workstation. All common areas such as locker rooms, lunch rooms, conference rooms, restrooms, etc., must also be fully accessible. The reasoning for this requirement is as follows: Title I of ADA states that an employer must make reasonable accommodations to allow a person with disabilities to perform the essential functions of the job. While in most cases, an employer can retrofit one workstation to meet the needs of an employee with disabilities at reasonable cost, completely renovating an office to provide wider aisles, accessibility to conference rooms, lunch areas, etc., would be far more expensive and could be an undue burden. ADAAG thus requires that common areas, hallways, and doors all are accessible in new construction or alterations, so as to minimize the probable cost of "making reasonable accommodations" for an employee in the future. There are no exemptions for workstations and common areas that will serve positions for which it would be inappropriate to hire a person with a significant mobility impairment (e.g., security, valets, etc.) because a supervisor or colleague might also be disabled.

Both NPA and IPI attempted to get cashier booths exempted from the "to and through the door" requirement. The ATBCB declined to do so. Further in the course of the rule making for Title II adoption of ADAAG, the Access Board issued this clarification in the Supplementary Information (page 31682 of the *Federal Register*, June 20, 1994):

> **Response.** An exception has been provided in ADAAG 4.1.1(5)(b)(iii) for single occupant structures accessed only by passageways above or below grade, such as toll booths that are required to be accessed from tunnels below grade. This exception does not apply to toll booths accessed at grade level.
>
> **Comment.** Other facilities recommended by commenters for exceptions include: cashier booths, border station inspection booths, guard booths, and portable classroom structures.
>
> **Response.** These recommendations did not point to specific structural conditions that would make access infeasible. Consequently, such facilities would not be exempt unless the conditions listed in ADAAG 4.1.1(5) (General Exceptions) are met.

Thus, in the rare case where the only access to a cashier booth is from a tunnel or overhead structure, cashier booths can be exempted from the "to and through the door" provision. However, cashier booths accessed from grade shall be accessible.

Regarding accessibility within the workstation, 4.1.1(3) specifically states that ADAAG does not require any workstation to have interior maneuvering space, adjustable shelves, accessible controls and operating devices, etc. The sentence in A4.1.1(3) above recommending that 5% of all work stations, with a minimum of one, be accessible, is only considered a guideline or suggested design standard. The intent of this guideline is also to minimize future costs of "reasonable accommodations," because it will likely be far less expensive to modify a workstation to meet the specific needs of a person with disabilities if it is already large enough for interior maneuvering.

ADAAG 2000 has slightly different wording of essentially the same requirements, and clearly, accessibility is required to and through the door. In the preamble to the document, there is quite a bit of discussion of the requirement for accessibility within large work areas, such as kitchens in restaurants and manufacturing floor; however, none of it modifies the applicability of the requirement to have accessibility to and through the door of the work area.

Thus, in parking facilities, an accessible route must be provided to every new cashier booth and the door must be accessible, but the booth interior need not be designed to meet the clear floor space, reach ranges etc., unless the owner/operator so chooses. It should be noted that the owner who chooses not to purchase a booth that can be modified easily to accommodate a person with a disability runs the risk of encountering significant expense to remove/replace the equipment, booth, and island to provide the required interior maneuvering clearance. Since the requirements for door opening and latch side clearance essentially require a booth size within a few inches of that required for interior maneuvering space, it is advisable to specify/purchase the slightly larger booth initially.

Even disregarding the requirements for interior maneuvering, the "to and through the door" requirement presents a considerable change in the design of entry/exit lanes, because booths have traditionally been designed to sit on 6 in. high islands that are relatively narrow. Providing an accessible route into the booth requires either setting the booth floor at the level of the driving lane or providing a curb ramp at the end of the island.

In the first case, the booth must be recessed into the island, as seen in Figure 11-7. The sliding door on the side of the booth would use the driving lane as the accessible route; note however, that a 3 ft. X 4 ft. level area (slope less than 2% in any direction) immediately outside the door is required to allow a person in a wheelchair to maneuver the door open. (This is called the latch side clearance area.) It is desirable to slope the driving lane up to this elevation on either side of the latch side clearance area for drainage away from the door, but without creating an excessive "bump" at the booth for vehicles to pass over. The standard booth doors and thresholds must be modified to meet ADAAG. Ceiling heights within the booth (indeed within all new booths) must be increased to 6'-8". The clear door opening must be 32 in., which requires a nominal 34 in. door. To slide the door fully open, the booth must be 7'-10" or longer. It should be noted that adding an accessible door on the opposite side provides a T-shaped wheelchair turning space that meets the requirements of interior maneuvering even with a 4 ft.

(nominal) width booth. Other modifications required for interior accessibility could be made later to bring the booth into compliance as a fully accessible workstation. There are, however, a number of other technical problems with this approach in many climates, particularly assuring proper drainage.

In the second case, the door is provided at the end of the booth. The island must be widened, and the latch side clearance area provided outside the door at the booth floor level. With a sliding door, the area must be 3 ft. X 4 ft. as before; with a swinging door the area must be 5 ft. X 5 ft. If the booth is placed on top of the island and the floor slopes down along the length of the slab in the direction of the curb ramp, it becomes possible that the curb ramp will have a rise exceeding 6 in. This rise, in turn, makes it a ramp, and triggers a requirement for handrails on both sides. Putting the booth on top of the island also combines with the 6'-8" ceiling height

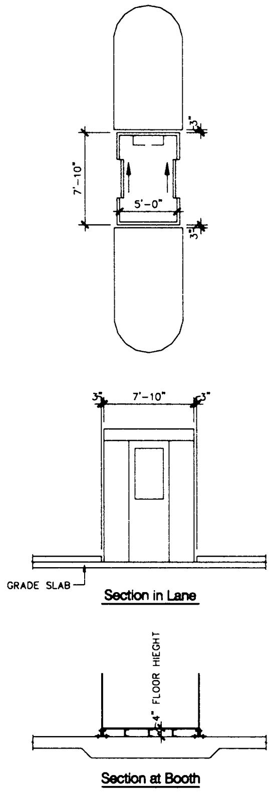


Figure 11-7. Accessible access to cashier booth through side doors

to compound the booth height clearance problems that already exist in parking facility applications. If the booth is recessed into the island so that the floor is at the top of curb elevation, an accessible means of bridging the gap required for placement tolerances and anchoring is required at the door and the platform outside the booth. The requirements for latch side clearance at the platform and door will bring the island to the width required to accommodate a booth with interior maneuvering space. In Figure 11-8, a layout has been shown for a rear swinging door to the cashier booth. The booth width must be 5'-4" to provide the required latch side clearance between the curb and the door edge, while at the same time keeping the cashier window close to the exit lane. In this case the length of the booth is not affected by the requirement to get to and through the door; however, with a 7'-4" or longer booth, the 5 ft. diameter interior maneuvering clearance for interior accessibility is provided. An alternative detail would have a rear sliding door; the booth must then be wider at 6'-0". Thus, purchasing a 5'-4" X 7'-4" booth with a rear swinging door, or a 6'-0" X 7'-4" booth with a rear sliding door, will allow for easy future adaptation to the needs of an employee in a wheelchair.

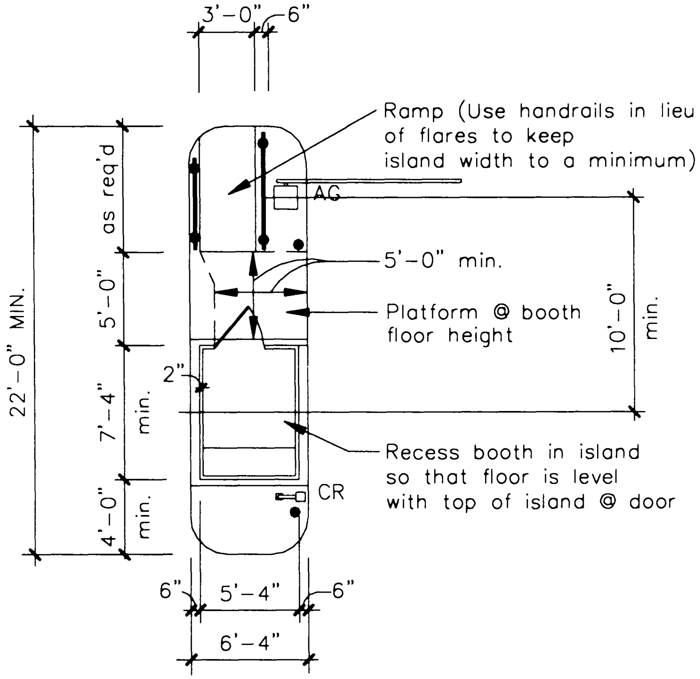
To achieve full interior accessibility, it is necessary to place all controls and operating devices within the ADAAG-specified reach clearances. This requirement will greatly limit the placement of controls, panels, switches, etc., under the counter. Also, it may be necessary to provide an adjustable counter so that the cashier can perform all essential functions including changing journal tapes. An adjustable counter in turn may affect the security of conduits and other control devices now provided in more secure rigid conduit. As previously noted, Title I of ADA says that reasonable accommodations must be made to meet the specific needs of the employee with a disability; it is very difficult to anticipate those needs in advance. Therefore, even though most booths will automatically have the required interior maneuvering space, it may be preferable to delay making all controls and operating devices fully accessible until the workstation must be modified to meet the specific needs of a person with disabilities.

There will be no exceptions based on the argument that there often is only one booth at a facility and a person in a wheelchair would not be placed as a cashier in such a facility. There will also be no exceptions allowed for valet/attendant facilities. This rule is based on the premise that a supervisor or manager visiting the site may be in a wheelchair.

As this is such a critical issue, and one that is often ignored, let us restate the overriding issues: **every** design for new construction must provide a means to get a person in a wheelchair **to and through the door** of **every** workstation, which includes **every cashier booth**. There are **no** exceptions! The interior of the booth does not **have** to be designed for full accessibility. The Appendix to ADAAG **recommends**, but does not require, that 5% of all work stations, with a minimum of one, be fully accessible.

11.2.13 Parking Access and Revenue Controls (PARC)

ADAAG requires that controls and operating mechanisms, as well as ATM machines must be accessible to pedestrians. Drive-up ATM machines, and by inference, PARC equipment in entry/exit lanes are excepted. Pay-on-foot devices that may need to be accessible include but are not limited to meters, slot boxes, multispace meters, pay-and-display stations, and automated pay-on-foot stations. Some parking facilities may have both types of equipment; for example, a parking facility designed for pay-on-foot may issue a ticket from a dispenser at the vehicular entry lane and require that an "exit ticket" indicating payment be inserted by the driver into a lane controller that opens the gate at the exit. Payment, however, is made at a central location while in the pedestrian mode. Only the pay-on-foot devices must be accessible.



Exit With Accessible Booth; Card

Figure 11-8. Accessible access to cashier booth through end doors

Although technically applicable to meters in the public right-of-way, ADAGG 14.2(2) in the 1994 Interim Rule address the accessibility of parking meters:

> (a) Parking meter controls shall be 42 in. (1065 mm) maximum above the finished public sidewalk. Controls and operating mechanisms shall be operable with one hand and shall not require tight grasping, pinching, or twisting of the wrist. The force required to activate controls shall be no greater than 5 lbf (22.2 N).
>
> (b) Where parking meters serve accessible parking spaces, a stable, firm, and slip-resistant clear ground space a minimum of 30 in. by 48

in. (760 mm by 1220 mm), shall be provided at the controls and shall comply with 4.2.4.1 and 4.2.4.2. Where only a parallel approach is provided, controls shall be within 10 in. (255 mm) horizontally of and centered on the clear ground space. Where only a forward approach is provided, controls shall abut and be centered on the clear ground space. Parking meters shall be located at or near the head or foot of the parking space so as not to interfere with the operation of a side lift or a passenger side transfer.

Note that paragraph (a) requires all meters (not just those at accessible spaces) to meet this standard. This requirement would apply to new meters at existing spaces and thus represents a new standard for the industry. However, Chapter 14 was never made an official rule and its provisions are not contained in ADAAG 2000. A separate committee was convened in late 1999 to address all issues related to public-right of ways, including parking therein.

When pay-on-foot devices are centrally located to serve multiple parking spaces, each device should comply with ADAAG 4.34, Automated Teller Machines, except where two or more similar devices are provided at a location, when only one must comply. When central cashier stations are provided in pay-on-foot systems, at least one such payment station should comply with 7.2, Sales and Service Counters. Note that pay-on-foot PARC devices are required to comply with 4.34.4, Equipment for Persons with Vision Impairments.

However, ADAAG 2000 contains extremely extensive changes to the requirements of ATMs and fare machines. It is unclear whether or not the requirements are intended to apply to other transaction machines such as meters and pay-on-foot machines. A separate committee report does recommend that the ATM requirements be extended to all "transaction and information machines" so it is likely that if compliance with them is not required by ADAAG 2000, it will be at some not-distant future date. Because the requirements require extensive redesign of manufacturer's products, our firm will not require full compliance with ATM requirements in accordance with ADAAG 2000 until and unless the issue is clarified and the manufacturers have modified their units to comply.

11.2.14 Communication Systems

All fire and other alarm systems must now be designed to communicate both visually and aurally. If two-way communication systems are provided in exterior facilities for use in emergencies, they shall include both audible and visual means of communication. A panic button and light that illuminates to indicate that the alarm has been noted and help is on the way will generally be sufficient to communicate with the hearing impaired.

11.3 SUMMARY

Accessible parking design has been and continues to be a major concern for the industry. A number of official clarifications have been issued via Bulletin #6; other, unofficial clarifications and interpretations have been obtained through meetings with the Access Board and DOJ staff. Changes included in the draft ADAAG 2000 shed further light on the Board's thoughts. While this text presents the "best available" interpretation, it is almost a surety that at least one thing in this chapter will be outdated by the time you need the information. The requirements are complex and still subject to future changes and clarifications. It behooves each owner and design professional to obtain the latest information before embarking on a parking structure design project.

11.4 REFERENCES

[1] Architectural and Transportation Barriers Compliance Board, 1991. *Americans With Accessibilities Act (ADA) Accessibility Guidelines for Buildings and Facilities; Final Guidelines*, 36 CFR Part 1191, July 26, 1991.

[2] Office of the Attorney General, Department of Justice, 1991. *Nondiscrimination on the Basis of Disability in State and Local Government Services; Final Rule, 28* CFR Part 35, July 26, 1991.

[3] Office of Attorney General, Department of Justice, 1999. *Nondiscrimination on the Basis of Disability by Public Accommodations and in Commercial Facilities*; *Final Rule 28*, CFR Part 36, July 26, 1991.

[4] Architectural and Transportation Barriers Compliance Board, 1994. *Americans With Disabilities Act (ADA) Accessibility Guidelines for Buildings and Facilities; State and Local Governments; Interim Final Rule*, 36 CFR Part 1191, June 20, 1994.

[5] CalDAG, 1996. *California Disabled Accessibly Guide Book: Intrepretive Manual & Checklist.* Second Edition, Canoga Park, CA. Builder's Book, Inc.

[6] Parking Consultants Council, 1992. *Parking Studies*, Washington.: National Parking Association (June 1992).

Chapter 12

STRUCTURE

Anthony P. Chrest

12.1 INTRODUCTION

Section 12.2 will discuss the various factors influencing the structural design of a parking facility. Among the items covered will be cost, schedule, and building codes.

Section 12.3 is a guide to help narrow down the selection of structural systems. Some systems are better than others for parking structures and some should be avoided.

Section 12.4 helps identify and design for volume change effects in parking structures. Their large plan areas and exposed structure makes parking structures more susceptible to these effects than other building types.

Certain design items are unique to parking structures. Discussed in section 12.5 are beam-column joints, variable height columns, torsion, and the relationship of stair and elevator structures to the main structure. Section 12.6 comprises a chapter summary. Please note that this chapter addresses only structural design as it pertains to parking structures. Seismic design is addressed separately in Chapter 14.

12.2 DESIGN

12.2.1 General

Structural design should satisfy requirements for strength, flexibility, durability, ease of maintenance, and repair. Equally important are function, cost, appearance, and user comfort.

A. P. Chrest et al., *Parking Structures*

12.2.2 Factors Affecting Design

12.2.2.1 Effect of Local Construction Technology on Cost

Let's say your design requires a column concrete strength of 14,000 psi, but no cast-in-place structure in the Project City has ever been built with concrete strength exceeding 10,000 psi. Bids for your cast-in-place structure will be higher than you expect; you may not receive any bids. However, assume for this example that precasters in the project city have had experience with concrete strengths as high as 14,000 psi. Unless you are willing to increase the cross-sectional dimensions of your columns to permit use of 10,000-psi concrete, you should select a structural system that uses precast concrete columns, not cast-in-place. An alternative would be for you to embark on an education program with the local ready-mix supplier, which has already been done as seen below.

Similar examples relate to silica fume (microsilica) concrete or high reactivity metakaolin (HRM) concrete. Either material is stronger and less permeable than conventional concrete, but if it has never been used in the project city, the bids will probably again exceed expectations or not materialize.

A final example concerns pretopped double tees. If no precaster in the project city has built a structure with pretopped tees, it is likely that none will be interested in bidding on your project. Or, bids will be high to cover the precaster's and erector's learning curves.

The above should not lead you to believe that there is no innovation in the construction industry. It is true that the engineer may have to spend more time educating builders and/or precasters in a given area, but, once understanding is reached, these people are almost always ready to adopt new technology or practices. As one example, with a high-strength concrete consultant, we helped a ready-mix supplier and builder team consistently produce 14,000-psi concrete for columns in a 15-story multiuse parking structure. As another example, we have helped a number of precasters fabricate and erect their first pretopped double-tee parking structures. Having done their first, all of the precasters want to do more.

12.2.2.2 Effect of Bidding Climate on Cost

If there is a general contractor available who likes to place concrete and is short of work, it is likely to give you a good bid on a cast-in-place structure. Conversely, if no precast projects have been built recently and precasters need work, a precast project will attract low bids.

On the other hand, if there are no precasters in an area or all available precasters have a full backlog, it would be unwise to bid a structure in precast concrete.

In some areas, there may be a shortage of construction tradesmen. A structural system that is less site-labor intensive, such as pretopped precast concrete or structural steel with a precast concrete floor, might be a good choice.

Poor soil conditions will require the lightest structural system available — steel — to achieve an economical structure

12.2.2.3 Cost of Quality Construction

A concern similar to that above is that even in some large cities, there may be few builders capable of producing quality cast-in-place concrete construction. A related problem is that trade union rules in at least one region require that all rebar bending be done on site. These two circumstances, singly or combined, have nearly eliminated cast-in-place concrete construction in those regions.

12.2.2.4 Effect of Owner's Budget on Cost

The project budget may eliminate some systems from consideration. As an example, though long-span construction is best for parking structures because it permits easier parking and flexibility in striping and in resizing parking spaces, short-span construction in which cars park between columns is less expensive. If the building code requires parking as part of the total project and the project will not be built unless the parking structure cost is rock bottom, then long-span structural systems will probably have to be discarded from further investigation.

12.2.2.5 Costs Associated with Building Codes

Local building codes and ordinances, especially those that have not recognized downsizing trends in automobile manufacture, may mandate parking module wall-to-wall dimensions of 65 ft. If the owner's and engineer's desires are to use clear span construction, then some systems will not work. For instance, if 24" precast concrete double tees are the deepest available within economical shipping range, a double-tee system will be eliminated because the available members do not have the capacity to carry typical parking structure loads for the required 65-ft-clear span.

The advent of the nationwide International Building Code (IBC), combining three model codes into one, may simplify building code impact on parking structures. At this writing, it's too soon to know.

12.2.2.6 Durability Costs

Durability requirements will raise the cost of certain structural systems more than others will, because some systems are inherently more durable than others will. (For additional discussion, see section 12.3 and Chapters 16 and 17.)

12.2.2.7 Schedule Costs

Speed always costs more, no matter what the structural system. If a compressed schedule is necessary and the project budget cannot be increased, the increased costs may dictate a compensatingly less expensive structure, which leads back to the discussion on budget.

The schedule second aspect is that in cold climates, winter construction is significantly more expensive than construction in other seasons. Summer construction is more expensive in hot climates. There is not always the freedom to choose when to start construction. If there is a choice, scheduling with the seasons in mind can lead to significant savings or permit extra features to be added to the facility, while keeping the project cost within budget.

12.2.2.8 Appearance Costs

Façade choices are almost limitless, and corresponding costs can range from zero dollars over the cost of the "bare bones" structure to tens of percent of the total project cost. As with schedule, there may be freedom in selecting the façade treatment, or there may not. As an example of the latter situation, it is not unusual to find a hospital campus surrounded by an urban or suburban residential neighborhood. In planning a parking structure to serve such a hospital, the planners often encounter objections from neighborhood groups. The objections must be overcome, either because the hospital wants to be a good neighbor or in order to get a building permit, or both. Overcoming the objections usually requires that the parking structure façade screen the cars inside from view from the surrounding streets, that its architectural appearance blend in with the hospital campus and/or the neighborhood, that the structure not be so high as to tower over surrounding residences or block sunlight, and that structure lighting does not spill outside. Answering each of these objections will add to the cost of the project.

If the structure must park sufficient cars and the ground space is limited, several stories of parking will be required. Yet if the structure height must be limited, the only solution to both requirements will be to go underground. On a per-car basis, all else being equal, underground parking construction costs are roughly double those for an above ground parking structure.

12.2.2.9 Schedule

The project schedule should encompass the entire project, with durations assigned for all design phases; whatever reviews are required by parties such as the client, local citizens groups, the building department, zoning, other public agencies, the financing body, and others; bidding or negotiating, and construction. Take long lead-time items, such as elevators, into account. Remember that winter weather in cold climates will affect the schedule for an open parking structure more than it would for a conventional building. A conventional building will be closed in at some point, permitting completion of finish items that require moderate temperatures. Examples of finish items are sealers, membranes, sealants, paints, curing compounds, and defect patching.

12.2.2.10 Building Code Loading Criteria

Magnitudes of live loads on floors and of live load reduction to floor members and column will vary. (Car bumper-impact load magnitudes and height above the floor to load point vary more.) These loads in turn will influence the structural design.

12.2.2.11 Live Loads, General

Building codes commonly require a uniformly distributed load of 50 psf and a 2000-lb concentrated wheel load distributed over a 20-sq-in. area anywhere on a floor, with additional load for snow (see next section) on the top (roof) level. Most building codes allow for the reduction of live loads for members supporting tributary slab areas. In some parts of North America, roof-level parking requires combining parking live loads with roof snow loads.

12.2.2.12 Snow/Live Load Combination

Some building codes require adding roof loads (usually snow) to the normal parking load. Some designers believe that for the design of principal members, this requirement is too restrictive. Combinations of snow and live loads that might be encountered are:

- Full snow load on an entire bay with live load reduced as permitted by building code
- Full snow load on an entire bay with live load in parking stalls only
- Full snow load on an entire bay with live load (reduced by code) in parking stalls only
- Full snow load on an entire bay with vehicle load in parking stalls only (no impact load or live load reduction)

An appeal may be made in advance of construction to local building departments to reduce the requirements. The following is an example of the fourth option above for combining snow and vehicle live loads to produce a realistic prediction of required capacity of a top level, which we recommend.

The fourth option approach to combining live loads (L) assumes vehicles in the parking stalls only. The vehicles, however, are considered immobile and therefore no impact is considered (that is, L = 25 psf live load nonreducible). For this example, we will assume a building code snow load of S = 40 psf over the entire 60-ft simple span and a 1-ft tributary width, as shown in figure 12-1.

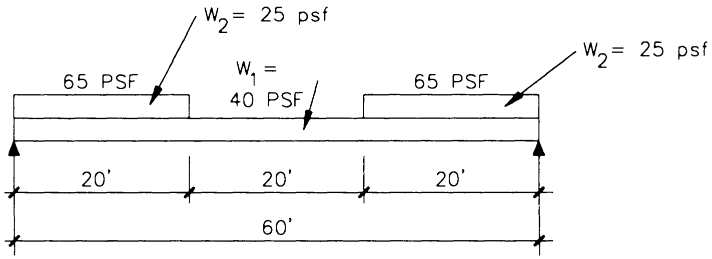


Figure 12-1: Snow and live load diagram

Service load moment $= w_1 l^2/8 + w_2 l_2/2$
$= (40x60x60)/8 + (25x20x20)/2$
$= 23{,}000$ ft-lb.

Equivalent load $= (23{,}000x8)/l^2$
$= (23{,}000x8)/60^2 = 51.1$ psf

In comparison, ASCE 7 requires a combined loading of 1.2 D + L + 1.6S. Applying these load factors to the L = 25 psf and S = 40 psf above, and omitting, for this example, the D (dead) load, produces a worst-case combined service load greater than that obtained using the last option above.

12.2.2.13 Wind Loads

Design and construct every parking structure and its component elements to resist the equivalent wind pressures given in governing building codes. Model building codes have methods with which to calculate wind pressures, using basic wind speed, importance factor, exposure factor, and projected areas. In most cases it is unrealistic to use anything less than the full building face area for the projected area. Don't subtract the open areas of the face; consider the face solid unless you make a more rigorous analysis.

12.2.2.14 Seismic Loads

Please see Chapters 14 and 15.

12.2.2.15 Barrier Requirements

Handrail heights, live load, and railing spacing requirements may vary and all affect design. Openings in barriers that resist car bumper impact are limited in size by codes, but these limits vary also.

Not all building codes deal with lateral load requirements for car bumper barriers at floor edges. Requirements vary from none, to the National Parking Association's (NPA) recommendation given below, to Houston's 12,000 lb. Designing for these loads will restrain a slowly moving vehicle. These requirements are in addition to other building code requirements are in addition to other building code requirements for handrails or similar barriers. The Parking Consultants Council of the NPA recommends a factored concentrated lateral load (strength design load) of 10,000 lb at 18 in. above the driving surface. At least one code requires the load be applied 27 in. above the floor – 50% more than the NPA requirement. Barrier-load-resisting reinforcement is additive to that required by other loads.

A typical curb, 6 in. high, or a precast wheel stop will not stop anything more than a slowly moving car, and should never be considered a barrier. A faster-moving car will jump the curb or wheel stop and will hit the bumper barrier beyond with barely diminished force. Curbs do add to driver comfort with the facility, though. A curb of proper width will ensure that the car's rubber tires reach the curb before its bumpers reach the wall beyond.

Some building codes require a barrier with greater impact resistance at locations such as the perimeter wall at the bottom of a ramp, especially if there are no parking places directly in front the wall.

Perimeter guardrails comprising only cables or post-tensioned tendons are not recommended, particularly if they are mounted on the exterior faces of the exterior columns. There is little redundancy in case of failure of a connection. Also, most building codes will not permit any barrier that resembles a ladder that a child could climb. In some jurisdictions, we have not been permitted to use interior guardrail details like that shown in figure 12-2. If such a detail is used, be sure to check the dimension between the lowest cable and the top of concrete wall as shown in figure 12-3.

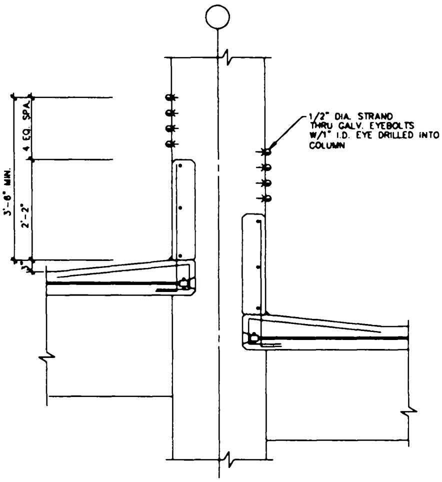


Figure 12-2: Interior bumper wall and handrail showing surface-mounted post-tensioning strand serving as handrail.

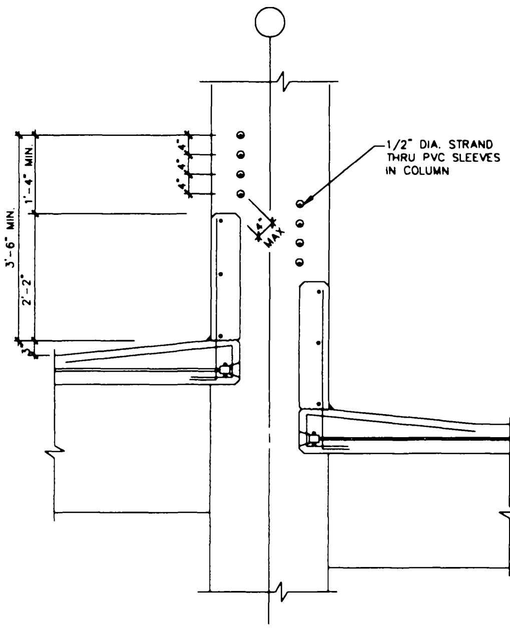


Figure 12-3: Interior bumper wall and handrail showing through-column post-tensioning strand serving as handrail.

12.2.2.16 Fire Ratings

Fire ratings vary considerably from one jurisdiction to the next. Protection requirements have the effect of dictating structural element thickness, and therefore weight, which in turn affects the structural design of all superstructure members as well as the foundations. Early determination of required fire ratings is critical.

Fire-rated expansion joints are specified more today than in the past. Check whether or not the slab thickness has to be increased to accommodate the expansion joint assembly and fire barrier at the joint location.

12.2.2.17 Standpipes and Sprinklers

Almost any parking structure of more than two or three stories will be required to have dry standpipes. Some building codes will require all standpipes, dry or wet, to be interconnected so that they can be filled or drained from any hose bibb. Hose-bibb threads must meet local fire department requirements. Underground garages and some multiuse parking structures, whether open or not, will be required to have an automatic sprinkler system. An example of the latter might be a multi-level parking structure taller than a mandated height, meeting the requirements to be considered *open* but having office space on its top floor or floors, even though the "roof" of the parking structure (bottom floor of the office space) meets the separation requirements for mixed-use occupancy.

12.2.2.18 Ventilation

As stated in Chapter 1, requirements for open space around the exterior walls of a parking structure vary. If the structure meets or exceeds the particular openness requirements, no mechanical ventilation of the parking and drive areas will be needed. There may be separate building code requirements for ventilation of ancillary facilities, such as restrooms, maintenance areas, stairs and elevators, attendants' booths, offices, isolated or dead-end areas, or low points where carbon monoxide could collect and endanger patrons or staff.

If the structure does need mechanical ventilation in large areas or throughout because it does not meet building code openness requirements, the project cost will increase.

12.2.2.19 Storage Room

A parking structure will often contain a storage room for maintenance equipment and supplies, parking and revenue control equipment parts and supplies, and odds and ends. As a corollary to the sections on fire protection and ventilation requirements above, if the storage room is truly for storage only, and is not used for maintenance of anything other than storage, it is important to label that room as *Dead Storage* on the contract documents. Otherwise, heat, mechanical ventilation, and sprinklers may be required.

12.2.2.20 Height and Area Limits

These, too, will vary, and are often tied to fire rating requirements. As in the example of the hospital campus located in a residential neighborhood, the height limitation may not be a previously set limit, but may be subject entirely to the opinions of a special interest group. Investigate other potential height restrictions, such as a Runway Protection Zone at an airport.

12.2.2.21 Appearance

Appearance is not within our scope; however, the nature of parking structures often requires a structural element to also serve an architectural function. An example is the typical exterior beam: it carries live, dead, and bumper loads, and may be part of a rigid frame that carries wind or earthquake forces, yet it must also contribute to the appearance of the structure. A second example is the often-required resolution of conflict between the functional design, which may require sloping floors, and the desire for horizontal elements on the building façade. As a third example, on a recent project, the architect wanted to reflect the 20-ft module of an adjacent existing building in the structure of the new parking project. A 20-ft column spacing is economical for a cast-in-place post-tensioned one-way slab and beam system, but not for a 10-, 12- or 15-ft-wide precast prestressed double-tee system. The architectural façade in this case decided the structural system. It is also important to resolve the possible conflict between the requirement for a stiff structure to support a rigid façade, such as masonry, and the flexibility of the main structure.

12.2.3 Associated Design Elements

12.2.3.1 Snow Removal

In cold climates, a snow removal system may be required. This provision may involve design for special vehicle loading in addition to the snow loads. Consider provisions for snow-melting equipment and snow-disposal chutes or containment structures.

12.2.3.2 Drainage

Proper drainage is *essential* to structure durability. If water is allowed to stand (pond) on the parking structure floors for long periods, deterioration will accelerate in the concrete beneath the ponds. If the water that collects is salt-laden, chances for accelerated deterioration are greater. If the structure is to be durable, it is important that the drainage system carry away all water rapidly, whatever its source, and not allow ponding anywhere. Drainage design requires attention to three criteria: proper slopes, proper catchment area sizes, and proper drains.

First, no parking structure floor should ever be flat, even if no rain can fall directly on it. Rain will be blown into lower floors. Cars will carry water in to lower floors also. Heavy rains may overload top floor drains. The overflow will run down ramped floors until the lower-floor drains can carry it away.

For drainage, the absolute minimum slope should be 1/8 in./ft, or about 1%. Preferred slope is 3/16 in./ft, or about 1.5%. Note that cement finishers will have a difficult time consistently achieving a slope of less than 1/8 in./ft, if they can achieve it at all.

When setting slopes on design drawings, be sure to take expected camber and deflections of all members into account; either could reduce design slopes if not recognized and allowed for. Pay particular attention to cantilever spans so that water drains off them instead of collecting at the unsupported ends.

Prevent ponding by controlling deflection of slabs and beams. In addition to sloping top surfaces, deflection control may be achieved by prestressing and by setting slopes or cambers into forms.

At the same time, do not forget that pedestrians will be walking across the slopes and swales; do not make walking uncomfortable. Drivers may also be adversely affected by driving on surfaces with frequent and abrupt slope changes.

Drain catchment areas should not exceed about 4500 sq. ft. on floors that are nominally flat – that is, sloped 1% or 1.5% for drainage only. On floors that have more than minimum slopes, drains may be spaced to drain more than the 4500 sq ft maximum. However, drains should be located so that runoff does not have to cross an isolation (expansion) joint seal or turn a corner to reach the intended drain.

Drains must be adequately sized or slightly oversize for the design storm. Locate them in gutter lines or other low points. Recess the drain 1 in. below the adjacent floor surface.

The drain basin should be shaped to generate a vortex in the water that will speed the flow out of the drain and into the downspout.

The drain top grate should have sufficient openings to admit the design runoff, but individual opening size cannot be so large as to present a hazard such as catching a shoe heel. The grate should be permanently attached to the drain body with a hinge on one side and a tamperproof screw on the other. With a hinged grate, lifting off the grate to clean out the drain will not run the risk of losing the grate. With a tamperproof screw to hold it shut, vandals will not be able to open the grate.

The drain should also have a sediment bucket that can be removed and emptied during regular drain maintenance. Drains at lower floors should include backwater valves to prevent flow from the downspouts backing up and over flowing into the lower levels.

Circular and square drains are usually sized small enough not to interfere with structure. For example, in a post-tensioned floor, the slab tendons can be curved around the drains easily. Sometimes, though, smaller drains are inadequate, particularly at a top floor (roof) or at the bottom of a ramp or ramped floor leading to a roof. Segmented or continuous trench drains may be necessary to accommodate runoff volume.

Segmented trench drains are simply short sections of trench drain, 12-23 in. long, separated by a foot or two of floor slab structure. Slope the floors between the drain segments into them. Below the floor slab, the trench drain segments are continuously connected to a downspout. The segmented trench drain permits less disruption of the floor structure. A continuous trench drain running completely across a bay creates a structural isolation joint. The resulting separation must be treated like any other isolation joint.

12.2.3.3 Electrical Conduit

If there is a choice, do not cast electrical conduit into the structure. While exposed conduit is initially more expensive than embedded, maintenance will be far easier. Rewiring, if ever needed, will be less expensive if the conduit is installed exposed.

Concrete durability will be improved. With cast-in conduit, if moisture enters the conduit through leaks or condensation, deterioration of the concrete around the conduit may be accelerated. If the moisture freezes and the ice is not free to expand within the conduit, the conduit may split and the surrounding concrete may spall. Moisture inside or around the conduit may cause the conduit to rust. The rust in turn will exert pressure on the surrounding concrete, spalling it. If conduit is cast-in, provide for three-dimensional movement capacity in the conduit whenever it crosses an expansion joint. Some designers may object to exposed conduit on esthetic grounds, but, if exposed conduit is properly installed, the average patron will never notice it. If conduit is to be exposed, provide formed holes in floor beams and/or tee stems to permit economical conduit runs.

12.2.3.4 Expansion Joint Systems

Even the best expansion joint systems for parking structures should be properly maintained following the manufacturer's guidelines. If floor expansion joints can prudently be avoided, do so, as so doing will save the owner and yourself future maintenance. Recommend that the owner budget for annual expansion joint inspection and maintenance.

Expansion joint spacing is discussed in a later section. System types, uses, pros, and cons are discussed in the remainder of this section.

The concern with expansion joint systems is that many unexpected factors affect their performance. Consider them during project design:

- Joint movement in excess of seal capacity
- Concrete shrinkage
- Structure elastic shortening caused by prestressing or post-tensioning
- Exposure to environmental factors such as ozone or ultraviolet light
- Chemical attack from gasoline, oil, and salt

- Snowplow damage
- Traffic impact loads
- Traffic-caused deflection across the joint

The perfect seal should therefore:

- Be leak-free
- Resist weather, ozone, and sunlight (ultraviolet radiation)
- Resist vehicle impact loading and resulting deflection across the joint
- Not be under tension or compression most of the time
- Not be a tripping or slipping hazard
- Meet ADA requirements
- Not collect water, ice, dirt or debris
- Resist normal abrasion from vehicle tires, even studded snow tires
- Without damage, accommodate movement caused by volume change forces
- Without excessive damage, accommodate movement caused by seismic forces
- Be protected from snow plow damage
- Not deteriorate under normal use
- Be fire-rated, if required by local building code
- Construction tolerances

The ideal system should therefore perform with these characteristics:

- Be leak-free
- Resist weather, ozone, and sunlight (ultraviolet radiation)
- Resist vehicle impact loading and resulting deflection across the joint
- Not be under tension or compression most of the time
- Not be a tripping or slipping hazard
- Meet ADA requirements
- Not collect water, ice, dirt or debris
- Resist normal abrasion from vehicle tires, ~~even studded snow tires~~
- Without damage, accommodate movement caused by volume change forces
- Without excessive damage, accommodate movement caused by seismic forces
- Be protected from snow plow damage
- Not deteriorate under normal use
- Be fire-rated, if required by local building code

Steps to select an expansion joint system are shown briefly below. Before making the final selection for each application, consult the manufacturer's local representative early in the project.

- Determine the location and size for each type of joint at each level
- Select the joint type, considering:
  - Pedestrian or vehicle traffic
  - If vehicle traffic, volume, type, and speed
  - If pedestrian traffic, ADA compliance
  - Fire rating
  - Opening width and movement capacity required
  - Direction of movement(s) expected
  - Seismic zone
  - Snowplow protection
  - Temperature (time of year) at which system is installed

Successful expansion joint selection for the life cycle needed depends on your understanding of the service requirements and the attributes and limits of the systems you consider.

Expansion joint seal types are outlined in Table 12-1 and discussed below.

Table 12-1. Common Types of Expansion Joint Seals

Type	Figure	Description	Pros and Cons
Premolded	12-4 12-5 12-6	Economical; good track record when used in the right application	Economical, but exposed to tire or snow plow damage. Requires a formed recess. Joint movement puts seal in tension. Maintenance more expensive. Ridged alternative makes surface less slippery when wet. ADA compliant in tension. Limited movement. Seal buckles upward under compression. Not recommended on roofs or in turning lanes.
Metal-edged	12-7	Seal protected from tire or snowplow damage. Provides armored nosing.	Requires a formed recess. Easy seal replacement for repair. Gland shape different than shown may make this seal ADA compliant. Many gland shapes available.
Elastomeric concrete-edged	12-8 12-9	Nosing reduces impact loading on adjacent edges.	Requires a formed recess. Expense is between metal-edged and premolded. Gland repair more difficult than metal-edged. Gland shape shown makes this seal ADA compliant. Seals accommodate less movement than metal edge but more than premold.
Adhered extruded	12-10	A good solution, if movement capacity sufficient. Elastomeric nosing can be used in this system. Seal can work in tension.	Does not require a formed recess. Expense is between premolded and elastomeric concrete edged. Gland shape different than shown may make this seal ADA compliant, but less flexible. Fewer internal webs allow for increased movement, particularly under lateral shear.
Extruded compression	12-11	Multi-cellular seal profile. Must remain in compression at all times to be watertight.	Does not require a formed recess. Economical; poor track record improved by changes such as using seal in correct application and improved bonding to concrete and gland supports shown. Gland shape shown may be ADA compliant. Many gland shapes available.

Foam compression	12-12	Expanded closed cell neoprene rubber profile. Seal can work in tension.	Does not require a formed recess. Economical; track record improved by changes such as improved bonding to concrete. Seal can be recessed to receive elastomeric topping for pedestrian traffic.
Bolt-in membrane	12-13	Same as for metal edged except bolt in panels are elastomeric EPDM material with steel insert.	Requires a formed recess. Durable and can withstand forklift traffic. Gland shape shown is ADA compliant.
ADA compliant	12-14	Same as for adhered extruded.	Same as for adhered extruded. This is one example of an ADA compliant seal. As stated above, changing the gland shapes shown in other types may make them ADA compliant.
Seismic	12-15	Uses a self-centering metal cover with heavy-duty edge frames.	Requires a formed recess if flush-mounted. Higher than normal costs. Gutter required to remove high volume of water drainage.
Under slab	12-16	Fabric reinforced membrane with drain tubes	Good alternative on existing structures where problematic expansion joint systems are not budgeted for replacement.

The premolded seal shown in Figure 12-4 satisfies most of the list of requirements above, except that it is almost always in tension or bending while it is in compression. It also is not particularly resistant to damage from snowplows. It is better, when possible, to install the premolded seal in summer, when the expansion joint gap is at its narrowest. Otherwise it will bulge upward in hot weather and become a tripping hazard. The bulge will violate ADA requirements. If necessary, the seal may be temporarily installed during cold weather, and permanently installed when summer comes.

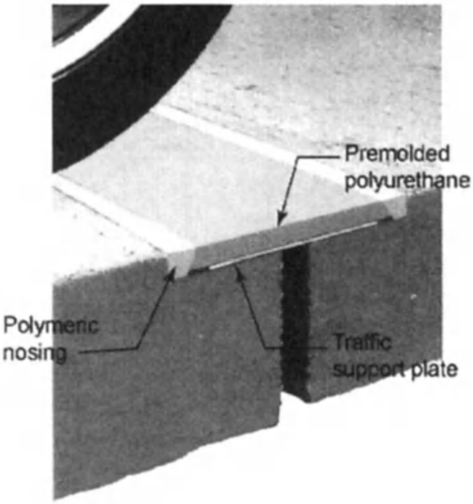


Figure 12-4: Premolded expansion joint seal – floor to floor. Photo courtesy of Watson Bowman Acme Corporation.

A variation of the premolded seal is shown in Figure 12-5. It is used to seal the gap between a floor slab and a vertical surface, such as a stair tower wall. Where the detail of Figure 12-4 meets that of Figure 12-5, ignoring strain compatibility will lead to seal failure. Figure 12-6 is a second variation of Figure 12-5. It may be used where there are no possibilities of tripping hazards, traffic, or snowplow damage. Its advantage is that it does not need a formed recess in the concrete. Such recesses are difficult to form properly. Both the edge and bottom of the recess are subject to variation unacceptable to the seal installer. Extensive refinishing of the recess may be required to produce a recess profile and finish that will result in a durable, leak-free installation. The detail of Figure 12-6 may be combined with that of Figure 12-4 to seal the condition shown in Figure 12-17 where the expansion joint has to go around a column.

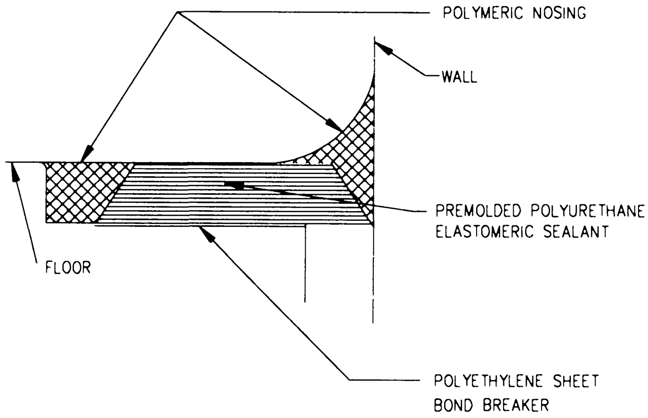


Figure. 12-5: Premolded expansion joint seal – floor to wall or column

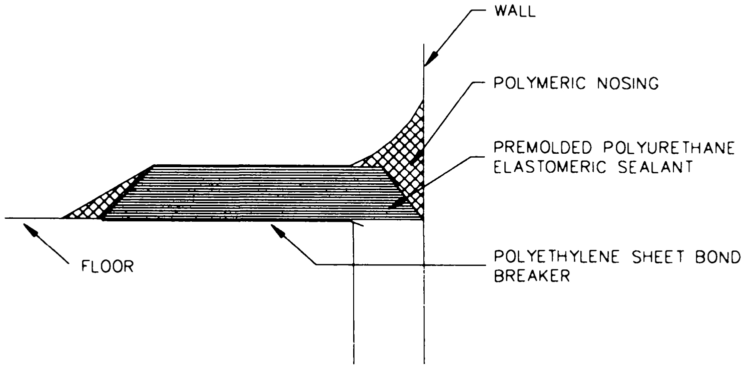


Figure 12-6: Premolded expansion joint seal – floor to wall or column. Mounted on floor.

Figure 12-7 shows an armored, or metal-edged, strip seal. There are many variations on the metal-edged seal, but the basic concept is the same. The metal edge protects the floor edge and seal gland from damage. However, in one project where heavy plows operating at high speeds were used, even the metal-edged may experience damage. Snowplow driver education is a critical requirement for joint seal durability. The metal-edged joint satisfies most of the requirements in our list. During cold weather, when the expansion joint opens widest, the seal may be a tripping hazard, if it has no metal cover. Choice of the seal gland (the flexible material bridging the gap between joint sides), in this type or in any other type, will reduce the possibility of tripping and can make the seal ADA compliant.

However, a gland that is ADA compliant usually has less movement capacity than one that is not. As said earlier, the requirements for a good expansion joint seal are contradictory.

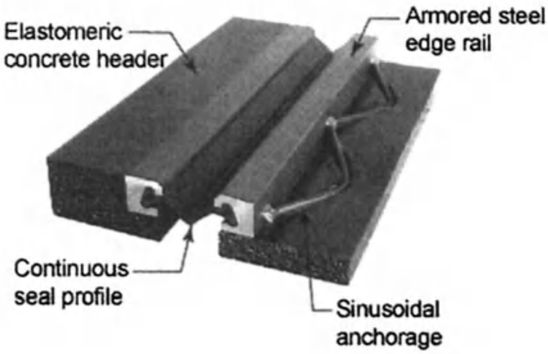


Figure 12-7: Metal-edged expansion joint system – floor to floor. Photo courtesy of Watson Bowman Acme Corporation.

The elastomeric concrete-edged system was originally developed to provide an alternative design to the commonly used premold joint and to mitigate the impact of vehicle tires on the joint edges. Like the metal-edged joint system, there are variations in size for this system. One example is shown in figure 12-8. The comments above for the metal-edged system also apply to the elastomeric concrete-edged systems.

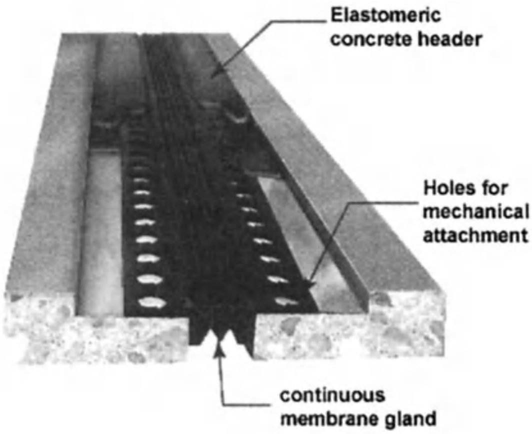


Figure 12-8: Elastomeric concrete-edged expansion joint system – floor to floor. Photo courtesy of Watson Bowman Acme Corporation.

Figure 12-9 shows a variation of Figure 12-8 similar to that of Figure 12-5, the slab to wall system.

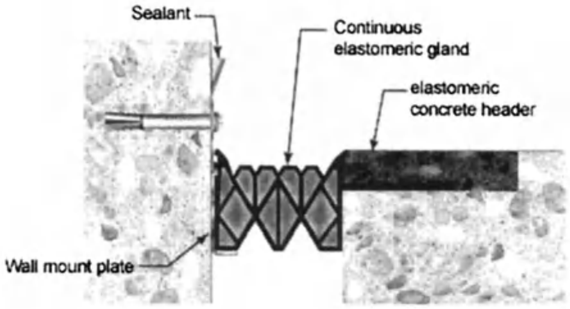


Figure 12-9: Elastomeric-edged expansion joint system – floor to wall. Photo courtesy of Watson Bowman Acme Corporation.

The adhered extruded seal (Figure 12-10) does not need an edging or a recess for installation, which is helpful for restoration work particularly, and for any work in general. If correctly installed, it performs within the manufacturers specified movement range. See Figure 12-14 for an ADA compliant variation.

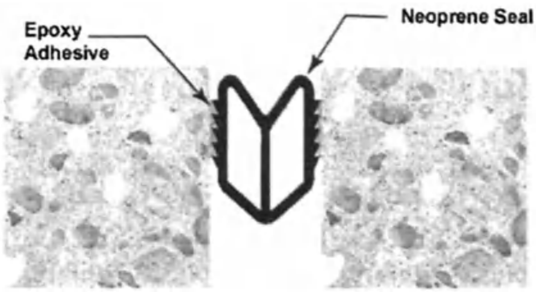


Figure 12-10: Adhered extruded expansion joint seal – floor to floor. Photo courtesy of Watson Bowman Acme Corporation.

Though the extruded compression seal (Figure 12-11) has been greatly improved since its introduction, it is not the preferred system for floor joints. While selection of the proper gland will make it ADA compliant, such a gland will have low movement capacity because it must always remain compressed (minimum 15% of nominal width). This seal provides an economical solution but is not watertight.

The closed cell expanded rubber seal is not recommended (Figure 12-12) for joints in open areas, though it too has been improved since its introduction through the use of an epoxy adhesive. The epoxy adhesive gives this seal greater movement capacity by allowing for tension as well as compression. The closed cell expanded rubber system is suitable for several vertical and horizontal applications. These include stair towers, elevator shafts, column conditions, floor-to-wall conditions and as a perimeter joint. However, this system is too soft for pedestrian traffic, particularly for high-heeled shoes. A metal plate or topping sealant is recommended for doors or passageways.

Both the extruded compression and closed cell expanded rubber seals are not flammable. However, they will show cigarette burns, detracting from their appearance. Have the individual manufacturer verify if the profile will support flame. Its best use is to seal between nonmoving joints. An example would be between elements of a precast concrete wall on a building façade.

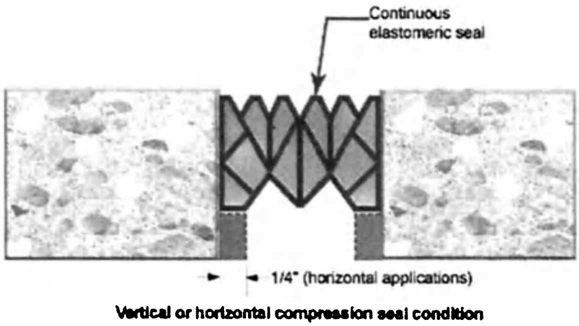


Figure 12-11: Extruded compression expansion joint seal – floor to floor. Photo courtesy of Watson Bowman Acme Corporation.

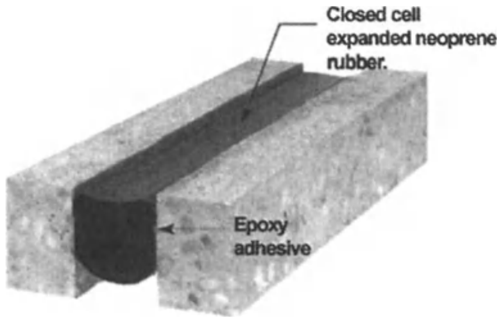


Figure 12-12: Closed cell expanded rubber– floor to floor. Photo courtesy of Watson Bowman Acme Corporation.

Though figure 12-13 does not show it, the bolt-in membrane seal does require a floor-edge recess. One might consider this seal type as being a prefabricated elastomeric concrete-edged seal similar to that shown in figure 12-8. It shares several characteristics with the elastomeric concrete-edged seal, one of which is the ability to cushion tire impact at the floor edge. Several marketed expansion joint systems continue to exhibit difficulty in providing this function satisfactorily. These systems continue to improve ability to cushion tire impact as well as their overall performance.

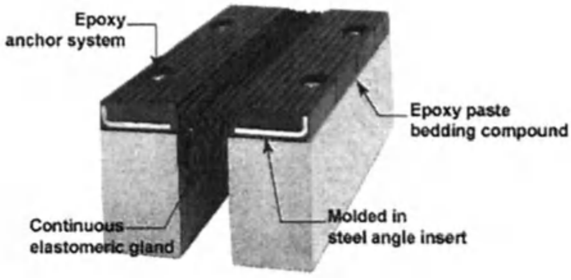


Figure 12-13: Bolt-in membrane expansion joint system – floor to floor. Photo courtesy of Watson Bowman Acme Corporation.

Figure 12-14 shows one ADA compliant seal. As stated in table 12-1, other types may be made compliant by proper gland selection. The seal shown achieves fair movement capacity and is less expensive than many of the alternatives. Each manufacturer will assist you in determining the proper seal size to accommodate specific project needs.

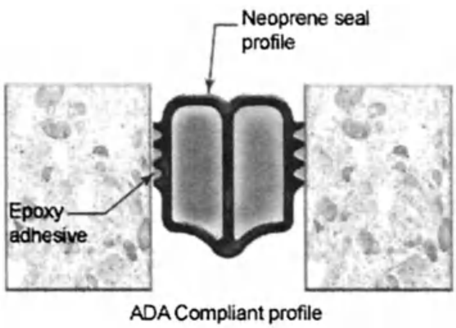


Figure 12-14: Example of an ADA compliant expansion joint seal – floor to floor. Photo courtesy of Watson Bowman Acme Corporation.

Development of expansion joint systems for seismic zones has lagged behind other types because of their complexity and the owner's unfamiliarity with seismic requirements and cost impact. In seismic zones, due to building code requirements, expansion joint openings often must be quite wide. Bridging an eighteen-inch wide opening (not an unrealistic example) with components strong enough to carry vehicle loads, while being safe for pedestrians, as well as being leak-free, is a design challenge! These systems tend to be complex. Periodic maintenance will continue their ability to accommodate multi-directional movements. Figure 12-15 shows one manufacturer's solutions.

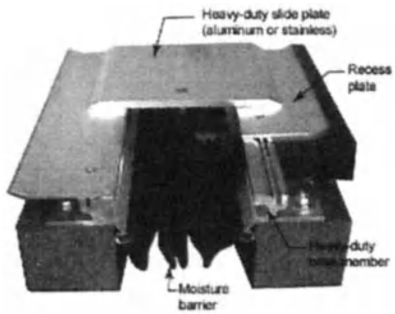


Figure 12-15: Example of a seismic zone expansion joint system – floor to floor. Photo courtesy of Watson Bowman Acme Corporation.

Figure 12-16 shows an economical way to catch water that may enter the opening and channel it into a drain. This system is generally installed below the primary expansion joint. It could also be used as a temporary or permanent fix problem joints not budgeted for replacement.

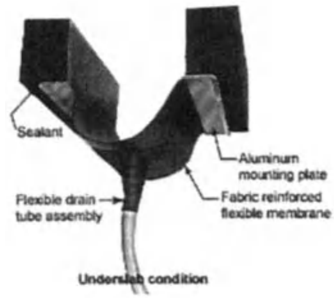


Figure 12-16: Under slab drain for expansion joint. Photo courtesy of Watson Bowman Acme Corporation.

Often, expansion joint details are shown in section only, as in figures 12-5 through 12-15. If so, when the installer encounters non-typical conditions, the installation may be unsatisfactory. Avoid such experiences by detailing both section and plan views. Figure 12-17 shows a plan view example.

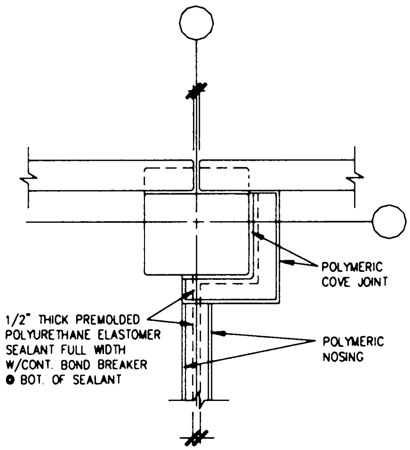


Figure 12-17: Plan of expansion joint seal around column

Figure 12-18 shows a method of terminating an expansion joint seal at a pair of columns – one column is one either side of the expansion joint. The seal is turned up the column faces, preventing water from running between them. It is critical that only the sides, not the end, of the seal are adhered to the column faces. Ignoring this advice will shorten the seal life.

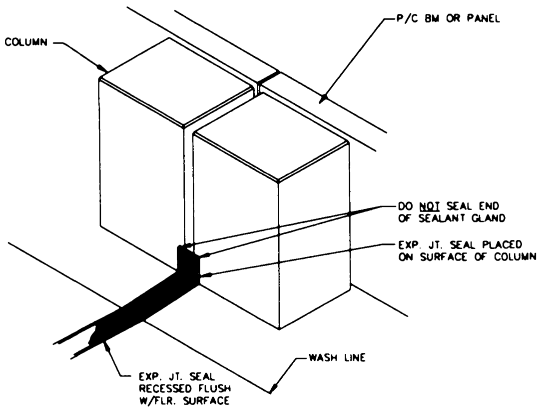


Figure 12-18: Suggestion for termination of expansion joint seal at double columns.

Whichever seal you select, you can improve its performance by following the advice below, if at all possible.

Locate expansion joints out of the runoff path; ensure that water drains away from the joint. If water must drain across the joint, ensure that slopes permit no ponding at the joint. Locate joints to avoid columns and other elements that will complicate installation and impede performance. If there are conditions that require that the seal go around a column or up a curb or wall, provide the details and views necessary to show what is to be done. Keep seal direction changes to a minimum and detail the appropriate seal terminations. In your specifications and details, require proper preparation of seal substrate and joint opening to guard against premature seal failure. Provide temperature adjustment tables and require field inspection of all work by quality assurance personnel (refer also to section 12.5.1). Locate expansion joints away from breakovers where the floor changes from sloped to flat, off express ramps, away from turns, and away from areas where cars will accelerate, as when they leave entry areas. Isolation joints in seismic zones must often be quite wide. System design for these joints is challenging and still evolving.

Again, if possible, eliminate the need for the expansion joint so that you can prudently eliminate the joint. However, don't be tempted to eliminate necessary joints and drainage provisions in the name of economy. Also see the following section.

12.2.3.5 Structure Vibrations

Structures with an efficient parking layout often have column spacing producing inherently limber long-span beams in one direction and a multiple of the parking stall width in the other. Alternatively, if the floor is precast, the dimension should be a multiple of the precast module, usually 30 or 36 ft or, if cast in place, an economical span in the 18- to 24-ft range. These long-span floors must have the necessary stiffness and mass to reduce vibration and noise to acceptable levels. Perceptible vibrations are a normal consequence of the span-depth ratios found in modern parking structures. As a rule, such vibrations are not detrimental to the use of the structure; what is acceptable is somewhat subjective as no building code requirements exist. The best resolution might be to visit several existing parking structures with the client, reaching agreement as to what is an acceptable level of vibration. Remember that pedestrians using the facility will feel vibration more than motorists.

A specific consideration is the effects of vibrations on an isolation (expansion) joint system. Concern is normally necessary only when the system bridges between two cantilevered elements or between a cantilevered element and a rigid element. For instance, an expansion joint may be located between two cantilevered slab ends, which are in turn located midway between two beams or double-tee stems. If differential vibration/deflection of the cantilever ends will expose the seal to premature wear from car tires or snow plows, then eliminate the differential. Provide a shear connection, which will permit free expansion and contraction of the joint in the horizontal plane while preventing relative movement in the vertical plane.

12.2.3.6 Tensile Stress Control

Areas of tensile stress-induced cracking are among the first to yield to weathering deterioration. The rate at which concrete deteriorates and steel corrosion begins will be proportional to the amount of concrete cracking.

Minimize bending stresses in exposed reinforced concrete in design by attention to structural depth and reinforcement clear cover, quantity of reinforcement, and provision of closely spaced small-diameter bars at the tension face.

Reduce or eliminate tensile bending stresses and, in turn, tensile cracks, by judicious use of prestressing. Use only as much prestressing as required to reduce stresses to non-cracking levels under service load conditions. Stiff walls and columns, and wide beams can reduce prestressing forces applied at a building perimeter. Account for this reduction by increasing the applied forces or by using temporary hinges to reduce member stiffness. Higher levels of prestressing will only increase problems due to elastic shortening and creep. Also see section 12.4.6.2.

12.2.3.7 Future Additions

Scope-of-work discussions with the owner should always include whether or not the design will allow for future horizontal or vertical additions. If future additions are planned, provide adequate structural capacity. Define the nature and extent of the future addition in the contract documents.

If the original structure is to be precast concrete, consider whether or not a precast addition will be feasible. There must be room for erection cranes. Will a crane be able to reach far enough to place the precast pieces? Cast-in-place additions have been built atop precast existing structures because a precast addition was not feasible.

Include details to permit easy future addition in the original contract documents. Figure 12-19 shows a detail that will accept a future column extension. Figure 12-20 shows a detail that permits future extension of a supported post-tensioned slab.

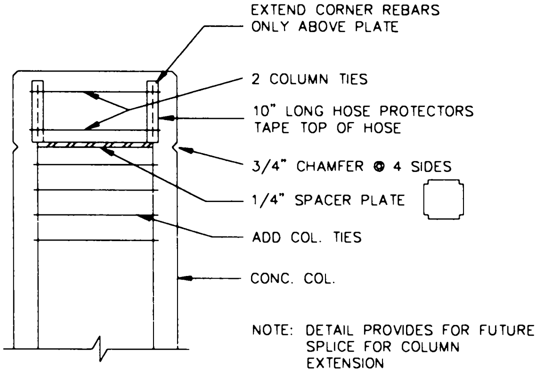


Figure 12-19: Detail at top of column to provide for future extension

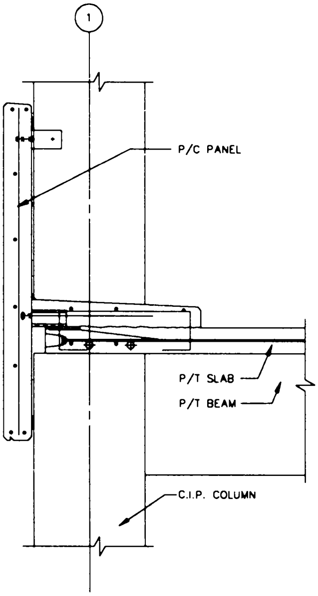


Figure 12-20: Detail at edge of floor to provide for future extension

When the time comes to add tiers to an existing structure, obtain from a Registered Land Surveyor a survey of the elevations of the existing column tops. Include the information in the contract documents for the addition.

12.2.3.8 Lighting

See Chapter 9 for a discussion of the interrelation between lighting and structure.

12.3 STRUCTURAL SYSTEM SELECTION

12.3.1 General

Selection of the structural system for a parking structure will be influenced by the factors cited in section 12.2. The designer provides the client with design options that the designer then develops into a final concept to satisfy the client. Though the engineer must recommend structural system alternatives, together with associated costs, the client ultimately decides which system will satisfy its requirements.

Important considerations in selecting a structural system are availability, cost, expected quality of construction, expected life, function, and appearance. The first five factors are equally important; the sixth may be less so. However, if the owner is a developer who intends to sell the project soon after it is completed, it may only be concerned about first cost. The owner may not appreciate the values of expected life and function in establishing an asking price. See Chapter 17 for more about life cycle cost analysis. Educating this owner type may be difficult. In the extreme case, the designer probably should not take the project.

Concern about quality has been much discussed in the construction industry. If a structure meets the requirements set for it in the scope-of-work statement, which must be part of the design services agreement, then it is a quality structure. Stating the project requirements clearly in the design agreement and the scope-of-work statement is of prime importance. Failure to reach agreement on project requirements should lead the designer to withdraw.

12.3.2 Restraint

Parking structures tend to move more than other building types do. Here is one common error as an example.

A designer considers the unbraced length of the first-floor columns as the dimension in the frame analysis and column design. The foundation details, however, show a foundation wall between footings and rising 3 ft.- 6 in. above grade. These details further show the walls cast tightly to the columns with wall reinforcement continuous from the walls into the columns. The resulting unbraced column length is actually only 50% to 60% of what the designer assumed. The column as shown in Figure 12-21 will probably crack. The point is to design properly and to be sure that construction mirrors design.

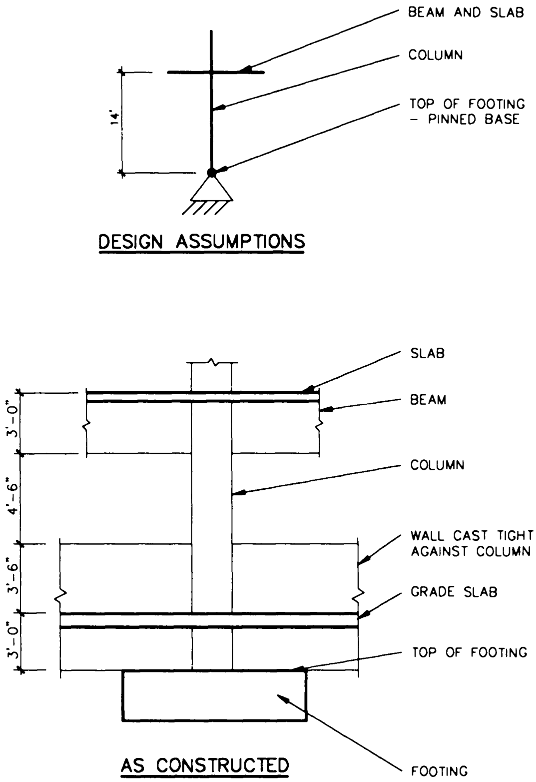


Figure 12-21: Assumed vs. actual column conditions

12.3.3 Lateral Load Resistance

Lateral load potential sources are wind, earthquakes, adjacent structures, or earth. The IBC model building code now states that all regions of the United States have to be designed with at least some capacity for resistance of earthquakes; all require capacity to resist wind loads. Below are discussed the three systems by which lateral loads are commonly resisted in parking structures.

12.3.3.1 Frame Action

To resist lateral forces, this method uses the frames formed by the beam-and-column assembly typically occurring at each grid line. Using frame action to resist lateral loads has much to recommend it, all else being equal. Frame action implies that there will be no shear walls to interfere with vehicle parking or circulation. Shear walls also provide concealment to lawbreakers, so should be avoided if feasible.

Since the typical structure contains ten or more such frames, the load distributed through the properly designed floor system to each will be reasonable, and required reinforcement quantities should be moderate. All structural systems described in this chapter may be modified so that frame action can be used effectively to resist lateral loads. However, frame action uses the bending resistance of the beams and columns to stiffen the structure laterally; it is not as efficient with taller buildings or greater loads. Therefore, if, because of building height or magnitude of loads, the resistance furnished by frame action is insufficient, other methods must be used, alone or in combination with frame action.

12.3.3.2 Shear Walls

In order to minimize slab cracking in large plan area structures, and if temporary isolation joints in shear walls are not practical, arrange the walls so they do not restrain the normal volumetric changes accompanying post-tensioning, temperature, shrinkage, and creep. Remember that these effects are more significant in parking structures than in other structures. Ideally, locate the walls at or near the center of rigidity of the structure, whether in the interior or on the perimeter. Interior shear walls may form hiding places – large formed holes will improve passive security. Coordinate wall location with isolation joints. Figures 12-22 through 12-24 show example arrangements.

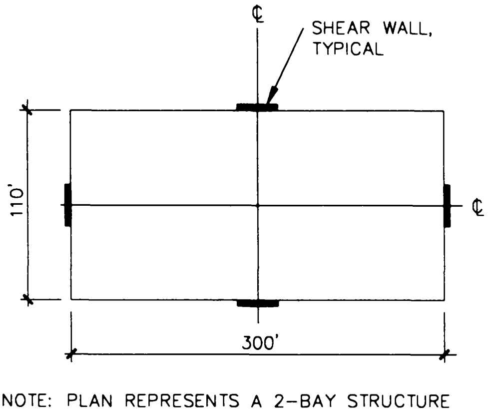


Figure 12-22: Example of shear wall arrangement. Placing shear walls at the exterior simplifies traffic planning, but may impair structure performance.

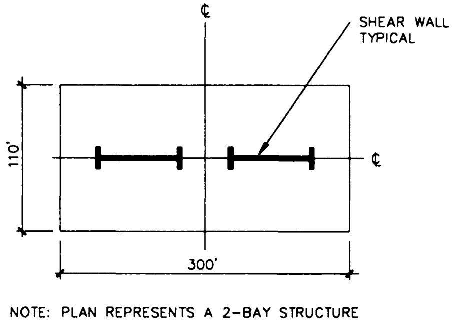


Figure 12-23: Example of shear wall arrangement. Placing shear walls near the center of mass will simplify structural design, but may adversely affect traffic and parking planning.

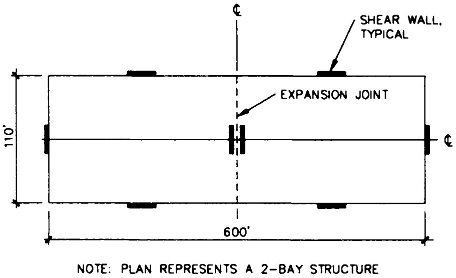


Figure 12-24: Example of shear wall arrangement. For larger structures, some combination of Figures 12-22 and 12-23 arrangements may be the best solution.

12.3.3.3 Truss Action

Frame action necessary to resist lateral forces may be lessened by the presence of structurally integral ramps connecting consecutive floors. This same approach may be used with continuously sloping floors. In some configurations you may achieve truss action by taking the ramps into account, perhaps in one direction only, but carefully analyze the effect of lateral displacements on interconnecting elements. (Figure 12-25.)

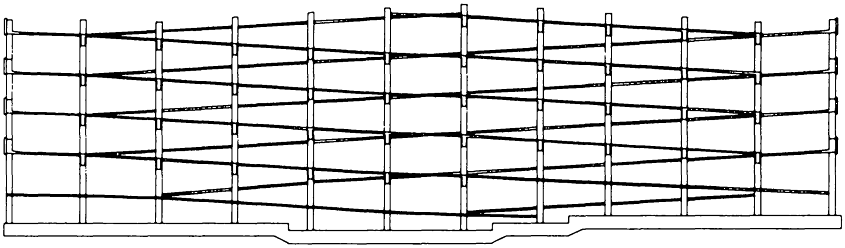


Figure 12-25: Simplified section showing truss-like construction of structure.

12.3.4 Superstructure Systems

Superstructure systems commonly used for parking structures may be classified into the following groups:

Cast-in-Place (CIP) concrete
Precast concrete
Structural steel
Combinations

When considering any superstructure system, remember that parking structure design and construction demand more attention to durability design than the design of weather-protected structures.

12.3.4.1 Cast-in-Place Concrete, General

Cast-in-Place concrete structures are typically rigidly framed with monolithically cast slab-to-beam-to-column connections.

12.3.4.2 Post-tensioned Cast-in-Place Concrete

Figures 12-26 and 12-27 show plan and section views of a typical post-tensioned one-way slab, post-tensioned beam, and conventionally reinforced column-framing system. Post-tensioning a member reduces its size for a given span. The more economical member size produces a smaller total structural weight, reducing moments. Negative moments and associated cracking are further reduced by post-tensioning-induced compressive stresses. This reduction lowers the exposure of steel reinforcement. Despite this advantage, maintain proper concrete cover.

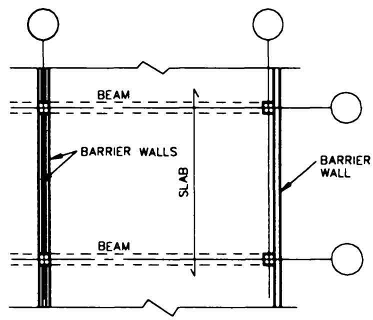


Figure 12-26: Example of post-tensioned one-way slab and beam system – plan view

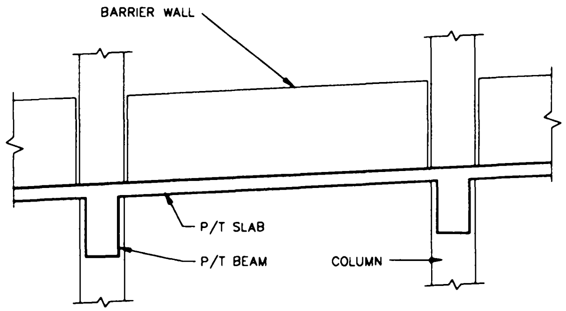


Figure 12-27: Example of post-tensioned one-way slab and beam system – section view

Though post-tensioning will generally reduce cracking, it is not necessary, or even desirable, to design post-tensioning to carry all gravity loads. Instead, use it only to reduce the tensile stresses at strategic dead load stress locations. Too much post-tensioning will increase both elastic shortening and creep-associated problems. Even at the lowest effective level of post-tensioning, these factors are important in design.

Post-tensioned structures contain areas where care must be taken to preserve system durability, especially where reinforcement is near the concrete top surface.

Through design, control volume change, creep deflections, and initial camber. Check the initial member camber, elastic deflection, and creep deflection so the final floor profile is consistent with the deck drainage system. Provide adequate concrete cover for reinforcement protection and fireproofing.

Two post-tensioning systems are in common use, bonded and unbonded. The former system, once common in the United States and now reappearing, is addressed in section 12.3.4.3 below. Those experienced in unbonded post-tensioned concrete design and construction should not believe that they therefore would not have problems with bonded post-tensioned concrete.

12.3.4.3 Bonded Post-Tensioned CIP Concrete

Bonded post-tensioned (P-T) concrete construction differs from unbonded construction in that tendon ducts with bare strands are pressure grouted after concrete placement. The hardened grout bonds the strands to the concrete. Bonded P-T construction offers the advantage of reduced nonprestressed reinforcement requirements compared to unbonded P-T construction.

Carefully plan the stressing location(s) for multi-strand beams and coordinate them with the size and sequence of the floor concrete pours. Knowledge of the physical size of multi-strand stressing rams is essential to avoiding construction problems.

Detailing for bonded P-T construction requires more care than for detailing unbonded P-T construction. Compare figure 12-28 below with figure 12-42 in section 12.6.2. Bonded tendon hardware is much bulkier and more rigid than is unbonded tendon hardware; because it's always comprises a multi-strand system. Fit problems must be solved during design, Solving them during construction will at best be expensive and at worst be impossible.

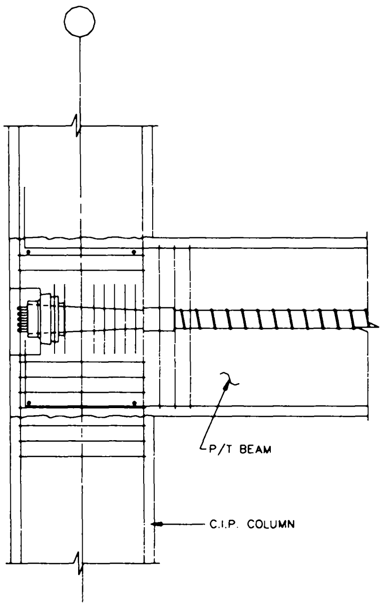


Figure 12-28: Bonded post-tensioned beam-column joint at structure exterior.

Construction joints must be located such that multi-strand stressing rams can be mounted without interference from previously placed beams or slabs. Plan the placement sizes to avoid creating beam stressing locations in the middle of a placement that would require blocking out the slab for stressing ram access. Strands may be placed in tendon ducts before or after the pour, preferably before.

At beam/girder and beam/girder/column intersections, P-T tendons must be located so that they do not interfere with each other or with the nonprestressed reinforcement. If two orthogonal beams with the same elevation meet at the same column, and one or both beams have P-T tendon anchor hardware at the column, the tendons must be offset to avoid fit-up conflicts with the bursting reinforcement of the tendon anchorages. Avoid stressing two orthogonal same-elevation beams from the same column. The two stressing blockouts in the column may create a void behind the anchorage of one of the tendons. Instead, make one beam's anchorage a dead end at the column, eliminating a stressing blockout.

Design beams for a constant P-T force in a given placement so that all strands will fit in one tendon duct. A non-constant beam P-T force in a placement will require the use of a second tendon duct. This arrangement is more expensive and frequently creates construction fit-up problems at anchorages. Avoid specifying a greater P-T force in a beam on the second-pour side of a construction joint. It may overstress the tendon in the first-pour side.

12.3.4.4 Conventionally Reinforced CIP Concrete with Non-Prestressed Reinforcement

Flexural members are typically deeper when designed in non-prestressed reinforced concrete than for post-tensioned concrete members of equal span and load. Because of larger member size and monolithic construction, performance under vehicle-induced vibrations is generally good. Increased member weight leads to increased reinforcement, form work, and foundation costs. Increased structural depth may lead to taller structures. This system's greater deflections may affect drainage design. This system would be used typically with short-span construction as part of a multiuse structure, such as lower level parking in an office building.

Analyze for allowable crack width control at negative moment locations such as beam-column joints. Water penetration at these points can lead to corrosion. Provide proper reinforcement cover everywhere. Provide sealant details at construction joints.

12.3.4.5 Precast Concrete, General

Figures 12-29 through 12-33 show a typical precast double-tee framing system plan and sections. For parking structures, precast concrete has two primary advantages: concrete quality is good, and the speed of assembly reduces on-site construction time and cost. Disadvantages are the installation and maintenance of the connections and sealed joints.

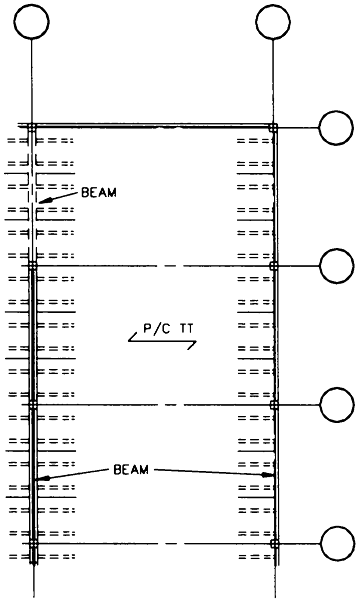


Figure 12-29: Example of precast double-tee floor system – plan view.

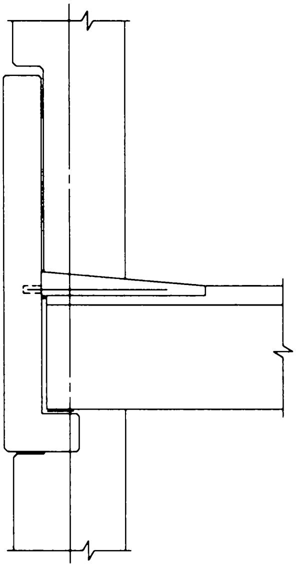


Figure 12-30: Example of precast double-tee floor system – section at exterior L-beam.

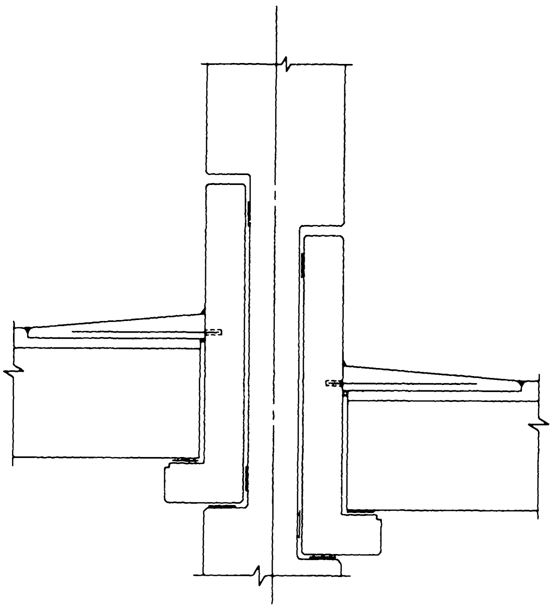


Figure 12-31: Example of precast double-tee floor system – section at interior L-beams.

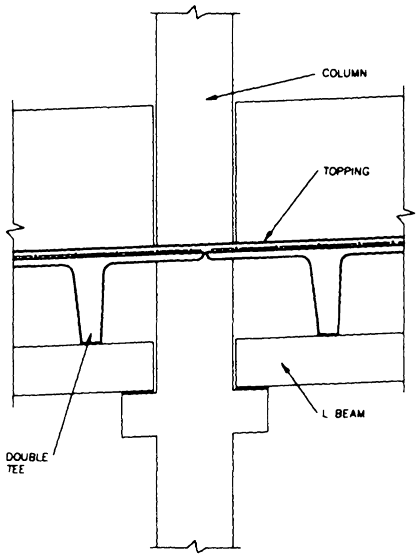


Figure 12-32: Example of precast double-tee floor system – section through tees at interior L-beams.

Plant-fabricated members are manufactured with close dimensional tolerances. Embedded item location control is usually critical for achieving quick erection. Coordinate drains and openings to ensure a properly detailed structure. When locating drains, account for member deflections and cambers. Provide for adequate member clearances in design. Pay particular attention to casting and assembly tolerances. Prohibit forcing units into position during erection; such erection stresses can cause local failures.

Member connection detailing is critical. Review special connections for ease of construction with a local fabricator. Connections are often exposed to water penetration through cracked topping and leaking joints. To prevent cracking and leaking, use proper materials. If connections are to be concealed in pockets that are concreted after the connections are made, and if building codes permit, use a sealant, not a grout to fill the pockets. Consider stainless steel connections and anchors to reduce metal corrosion and corrosion-caused concrete spalling. Where field welding is required, detail to allow heat-caused expansion of the metal embedments without cracking the adjacent concrete. Use field-applied coatings to protect welds and ferrous metals after welding. Connections need not be concealed if detailed to be clean and simple. Exposed connections, suitably protected against corrosion, are not objectionable. In fact, it may be better to have visible connections, which are more easily monitored and maintained.

Connections may become complicated in areas of seismic risk where continuity is essential. Even in areas of low seismic risk, volumetric and temperature changes in large structures may induce large forces and moments in connections. (See Chapter 14.)

12.3.4.6 Precast Concrete with Non-Prestressed Reinforcement

Precast concrete with non-prestressed reinforcement is sometimes used for architectural spandrel beams and for short-span structural members.

Structural columns, stair units, walls, short-span slabs, and short ramps may be designed in non-prestressed precast concrete. Some precasters prefer pretensioning these members for ease of handling, so check local precaster preferences to save time checking shop drawings later. See the discussion for non-prestressed CIP concrete.

12.3.4.7 Pretensioned Precast Concrete

Properly used, pretensioning provides strength, deflection, and crack control, and shallower slabs, joists, and beams. Pretensioning may be used simply to protect against damage during transportation and erection.

Proper pretensioning effectively closes service load cracks, reducing water penetration. If cracks are likely to be an owner perception problem in façade members, pretension those members. Pretensioned concrete units have already undergone full elastic shortening before erection, so further elastic shortening may be neglected. However, do not neglect the effect of long-term creep of pretensioned members after erection. Much of the discussion for post-tensioned CIP concrete, as it relates to crack control and stressing levels, applies here also.

12.3.4.8 Post-tensioned Precast Concrete

Coupling together an assembly of precast units with post-tensioning may be desirable. Take care to ensure that such stressing does not cause unacceptable geometry changes in the structure, either at the time of stressing or in the long term. Individual members also may be post-tensioned. A common scheme is to pretension a large member for self, dead, and construction loads, and then post-tension it for live loads.

12.3.4.9 Structural Steel

Figure 12-33 shows one structural steel framing system for parking garages. This system features a cast-in-place post-tensioned concrete floor. As supplied by one firm, after shop fabrication the steel members are cleaned to white metal, then three coats of epoxy paint are applied, providing long-lasting protection against corrosion. All erection connections are bolted; no welding means no field touchup of damaged coating will be required. A plan view of this scheme would resemble the all-concrete scheme shown in Figure 12-26, with steel substituted for the concrete beams.

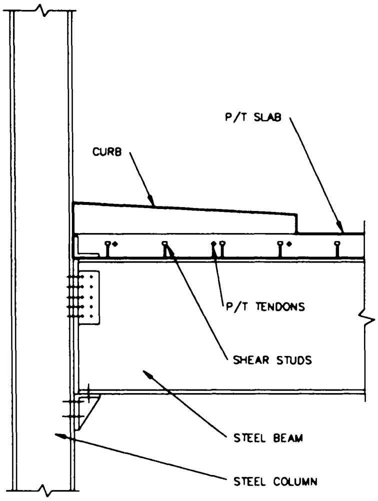


Figure 12-33: Example of a structural steel frame with post-tensioned concrete slab system.

Figure 12-34 shows a steel frame with a floor of short-span precast prestressed double tees. This system has much to recommend it. It can be built quickly, capitalizes on the strengths of concrete and steel, and performs well. Another scheme rotates the double tees 90 degrees to span the long dimension of the bay to take better advantage of their structural efficiency.

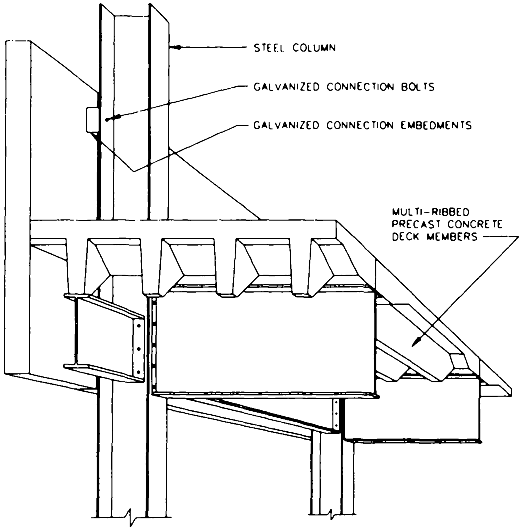


Figure 12-34: Example of a structural steel frame with precast concrete double-tee system.

Corrugated metal deck forms, open web steel joists, and certain weathering steel connections may not perform well in regions where road salt use is common, rainfall is high, or in coastal environments. Protective coatings are necessary for these systems in such areas. Local building codes may require fireproofing.

In many areas, a life cycle analysis will show that first cost and maintenance cost of a structural steel frame are greater than those of a corresponding concrete frame; however, recent developments in coating technology and in building code requirements have made steel parking structures more competitive. Reasons for using structural steel might be (1) the need for as lightweight a structure as possible to permit economical foundations despite poor soil; (2) a shortage of skilled concrete tradesmen in the project locale; or (3) local preference.

12.3.4.10 Combinations

A number of combinations of cast-in-place and precast concrete combinations are discussed in both the section above and in the sections following. All utilize composite action between the precast and cast-in-place elements, or between concrete and structural steel members. The combination of precast beams and columns, or of precast beams, girders, and columns, is noted here for two reasons. First, it is not mentioned elsewhere. Second, it is widely used on the west coast of North America, and its use is spreading. This system was used not uncommonly in many locales 20-30 years ago, then fell into disuse. Now there is a resurgence.

12.3.5 Structural Components

12.3.5.1 Thin-Slab CIP Floor Systems

Thin-slab systems, such as waffle slabs and pan joists, usually require less concrete than one-way-slab designs and so may appear economically attractive initially.

These systems use thin slabs, usually 3-4 in. thick, stiffened by a stem-web pattern underneath. The main advantage of these systems is that long spans are achieved with a relatively light structure. However, there are more drawbacks than advantages.

Waffle slabs and pan joists present specific problems with cracking and reinforcement protection. Small-scale cracking can be expected at the slab periphery owing to variations in curing rates and shrinkage between slabs and joists because of the differences in volume/area ratios. These characteristics lead to stress cracking, which might not otherwise occur. In any case, the cracks will accelerate the weathering process when water is present. In a thin slab, it is more likely that cracks will fully penetrate the slab, permitting water to reach both top and bottom reinforcing and causing objectionable leaching on the slab underside. These problems may be lessened by careful control of the construction process, particularly curing, and by attention to the arrangement and placement of the reinforcement. A traffic-bearing protective membrane should be required protection. Crack control by tooled and sealed control joints may reduce the section to an unacceptable degree and is not generally practical for thin slabs. However, provide tooled and sealed joints at every construction joint. Waffle slab and pan joist systems are not recommended for parking structures.

A system with similar characteristics incorporates cast-in voids to form a floor structure resembling a deep hollow-core unit. A composite system incorporating precast pretensioned joists spaced at around 7 ft.- 6 in. on centers and spanning 40-68 ft shares the same behavior. This system can perform well if designed with sufficient control joints and slab reinforcement to prevent cracks, but seldom is. This system is not recommended for parking structures.

Hollow-core units with topping share thin-slab characteristics. They are also vulnerable to slab deflections and shear stress failure. In design, reduce excessive elastic and creep deflections to prevent ponding and poor drainage. Specify weep holes in the downslope ends to permit drainage. This system is not recommended for parking structures.

We have seldom used any of the above-described systems, but have seen problems with them in our restoration practice. We do not recommend their use. Some designers, particularly in the northeast United States of America, still use thin-slab systems. They spend much time and money making them more durable. It would be better to avoid such systems. Beware of any structural system with thin elements and vulnerable top reinforcement.

One- and two-way slab systems will generally have high tensile stresses at slab-top fibers at supports. Cracking is likely to be more visible at these locations and may penetrate the slab full depth. The top reinforcing in these systems is vulnerable, and will require protection against corrosion. Deflections are a concern in the design of longer spans. Careful control of camber and attention to live load deflection are essential. Two-way slab systems are not recommended for parking structures, as stresses are typically high and slabs are thin.

In general, most structural systems can be made to perform adequately in parking structures if sufficient effort is made in both design and construction. As discussed above, however, some systems are more suited for parking structures, while others are better avoided.

12.3.5.2 Precast Concrete Floor Systems

Parking-structure floors may be made of solid or hollow-core plank. Tees of all kinds, single, double, triple, and quad, and in widths from 10 to 15 ft, have been used. Plank and tees may be made composite with cast-in-place topping or may not require topping. The latter, referred to as "pretopped," have become more common in recent years. (See Figures 12-35 and 12-36 for illustrations of field-topped and pretopped double tees.)

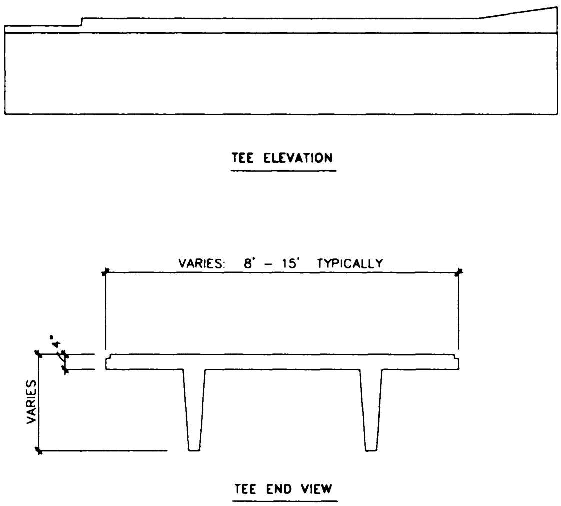


Figure 12-35: Pretopped double tee. Some manufacturers prefer the profile shown at the left end, which requires CIP concrete to complete. More recently, the profile shown at the right end has become the product of choice for some manufacturers.

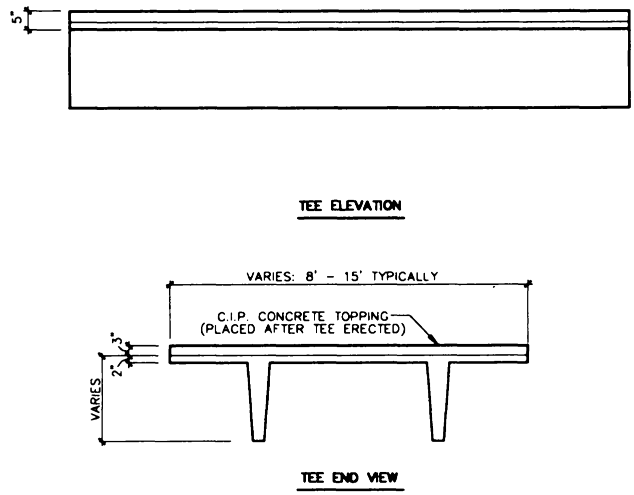


Figure 12-36: Field- or site-topped double tee. Project conditions may make using some field-topped tees to make floor slopes easier to achieve in specific areas of an otherwise pretopped tee floor.

In both field-topped and pretopped floors, welded connections between members are required to provide deflection compatibility between adjacent members and to help transfer shear across slab diaphragms.

If floor members are topped, there is a change in structural cross section at the joints between adjacent members. Though the composite thickness of the 2-in.-thick tee flange and the 2-in. topping is 5 in., at the joint between flanges, only the 3-in.-thick topping exists. This thinner section comprises a weakened plane that will crack as the topping concrete cures and shrinks. To make a more durable floor structure, it is important to control cracking and minimize leaks by specifying tooled and sealed control joints in the topping at every joint between precast members. Joint depth should be 20% to 25% of the concrete thickness to be effective (see Figure 12-37).

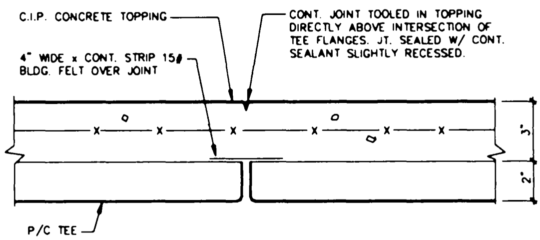


Figure 12-37: Tooled and sealed control joint in site-cast concrete topping over precast double tee.

Avoid saw-cutting control joints. If sawing is done too early, the edges of the cut will ravel; leaving an uneven joint that will be difficult to seal and objectionable in appearance. If the sawing is done too late, the concrete will have already cracked. Even if done correctly, the saw cut leaves a right-angle edge that is weaker than the rounded edge left by tooling. Even if the saw-cut joint is initially sealed successfully, difficult because of its narrow width, the edge is likely to crack, rendering the joint sealant useless.

Concrete topping for precast floors is often the last concrete placed. Quality of placing, finishing, and curing may suffer because of the hurry to finish the job. Also, because the topping usually varies in depth from 3 in. typically to 5 in. at a thickened edge at the floor perimeter, one truckload of poor concrete means poor topping over a large area. A 9-cu-yd truck will cover 972 sq ft with 3-in-thick concrete.

12.3.5.3 Floor Systems With Structural Steel Framing

Floors in steel-framed parking structures may be cast-in-place conventionally reinforced or post-tensioned concrete on composite steel decking or on corrugated metal form, or precast members. For CIP slabs, the Steel Deck Institute recommends that steel deck be used only as the form for the concrete slab, not as composite reinforcement. The Institute also recommends that in corrosive environments, a traffic-bearing membrane be applied over the concrete.

Concrete topping placed on corrugated steel forms often cracks due to shrinkage. Control this cracking with properly spaced, tooled, and sealed construction and control joints. Also, use welded-wire fabric or fiber reinforcement or both. Short- or long-span precast concrete double tees work well with steel framing.

12.3.5.4 Beams and Joists

Cast-in-place beams are usually formed in a T or L shape, the latter occurring at spandrel beams that may have the vertical leg of the L either upturned or downturned.

Precast members may have many shapes, such as rectangular, trapezoidal, tees, inverted tees, L beams, I beams, etc. (see Figure 12-38) and may be non-prestressed, pretensioned, post-tensioned, or some combination of two or all three. Precast members are often made composite with a cast-in-place topping. (For a discussion of torsion in beams, see section 12.5.4)

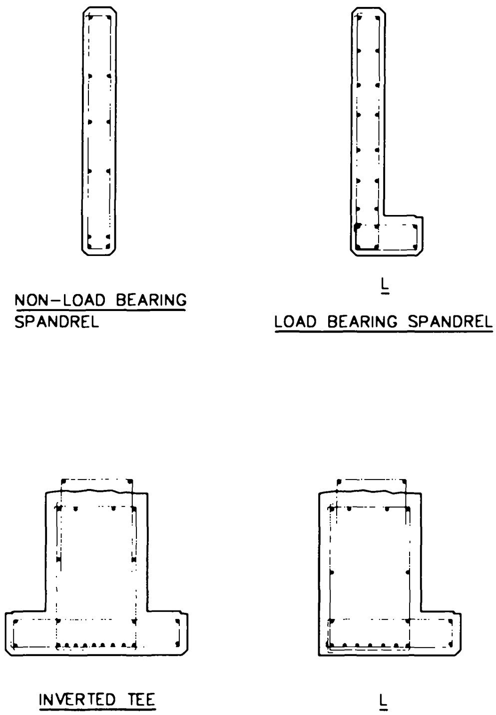


Figure 12-38: Commonly available precast concrete beam types.

If a perimeter curb is cast perpendicular to and atop a cast-in-place T beam, it is likely that the curb will crack parallel to the sides of the beam below. There is usually not a problem with reflective cracking over the beam with the slab alone, or with a thickened edge, but a 6-in.-high curb will crack. Prevent these cracks by tooling and sealing a control joint in the curb directly above and parallel to each beam face below.

Steel shear studs are often used with structural steel members to develop composite action between the member and a cast-in-place slab. Steel beams and girders may be castellated or cover-plated. Steel joists may be the open-web type, but are not recommended.

12.3.6 Summary of Structural System Selection

As seen from the discussion above, some structural systems are more suitable for parking structures than are others. Some systems will work just as well as others, but only if additional protection is provided. That additional protection, though, will likely make the selected system uneconomical.

In summary, of all the structural systems that have been used for parking structures, there are perhaps half a dozen that can be recommended, without added protection such as traffic-bearing membranes (Chapter 16). A durable system should include a pretensioned or post-tensioned concrete floor to reduce the likelihood of cracks and render a traffic-bearing membrane unnecessary. The floor should be thick enough to provide sufficient cover for reinforcement and sufficient mass to prevent undesirable vibration. The system must permit good drainage. Its nature must permit uncomplicated construction practices. Finally, the cost of the system must be competitive.

The systems currently meeting these requirements, in no particular order:

- Cast-in-place post-tensioned concrete framing and floors
- Precast pretensioned concrete framing with pretopped double-tee floors
- Precast pretensioned concrete framing with field-topped double-tee floors
- Precast pretensioned concrete framing with cast-in-place post-tensioned concrete floors
- Structural steel framing with cast-in-place post-tensioned concrete floors.
- Structural steel framing with precast prestressed double-tee floors

It should be noted that in some regions, building codes effectively prohibit post-tensioned concrete floors. Some parking structures are now being built in those regions with nonprestressed reinforcement in the floors (protected by traffic-bearing membrane) and post-tensioned beams.

12.4 VOLUME-CHANGE EFFECTS

Volumetric changes affect frame action in structures, especially those large in plan area. The results can include development of high shears and bending moments in the first-story frames at or near the building periphery.

12.4.1 General

Volume change is the change in dimensions in the structural elements due to drying shrinkage, temperature change, elastic shortening, and horizontal creep. The strains and forces resulting from structural restraints have important effects on connections, service load behavior and ultimate load capacity. Consider these strains and forces in design. The restraint of volume changes in moment-resisting frames causes tension in the beams and slabs, and moments and deflections in the beams and columns.

12.4.2 Drying Shrinkage

Drying shrinkage is the decrease in concrete volume with time. This decrease is due to changes in concrete's moisture content and chemistry. These changes are unrelated to externally applied loads. If concrete shrinkage is restrained sufficiently, cracking will provide relief at weak points. For proper durability and serviceability, predict and compensate for drying shrinkage, which is likely to be significant in open parking structures. (ACI 209R, *Predication of Creep, Shrinkage, and Temperature Effects in Concrete Structures* gives recommended shrinkage values.)

12.4.3 Elastic Shortening

In prestressed concrete, axial compressive forces applied to the concrete by prestressing tendons cause elastic shortening. This shortening causes some loss of prestressing force, which must be accounted for in determining the final effective prestressing force. Elastic shortening is additive to drying shrinkage. The Precast/Prestressed Concrete Institute and Post-Tensioned Concrete Institute Design Handbooks provide recommendations for predicting elastic shortening and all the types of volume change described in this section.

12.4.4 Creep

Creep is the time-dependent change in dimension in hardened concrete subjected to sustained loads. Concrete continues to deform inelastically over time under sustained loads. Its total magnitude may be several times larger than short-term elastic shortening. Frequently, creep is associated with shrinkage, since both occur simultaneously and provide the same net effect – increased deformation with time.

12.4.5 Temperature

A change in temperature will cause a volume change that will typically affect the entire structure. In addition, sunlight will affect local areas (such as the roof and edges of lower levels) more than the rest of the structure. The change can be expansion or contraction, so may be additive or subtractive to the above-discussed volume changes. Unlike drying shrinkage, elastic shortening, and creep, temperature changes are cyclic. The resulting expansion and contraction occur in both daily and seasonal cycles. The structural movements resulting from temperature changes must be a major design consideration.

12.4.6 Control Measures

12.4.6.1 Overall Structure

The degree of fixity of a column base has a significant effect on the size of the forces and moments caused by volume-change restraint. The assumption of a fully fixed column base in the analysis of the structure may result in significant overestimation of the restraint forces. Assuming a pinned-column base may have the opposite effect. The degree of fixity used in the volume-change analysis should be consistent with that used in the analysis of the column loads, determination of column slenderness, and construction document details.

A change in center of rigidity or column stiffnesses will change the restraint forces, moments, and deflections. Parts of a structure to be treated with extra attention to volume change are:

1. Any level with direct exposure to the sun and the columns directly below that level
2. The first supported level and the columns directly below it
3. The southern (in the Northern Hemisphere) and western faces

Creep- and drying-shrinkage effects occur gradually. The effect of the shortening on shears and moments at a support is lessened because of creep and microcracking of the member and its support. These volume-change shortenings can be designed for by using the concept of equivalent shortening in the *Precast/Prestressed Concrete Institute Design Handbook.*

12.4.6.2 Design Measures

In dealing with the volume-change forces, consider:

1. Parking structures have large plan areas. This characteristic will result in significant secondary stresses due to temperature change, shrinkage, and creep. Place isolation joints to permit separate segments of the structural frame to expand and contract without adversely affecting the structure's integrity or serviceability. Table 12-2 gives *general* guidance in spacing permanent and temporary isolation joints in a structure. Dividing the structure into smaller areas with isolation joints may be complicated by the presence of interfloor connecting ramps. Full-structure isolation joints must be aligned in both the vertical and horizontal planes in order to keep the full height of each column on one side or the other of the joint; otherwise columns may shear or other distress result.

Table 12-2. Example Guidelines for Expansion Joint Spacing

Number of Expansion Joints	Cast-in-Place, Post-Tensioned Concrete Structure	Precast Concrete Structure, Prestressed in Direction of Consideration	Precast Concrete Structure, No Prestress in Direction of Consideration
None	200 ft maximum w/ no additional pour strips, or 275 ft maximum w/ one pour strip at center	225 ft maximum	300 ft maximum
One, at about mid-length or width	550 ft maximum w/ two additional pour strips a quarter points	450 ft maximum	600 ft maximum
Two, at about third points	600 ft maximum w/ no additional pour strips, or 825 ft maximum w/ three additional pour strips at sixth points	675 ft maximum	900 ft maximum

2. Isolate the structural frame from stiff elements – walls, elevator cores, stair cores. Do not allow the superstructure to move freely with respect to the substructure; this is a trap for the unwary. Figures 12-39 and 12-40 show two details that will be helpful.

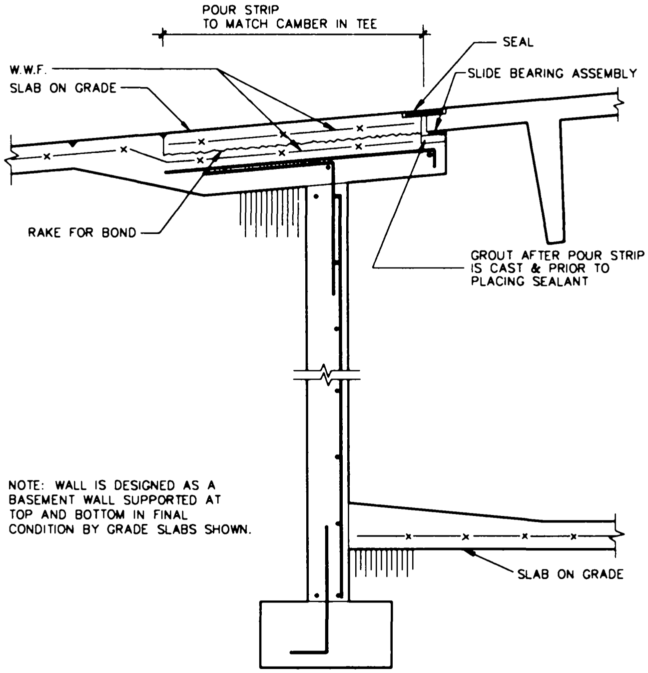


Figure 12-39: Example of a detail that permits relative movement between foundation and superstructure.

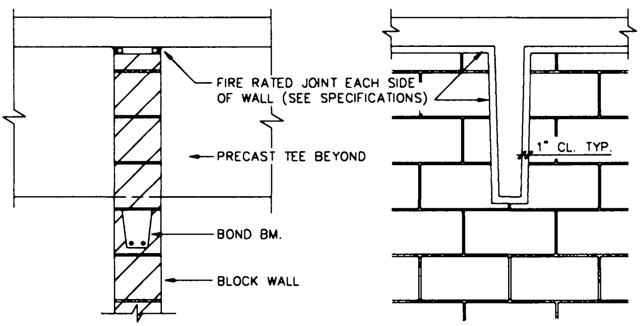


Figure 12-40: Example of a detail that permits relative movement between a foundation wall and a superstructure beam.

3. Reduce the rigidity of certain members or connections, using pinned (or partially pinned) connections at column foundations, or using longer unbraced column lengths may be increased without increasing structure height, particularly between grade and first supported levels.

   Leave a sealed gap between slab on grade and the column to produce an unbraced length beginning at top of foundation rather than top of grade slab. This measure may also be combined with lowering the top of foundation to further increase the unbraced length. When needed, use only soft connections at the first supported level to increase the unbraced length.

   To temporarily reduce column rigidity to any location, consider using a temporary hinge. Block out the column form, leaving a length of concrete supported only by the vertical reinforcement; later fill the gap. If you use this method, be sure to check the capacity of the vertical reinforcement alone versus the column loads expected before the gap is filled and full column capacity is restored.

4. Install temporary open "pour-strip" joints that are closed before construction is complete (See Figure 12-41). These temporary contraction joints allow the dissipation of early-age volume-change effects, such as elastic shortening, temperature movement, and shrinkage, which occur before placing the pour strip. Give close attention to pour-strip concrete quality. Use tooled and sealed construction joints and protected reinforcement. Control joints transverse to the pour-strip length at spacing equal to the strip width, and fibrous reinforcement may be necessary. In particularly hostile environments, consider a traffic-bearing coating overlapping the pour-strip edge construction joints.

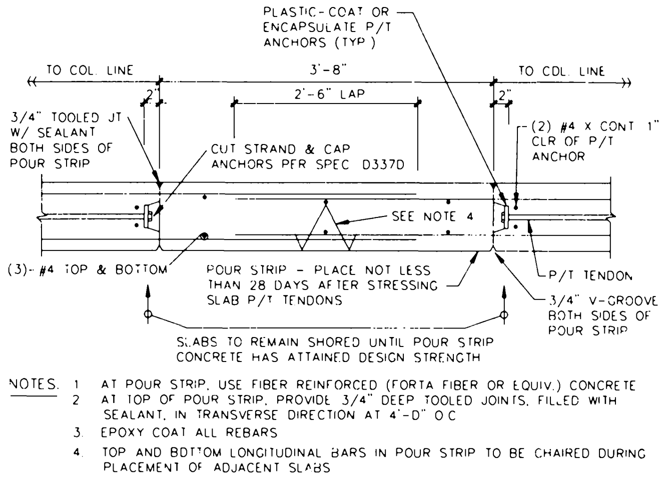


Figure 12-41: Pour-strip (temporary expansion joint) detail.

5. Frames with unequal column heights and stiffnesses, differential thermal response of members, and inelastic behavior cause further difficulties in predicting isolation joint movement. Computer modeling of parking structure frames can be effective in predicting volume-change-induced moments, forces, and movements, provided the model is not oversimplified.

6. Show *Temperature Adjustment Tables* in your contract documents. The tables can be generated with the assistance of the expansion joint manufacturer. They will help ensure that the correct opening width is formed at the corresponding temperature. The table can show whether or not the specified openings have been adjusted to consider the effects of creep, shrinkage and construction tolerances.

12.5 PROBLEM AREAS

12.5.1 Structure Flexibility

Parking structures are large and exposed to the weather. They are mostly concrete. That concrete may be pretensioned or post-tensioned. All of these factors combine to produce a structure that tends to expand and contract with daily and seasonal temperature cycles, to shrink and shorten as the concrete ages, and to shorten both elastically and inelastically under compressive load. This movement is real and cannot be ignored. As one respected engineer puts it, "Let the structure breathe." The solution is to allow the structure, particularly the columns, to be flexible enough to permit movement without structural distress. The trick is to do this while providing for adequate strength to carry the imposed load. Further discussion occurs elsewhere in this chapter.

12.5.2 Beam-Column Joints

Columns in parking structures are often subjected to unusual forces compared to those in other buildings. Effects of the prestressing system, relatively high joint moments and shears associated with long spans, and effects of volume change all contribute to highly stressed joints.

Exterior columns and beams will typically have high joint moments, requiring special consideration of the anchorage of the beam top reinforcement. In columns, the shear within the joint caused by the beam negative moment can exceed the shear capacity of the concrete alone. Ties are required within the joint. (Factors affecting the behavior of these joints are discussed in ACI 426, *Shear Strength of Reinforced Concrete Members,* and ACI 352, *Recommendations for Design of Beam-Column Joints in Monolithic Reinforced Concrete Structures.*) Shear in the columns may require increased tie reinforcement throughout the column height, particularly in seismic zones. Where column vertical bars lap, development of those bars and the corresponding column-tie requirements both need evaluation. Typical post-tensioned beam column details are shown in Figures 12-42 through 12-45.

These figures show the typical beam/column joints in an unbonded post-tensioned structure. Make sure that confinement reinforcement is properly detailed. Also review the beam schedule for possible conflict between top bars and post-tensioning. If there appears to be a conflict, get a larger scale detail with bar sizes and bends shown correctly to ensure that there is no congestion that will prevent proper construction of your design.

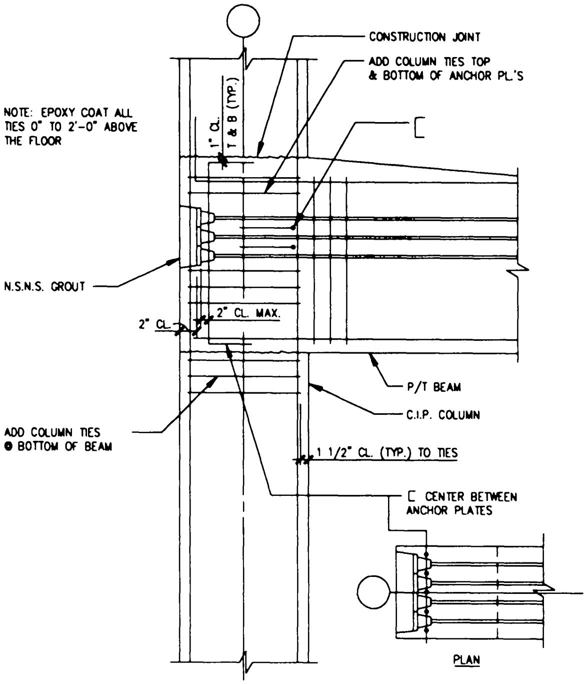


Figure 12-42: Cast-in-place unbonded post-tensioned concrete beam-column joint at structure exterior.

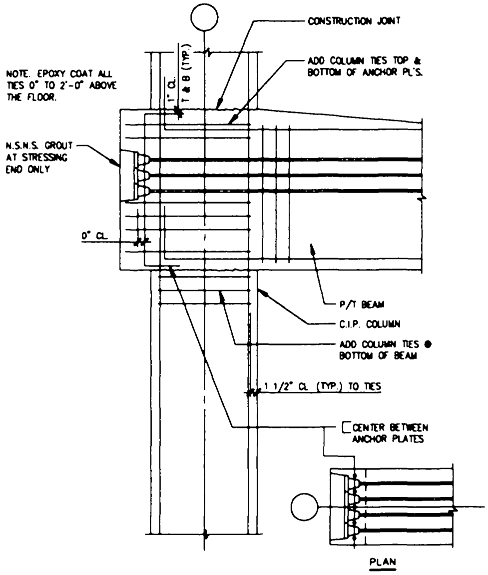


Figure 12-43: Cast-in-place unbonded post-tensioned concrete beam-column joint at structure exterior. This detail alleviates reinforcement congestion at the post-tensioning anchorages by moving them outside the column reinforcement. It is also suited for use when the column cross-section is not rectangular.

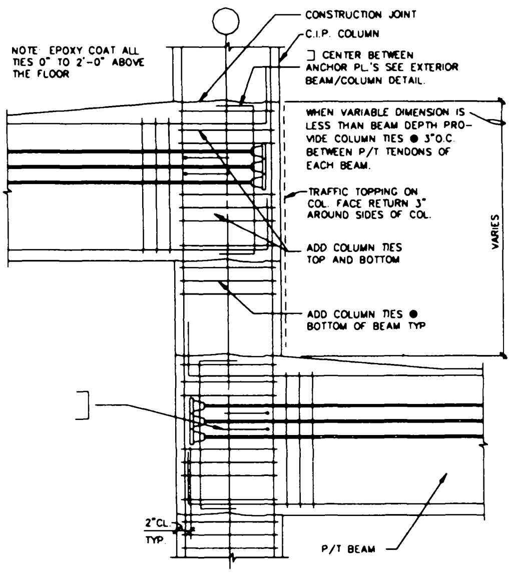


Figure 12-44: Cast-in-place unbonded post-tensioned concrete beam-column joint at structure interior. Ramped floors result in beam-column relationships as shown here and in Figure 12-46.

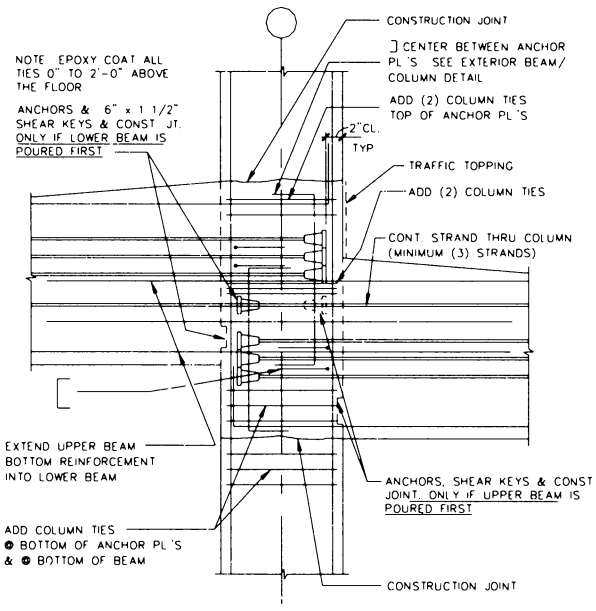


Figure 12-45: Cast-in-place unbonded post-tensioned concrete beam-column joint at structure interior. This detail would apply near the point where two ramped floors meet.

In cast-in-place post-tensioned structures, shortening of the first supported level beams due to elastic shortening, creep, and shrinkage will induce tension in the beam bottoms. Similar but lesser effects will occur at the upper levels.

Precast concrete beam column joints require special attention. Joints in precast concrete structures are subjected to repeated movement owing to cyclic volume change and vehicle traffic.

On the roof levels of parking structures of all types, the sun heats the top surface of the structure while the underside remains cooler. The result is a daily cycle of camber and deflection. Resulting rotations and forces at member ends can distress both simple-span and rigid-frame construction. Special detailing may be necessary.

12.5.3 Variable-Height Columns

The typical method for accessing the successive levels of a multilevel structure is via continuous sloping ramps. These ramps may comprise entire floors and be used for both parking and through traffic (refer to Figure 12-25 and see Figure 12-46).

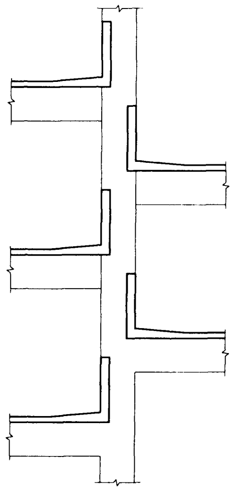


Figure 12-46: Section view of ramped floors at the column line between them.

The presence of integrated interior or exterior ramps will have a significant effect on the action of the structure. Internal ramps interrupt the floor diaphragms and complicate their analysis. High moments and shears are induced in columns adjacent to ramps where monolithic beams enter opposite sides of the columns at varying elevations (Figure 12-46). Split columns – that is, columns divided in two, each with beams framing in from one side only – will help.

12.5.4 Torsion

Avoid torsion if you can. Spandrel beams at slab edges, built integrally with the floor slab, are subjected not only to transverse loads, but also to a torsion moment per unit length, equal to the restraining moment at the slab's edge. ACI 318-99, Section 11.6, addresses design requirements with respect to torsion requirements in combination with shear and bending. Typically, monolithically cast spandrel beams, whether prestressed or not, are easily reinforced to meet minimum code requirements, but design them to reduce cracking.

Precast spandrel beam design is one of the most complex elements in parking structures. Figure 12-47 shows the major loads on one such typical beam. The *PCI Design Handbook,* Section 4.4.2, and the *PCI Research and*

Development Project No. 5 also address the behavior and design of precast spandrel beams. Pocketed beams, such as that shown in Figure 12-48, are one way to reduce torsion in spandrel beams. *PCI R&D Project No. 5* considers both L and pocketed beams.

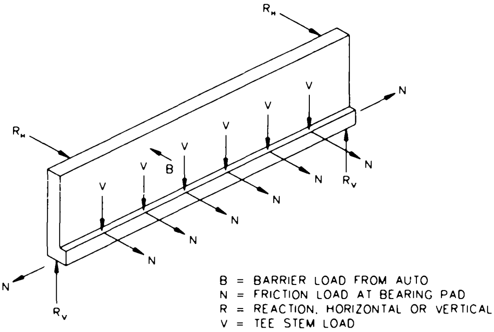


Figure 12-47: Example of the loads and reactions on a precast concrete L-beam.

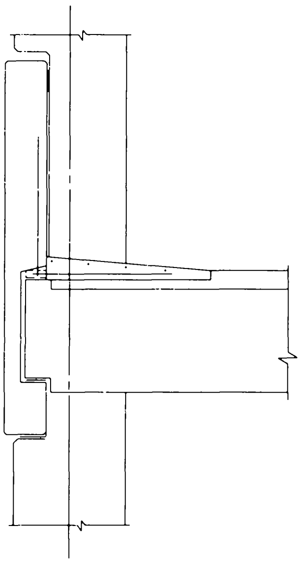


Figure 12-48: Example of a precast concrete pocketed beam – an alternative to the L-beam shape.

12.5.5 Stair and Elevator Shafts

Shafts interrupt the regular pattern of framing (see Figures 12-49 and 12-50) and may cause differential deflections in the adjacent structure, causing localized cracking. For instance, one beam or tee may end at the wall of a shaft while the adjacent one continues. Prestressing may reduce the effects of dead load deflection; however, differential deflections due to live load will occur both in beams and in the connecting floor structure. Local differential cambers and movements parallel to the members may also be a problem. These concerns may be addressed with a reinforced, cast-in-place topping or by accepting the movements and installing an isolation joint between the two members.

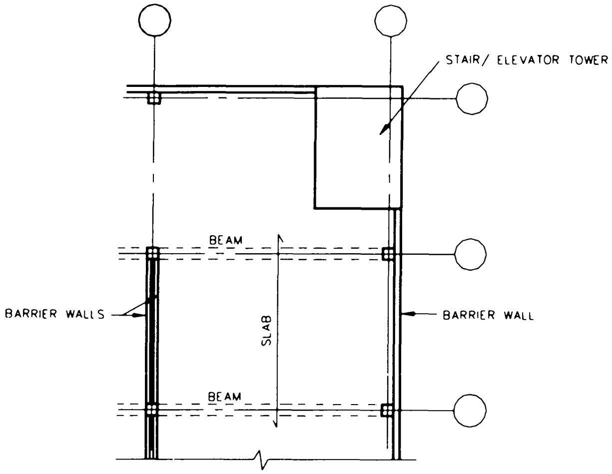


Figure 12-49: Cast-in-place concrete structural framing around a stair or elevator tower.

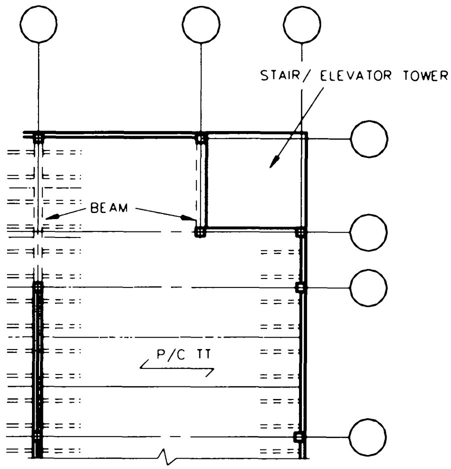


Figure 12-50: Precast concrete double-tee structural framing around a stair or elevator tower.

12.5.6 Expansion Joints

The best expansion (isolation) joint is one formed by a complete separation of one side of the joint from the other. Avoid sliding joints (joint movement requires relative movement of bearing surfaces). (See section 12.2 for more discussion.)

12.6 SUMMARY

In Chapter 12 we have reviewed a number of factors that might influence the structural design of a parking structure, such as cost, schedule, and building codes.

We have also looked at items such as drainage of rainwater runoff and expansion joint sealants that, while not an integral part of structural design, must certainly be taken into account if the structure is to work.

We have considered several possible structural systems regarding the relative suitability of each for parking structures. We have also noted which systems will need additional protection in corrosive environments and which are not recommended for parking structures.

Since parking structures are usually large enough and exposed enough to the elements for volume-change-induced forces to become significant in structural design and performance, we have examined the effects of shrinkage, elastic shortening, creep, and temperature.

There are some aspects of design that are unique to parking structures, such as variable height columns, which we have also addressed.

Chapter 13

PLAZA DECK SYSTEMS

Sam Bhuyan

13.1 INTRODUCTION

It is common to find many of the parking garages in an urban setting to be partially or completely covered by a plaza deck. The demand for open space creates a need for underground parking facilities. A plaza deck is an architectural feature that will often enhance the appearance and stature of any building or property. In addition to parking, some of the aesthetic and architectural features that may be present in a plaza deck include elements such as (see Figure 13-1):

- Landscaping with lawn, shrubs and trees
- Planters
- Pedestrian walkways
- Water pools and fountains
- Sculptures or other similar art exhibits

Plaza decks are expensive to build and are difficult to repair. It is very important to design an effective waterproofing system for a plaza deck. Water leakage through the plaza deck can adversely affect the floor system and other underlying structural elements (see Figure 13-2). Leaching and water dripping from the plaza deck above will contribute to concrete deterioration and damage automobile paint. Also, plaza decks must be built with extreme care and effectively maintained during service.

There are some very basic waterproofing concepts that drive the selection and installation of plaza decks. The purpose of this chapter is to review some of these basic features that affect the overall performance of the plaza deck waterproofing. The reader is encouraged to review other materials and industry literature that is available. The discussion in this chapter is intentionally limited

A. P. Chrest et al., *Parking Structures*

Figure 13-1: (a) Underground-parking facility with park and roadway. (b) Plaza deck with pedestrian walkway, landscaping, and building.

Figure 13-1 (contd.): (c) Protected membrane system driveway over parking garage. (d) Plaza deck planters.

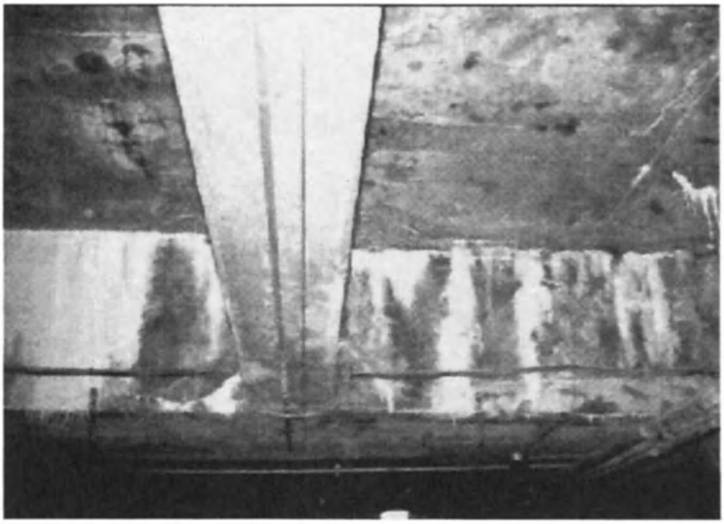


Figure 13-2: Leaking and leaching on underside of a failed plaza deck system.

to traffic and pedestrian bearing plaza decks that are more commonly encountered above parking garages.

13.2 GENERAL

Waterproofing of parking structure floor surfaces is extremely important to extend the service life and maintain operations of the facility. The horizontal floor surface tends to collect all the water and moisture, and this water accumulation must be channeled away as quickly as possible. The surface waterproofing keeps water out of the structure and directs it away from the surface. There are two basic approaches to protect and waterproof the surface of a parking structure. The two approaches include the use of a waterproofing membrane that is either:

- Directly exposed to the traffic – Traffic Topping, or
- Protected membrane system – Plaza Deck System.

A brief discussion of the traffic bearing and the protected membrane systems is included in Chapter 15. The discussion includes the advantages and disadvantages of the two systems. Although it is preferable to use a traffic bearing membrane system, a plaza deck system may be intentionally selected for reasons such as:

- Need for open space as opposed to parking.
- Aesthetic and architectural considerations.
- Reduce future membrane maintenance.
- Protection of retail or other occupied spaces below.

13.3 PROTECTED MEMBRANE SYSTEMS

There are two types of protected membrane system that have been used on parking structure plaza deck systems:

- Adhered protected membrane systems, and
- Loose-laid protected membrane systems.

It is more common to specify the adhered system. Although, historically, both loose-laid and adhered systems have been specified. The different types of plaza deck waterproofing systems are summarized in Figure 13-3.

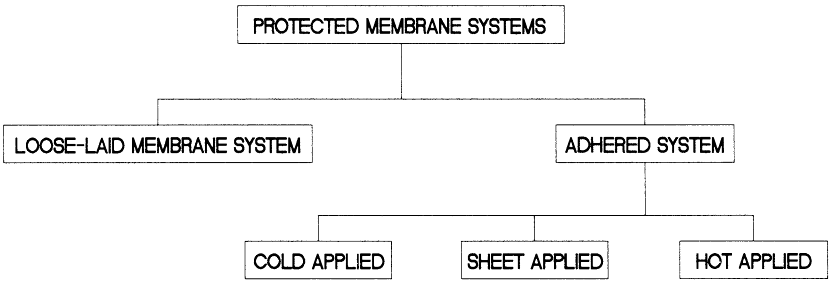


Figure 13-3: Types of plaza deck system membranes.

13.3.1 Loose-laid Membrane System

In a loose-laid system, a preformed membrane is laid directly on the structure. The most common membrane is a modified rubber or other elastomeric waterproofing material, which is about 60 to 100 mils-thick. Membrane pieces are spliced and glued together as necessary to form a continuous waterproofing system. The loose-laid system is attached only at the outer perimeter or edges of the structure. This permits the structure to move freely without transmitting the movements directly into the membrane. Also, any cracking in the structure is not reflected into the loose membrane above (see Figure 13-4).

Long-term integrity and membrane durability are essential for the system to work. Any defect, anywhere, will undermine the effectiveness of the entire waterproofing. Once the water penetrates the membrane, it can travel and leak through virtually anywhere. It is extremely difficult to trace and locate the point of membrane failure.

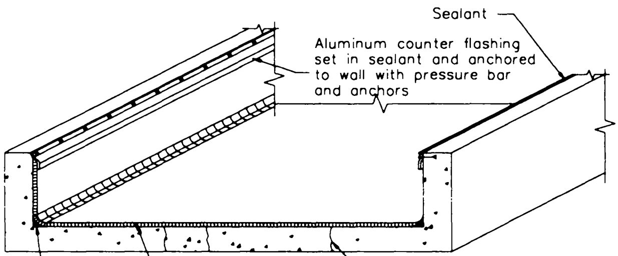


Figure 13-4: Loose-laid plaza deck system

The loose-laid system, in the author's opinion, is a carryover from the roofing concept of waterproofing. The roofing waterproofing membranes are essentially considered to be a non-traffic bearing system. Conversely, most plaza deck systems in parking structures are classified as traffic bearing systems. The adhered systems generally perform better under the exposure and loading conditions of pedestrian and vehicular traffic. The only exception is perhaps the use of loose-laid systems under heavy soil cover such as under landscaped areas. The loose-laid membrane is then able to move and little, if any, shear is transmitted directly to the membrane. Sometimes the soil cover also tends to protect the structure and the membrane from rapid temperature-related movements that can potentially damage the membrane.

In the following sections of the Chapter, discussion will be limited to adhered systems. As previously mentioned, it is more common to specify or encounter adhered protected membrane systems in parking garage applications.

13.3.2 Adhered Membrane Systems

As the name suggests, the adhered system is glued on to the concrete substrate over the entire surface area. The most common material is a modified asphaltic material. The membrane thickness ranges from 60 to 215 mils. Since the membrane is attached to the concrete surface, any cracking or structural movement is directly transmitted into the membrane. The ability to bridge cracks and absorb movements is provided by the membrane thickness, high flexibility and low modulus of elasticity.

Membrane failure results in a localized breach of the waterproofing system, and water leakage is contained in affected areas. This confinement provides the opportunity to trace easily the source of the water leakage and repair the membrane.

As shown in Figure 13-3, there are three types of waterproofing membranes that can be used with the adhered protected membrane systems. This classification of the waterproofing system is based on the type of membrane used.

13.3.2.1 Cold Applied Systems

The cold applied membrane systems consist of a polyurethane-based bitumen-modified material. The installed membrane thickness is about 60 to 90 mils. It is usually less expensive than the hot-applied membrane systems.

It is difficult to maintain a uniform membrane thickness due to difficulty in applying the material. The material is very sensitive to temperature and method of placement. The membrane will not cure under cold temperature conditions. Since the cold applied systems are relatively thin, they tend to be more susceptible to damage by construction equipment during placement of the wearing course and other plaza deck components on top of the membrane.

When greater assurance for membrane integrity is desired, it is preferable to use a hot-applied system. Therefore, application of cold applied systems is generally not desirable over occupied spaces.

13.3.2.2 Hot Applied Systems

The hot-applied systems consist of a rubberized-asphalt material. The installed membrane thickness ranges from 120 to 215 mils. The material is first heated in special mobile melter to a temperature of 350 to 400 degrees F (see Figure 13-5). Once it is melted, the material is squeegeed or rolled onto a prepared surface to form the waterproofing membrane. The thicker "heavy service" membranes are reinforced with synthetic fabric for greater strength and ability to bridge cracks (see Figure 13-6).

The hot-applied systems can be placed below freezing temperatures as long as the concrete substrate is not frozen and does not have any surface moisture. The ease of application generally results in a membrane with relatively uniform thickness. The membrane is seamless and continuous, which minimizes the potential for water leakage. Performance history suggests that the hot-applied membrane systems perform better than the sheet-applied systems with laps or seams.

Figure 13-5: Mobile melter for heating the hot-applied membrane materials

Figure 13-6: Hot-applied membrane application with fabric reinforcement.

13.3.2.3 Sheet-Applied Systems

Joining together 3 to 4 ft wide rolled sheets of material forms the membrane for this system. The membrane material is a preformed rubberized-asphalt material similar to the hot applied systems. The preformed sheet adheres to the concrete substrate. The preformed sheets are packed with a special peel-off material, which is removed prior to installation, so that the sheets can adhere to the prepared substrate. The sheets are lapped at the edges to form a continuous membrane (see Figure 13-7). The sheet thickness is generally about 60 mils.

The sheet-applied system results in a waterproofing membrane with a tremendous number of lapped joints that are potential sources for water leakage. There is a great potential for failure at these joints due to improper installation of the sheets (see Figure 13-8). It is difficult to apply the sheet membrane tightly around penetrations and at transitions (horizontal to vertical applications), which can also become a potential source of water leakage. The sheet-applied systems also tend to be more susceptible to damage during construction.

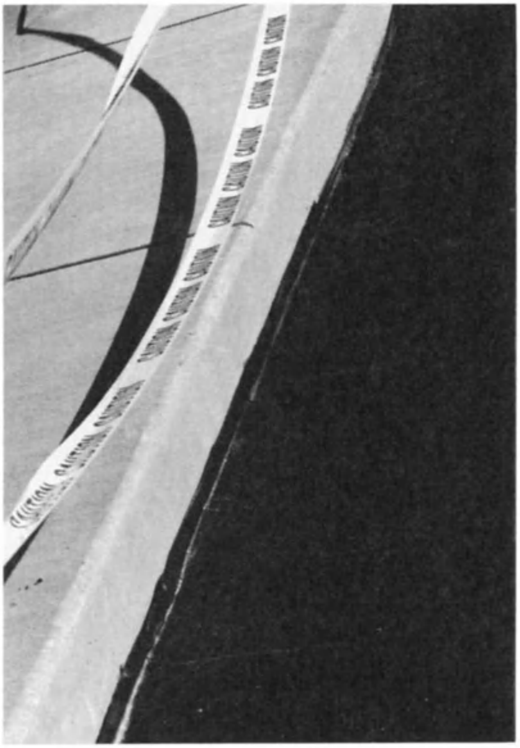


Figure 13-7: Sheet-applied membrane installation.

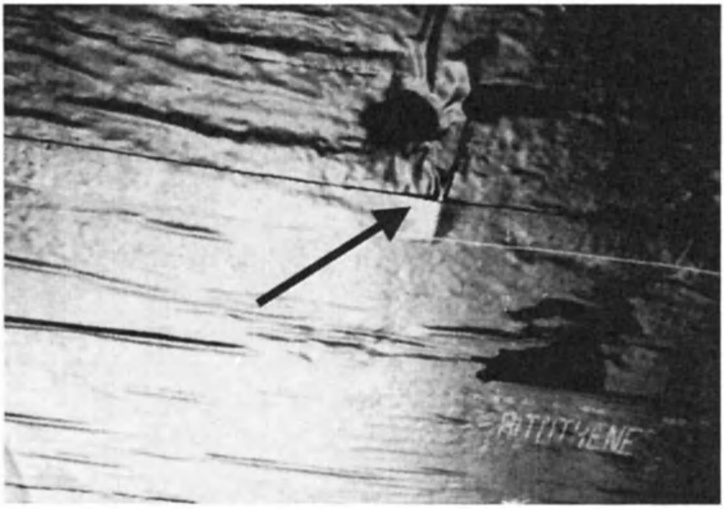


Figure 13-8: "Fish mouths" at lap joints of sheet-applied membrane system are potential source of water leakage in plaza deck systems.

13.4 PLAZA DECK SYSTEM COMPONENTS

A plaza deck system consists of several different components that are assembled together to form the protected membrane system. The various plaza deck components, from the top surface to the bottom, are as follows:

- Wearing surface
- Slip sheet
- Drainage layer
- Insulation
- Protection board
- Waterproofing membrane
- Structural slab

The individual plaza deck components are also shown in Figure 13-9. Each component has a specific purpose. The composite has to work as a unit to waterproof the structure and protect the waterproofing membrane from traffic abrasion and wear. Since the plaza deck is a very expensive system, it has to provide a 10 to 30 year service life to make it cost effective. Each component adds to the cost of the system. More components result in higher cost for the installed system. Also, each component must be installed carefully and correctly

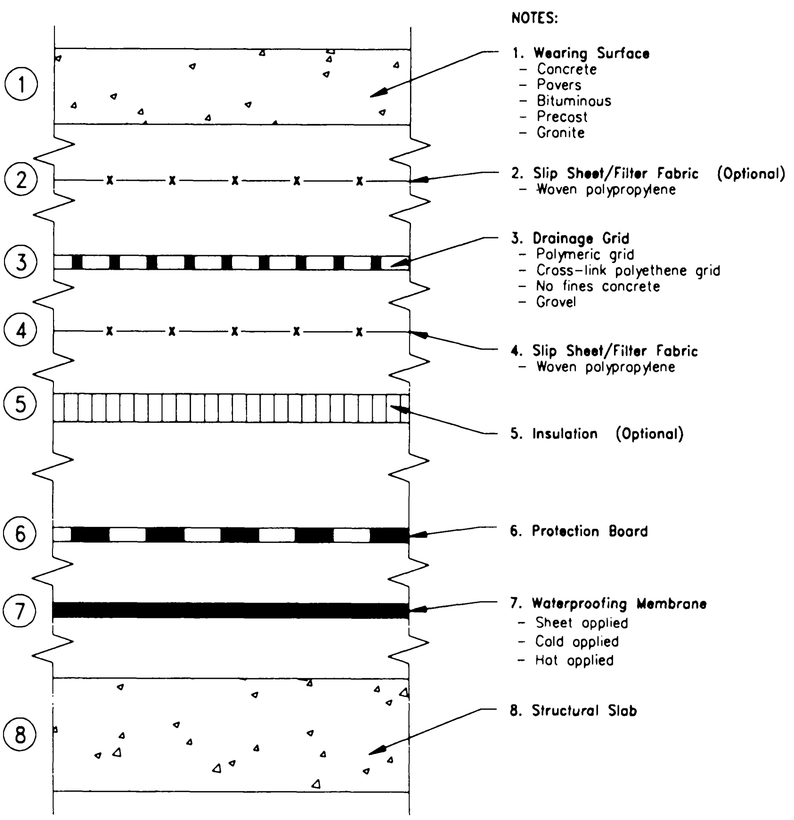


Figure 13-9: Plaza deck system components

to realize the desired service life of the system. Extreme care and supervision during construction is required to reduce the potential for future problems.

13.4.1 Wearing Surface

The wearing surface is the primary protective element of the plaza deck system This wearing surface also provides the desired aesthetics for the plaza deck. Traffic bearing systems are designed to carry vehicular or pedestrian traffic. For a non-traffic bearing system, the finished surface generally consists of a soil fill for green space or planters. Materials commonly used for a wearing surface include:

- Cast-in-place concrete slabs
- Brick or stone pavers
- Asphalt or mastic overlay
- Precast concrete pavers

13.4.2 Slip Sheet

The slip-sheet consists of a permeable woven polypropylene material or other inert, low friction materials. The slip sheet isolates the wearing surface from the underlying plaza deck components (see Figure 13-10). This horizontal isolation plane assists in accommodating the differential movements between the wearing surface and the underlying plaza deck components. Since the wearing surface is directly exposed to the elements, it tends to experience relatively large thermal movement induced stresses due to the temperature variations. A cast-in-place concrete wearing slab will shrink and will crack if restrained by adhering to the underlying plaza deck components. The underlying structural slab and other buried components of the plaza deck system experience only limited thermal movements. This horizontal isolation plane reduces the potential for damage to the underlying plaza deck components, including the waterproofing membrane, due to the movement of the wearing surface.

13.4.3 Drainage grid

The drainage grid provides the avenue for the water to be removed from the plaza deck system. Some of the water is drained or removed at the surface level, and the remaining portion of the water is removed by the drainage course provided within the plaza deck system. It is important to provide this sub-surface drainage system since it is virtually impossible to remove the water entirely at the surface level. Joints and cracks in the wearing surface will allow the water to penetrate through and burden the sub-surface drainage course to remove this water. Sealing joints and cracks in the wearing surface will tend to reduce this burden on the sub-surface drainage system; but it cannot be entirely eliminated.

There are several types of sub-surface drainage materials. Historically, drainage courses have been provided beneath plaza decks where plantings are the primary surface feature. These older drainage layers consist of a layer of pea gravel with a filter fabric on top of this drainage layer.

When these plaza decks were utilized as a traffic-bearing surface, the pea gravel was replaced with a no-fines concrete drainage course. No-fines concrete is obtained with a concrete mixture that contains only a single grade of aggregate, essentially uniform in size. This mixture does not contain the various combinations of graded aggregates that tend to reduce concrete porosity. Also, only sufficient cement slurry is provided to glue the aggregates together and leave sufficient voids for the water to flow through the matrix. Since the no-fines concrete drainage course provides dimensional stability, it has been used in traffic bearing applications. The use of the no-fines aggregate drainage grid may tend to "lock-up" the wearing slab and adversely affect the long-term performance of the plaza deck system. The minimum thickness of both the pea-gravel and the no-fines concrete drainage course is about 3 in.

Currently, extruded or molded high-density plastic drainage elements are used (see Figure 13-10). These preformed drainage panels are about ¼ to ½-in. thick. When these preformed drainage systems are used with a slip sheet, they do not tend to "lock-up" the wearing surface from temperature and shrinkage related movements.

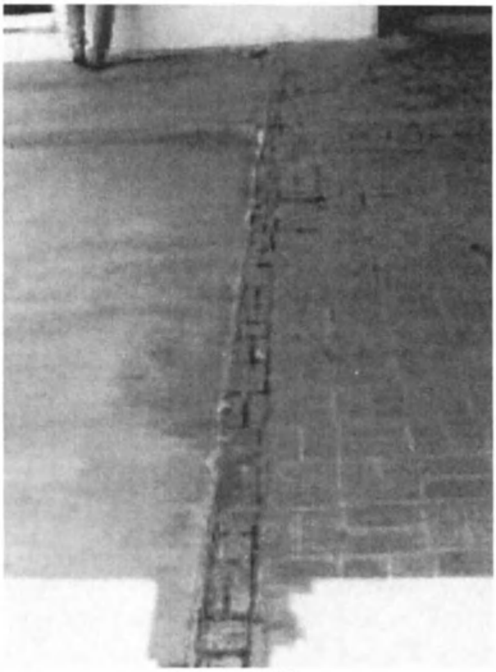
13.4.4 Insulation

In some instance it is necessary to include rigid insulation as a component of the plaza deck system over occupied space. The rigid insulation consists of an extruded-polystyrene board complying with ASTM C 578. The minimum compressive strength of the rigid insulation board ranges from 25 to 100-psi. The insulation is provided directly on top of the membrane and the protection board (see Figure 13-10). The wearing surface is generally susceptible to freeze-thaw damage if it is placed on top of this insulation layer. Long-term performance can be improved by providing drainage course above the isolation. It is also important not to overload and damage this insulation during construction.

13.4.5 Protection Board

A protection board is normally provided directly on top of the waterproofing membrane. These semi-rigid boards are 1/8 or 1/4-in thick. The thickness selection depends on board material and the manufacturer's recommendations. The primary function of the board is to provide an accessible working surface during construction of the other plaza deck components without damaging the underlying membrane.

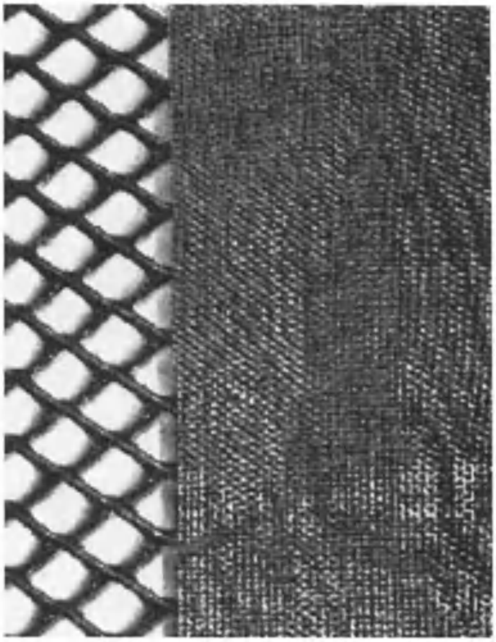
(a)



(b)

Figure 13-10: Plaza deck components: (a) Asphalt overlay wear course (b) Concrete slab and brick pavers

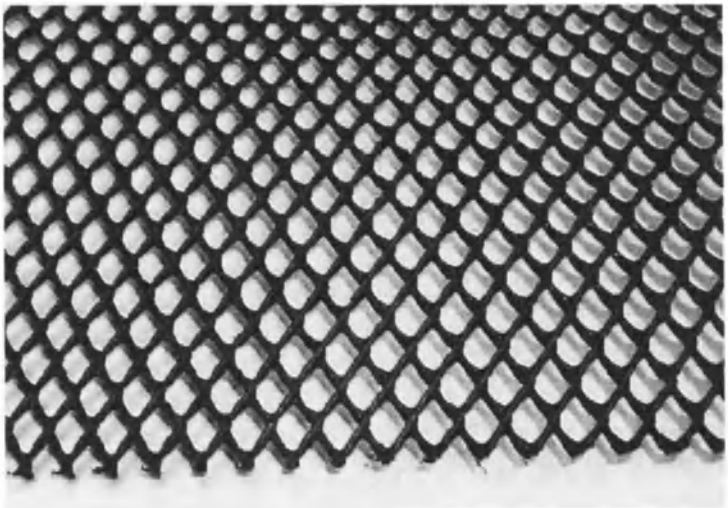
(c)



(d)

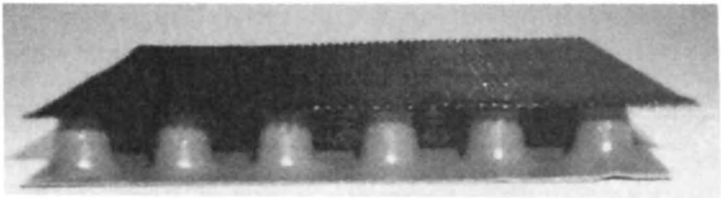
Figure 13-10 (contd.): Plaza deck components: (c) Stone pavers (d) Woven polypropylene slip-sheet

(e)



(f)

Figure 13-10 (contd.): Plaza deck components (e) Rigid board insulation. (f) Extruded grid drainage net.



(g)

(h)

Figure 13-10 (contd.): Plaza deck components (g) Molded-sheet drainage panel. (h) Sheet membrane.

13.4.6 Waterproofing membrane

Waterproofing membranes are discussed in Section 13.3.

13.4.7 Structural Slab

The structural slab supports the plaza deck system. The membrane is directly adhered to the surface. The slab surface must be properly textured and cleaned for the membrane to adhere to the prepared surface (see Figure 13-11). Also, the temperature and the moisture content of the substrate must be properly monitored during application of the membrane. It is best to follow the membrane manufacturer's recommendations for the membrane application, since each material has its own limitations and requirements.

With respect to restoration work, the substrate has to be patched or repaired prior to membrane application. The membrane must always be placed on a sound substrate. If for some reason the underlying structural slab is chloride contaminated (by road salt), the life expectancy of the plaza deck system may be limited by the continuing corrosion of the embedded reinforcement in the structural slab. Refer to Chapters 19 and 20 for discussion of chloride contamination and life expectancy of repairs. Also, refer to the following section on structural considerations in this Chapter for other plaza deck design related design elements.

Figure 13-11: Surface preparation is required prior to membrane application.

13.5 PLAZA DECK SYSTEM DESIGN CONSIDERATIONS

A plaza deck system should be designed to remove water and moisture efficiently to reduce the potential for water leakage. Also, the plaza deck wearing surface should be durable to protect the waterproofing membrane that collects the water below the surface level. The design service life of a plaza deck can range from 10 to 30 years. Since the waterproofing membrane is protected from UV exposure and traffic abrasion, a membrane can be selected that will provide a service life of more than 25 years. The service life of all the individual components within the plaza deck must be matched to provide the desired service life for the entire system. It is important not to have a weak link in the plaza deck that will limit the service life of the entire system. The essential design considerations that will reduce the potential for plaza deck performance problems relate to the following issues:

- Selection of the plaza deck components, including the wearing surface
- Drainage
- Slope
- Membrane continuity
- Characteristics of the floor slab structural system
- Temperature and movements
- Special membrane details

13.5.1 Wearing Surfaces

The most common wearing surface in parking applications is a concrete slab. The primary cause of premature concrete wearing surface deterioration is lack of adequate air-entertainment (see Figure 13-12), thermal movements and concrete shrinkage. Give due consideration to the following:

- Properly air-entrained concrete to resist freezing and thawing.
- A good quality concrete with a low water-cement ratio and high compressive strength. Specify a minimum concrete compressive strength of 5000 psi. with water-cement ratio of 0.45 or less, so that the concrete is more durable and can resist traffic abrasion more effectively.
- Provide adequate control joints to reduce cracking due to shrinkage. For instance, limit control joints spacing to maximum of about 7-ft for a 3-in thick concrete slab. Also, focus on the concrete mix design to reduce shrinkage.
- Provide adequate isolation joints. The wearing surface is subjected to extreme temperature variations that can result in significant horizontal movements. Provide isolation joints along the perimeter of the structure and at about every 50 ft of the slab surface. Terminate slab reinforcement appropriately at control and construction joints.
- The thermal and volume change movements of the wearing surface will generally require the use of slip-sheet (bond breaker) just below the wearing slab. The slip-joint will also help to reduce slab cracking. Refer to Section 13.4.2 for discussion of the horizontal slip plane.
- Slope the wearing slab to drain the surface moisture quickly. A desired slope is ¼-in per foot and limits the minimum to 3/16-in per foot.

Asphaltic and mastic overlays tend to deteriorate when exposed directly or indirectly to the sun. The life expectancy of asphalt and mastic membrane is about 10 to 15 years and will require reapplication during the service life of the plaza deck (see Figures 13-10(a) and 13-13). These systems generally do not have the built-in drainage course component and tend to be less expensive.

Brick and concrete pavers are generally used only for pedestrian traffic. These pavers are also susceptible to freeze- thaw deterioration (see Figure 13-10 (b)). The pavers require a setting bed and a drainage course that will quickly remove the moisture away from the pavers.

Figure 13-12: Deteriorated cast-in-place concrete slab due to lack of adequate air entrainment and poor drainage.

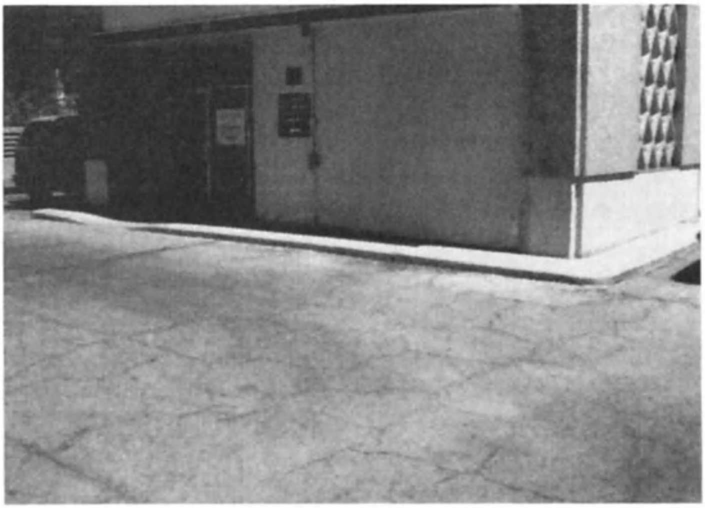


Figure 13-13: Protected membrane with asphalt overlay that needs replacement. The asphalt is extensively cracked and deteriorated by natural weathering.

13.5.2 Drainage and Slope

Many of the plaza deck performance problems can be attributed to inadequate drainage. Poor drainage will adversely affect the service life of a plaza deck system. As discussed in Section 13.4.3, plaza deck drainage considerations should address the need to drain the surface moisture, as well as the moisture that filters through the plaza deck system and collects on top of the membrane. The membrane is designed to function as a barrier, and the water at this point has to be drained effectively. The drains in turn must be equipped with 'weep holes' below the surface level to drain the water away from the membrane (see Figure 13-14). These drain basins are perhaps the most critical feature of the plaza deck system and consist of a two-stage drain assembly. The first stage of the drain basin removes the subsurface moisture at the membrane level, and the second stage removes moisture from the wearing surface through the exposed upper grates.

It is necessary to slope the sub surface drainage layer to drain the water that collects on the membrane. A slope of ¼-in per foot is ideal for the drainage course. Also, try to maintain an absolute minimum slope of 3/16-in per ft. This is an essential requirement. Do not try to compromise on the slope. Some of the performance problems related to poor sub surface drainage and water ponding on the membrane include:

- Premature deterioration of the surfacing material. This deterioration can cause the surfacing material to be saturated and then damaged by freezing and thawing.
- Horizontal displacement or vertical faulting of the surfacing material. Heaving due to frost action will displace the surfacing material that can lead to trip hazards.
- Premature failure of the waterproofing membrane. The wetting and drying, prolonged ponding, and freezing and thawing will reduce the service life of the membrane itself.
- Water leakage due to membrane failures at penetration, transitions, joints and cracks. Ponding increases the potential and frequency of water leaks.

Many plaza deck performance problems can be attributed to lack of an understanding to provide for sub-surface drainage. A common misconception is that the sub-surface drainage can be eliminated if the all the joints in the wearing course are sealed. Although this effort to seal the joints will reduce the amount of water getting down to the membrane, it is virtually impossible to eliminate it. More often, sufficient water will get through to the membrane to cause serious performance problems.

Another poor assumption is that, it will suffice to provide effective slope for the wearing surface to drain all the moisture at the surface level. Based on

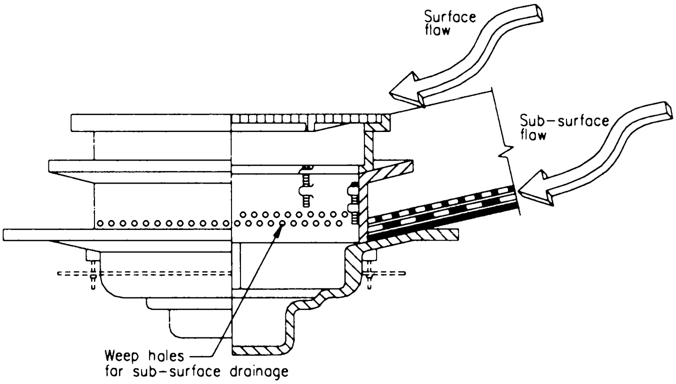


Figure 13-14: Two stage drain assembly is a very critical feature of the plaza deck system

this misconception, the slope for the sub-surface drainage is neglected. Although effective surface drainage is helpful, it cannot remove all the moisture. Without an effective slope for the drainage course, the sub-surface water will pond at the membrane and lead to serious performance problems.

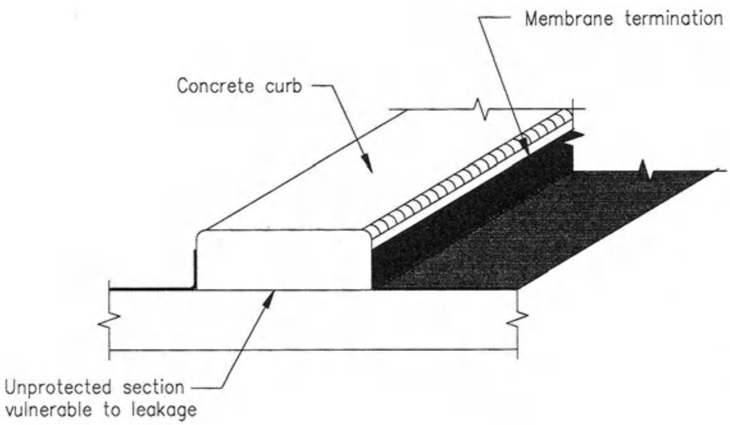
There are some instances when the selection process for the waterproofing leads to a plaza deck system without a drainage course. If the volume of moisture is very small, such as for a covered area, the drainage course could be eliminated. The situation is very similar for a structure located in an arid climate. Some of the design considerations for a protected membrane system without a drainage course are as follows:

- Good slopes (> ¼ -in per ft.) for the wearing surface as well as the structural slab.
- Two stage drainage basin with weep holes for sub-surface drainage.
- Porous wearing course that will permit water at the membrane level to eventually percolate to the drains.
- The wearing course is not bonded to the membrane. A slip-sheet between the membrane and the wearing course will provide a way for the sub-surface moisture to get to the drains.

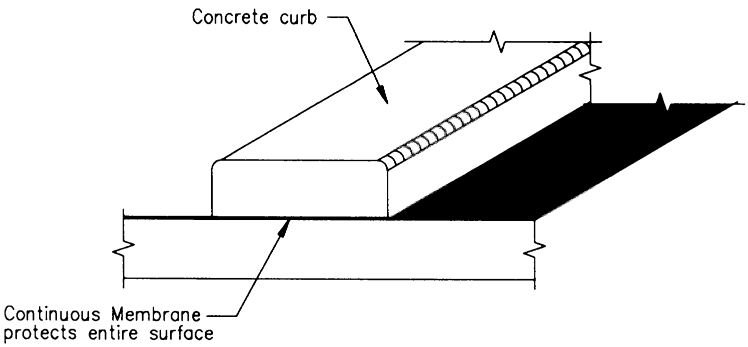
13.5.3 Membrane continuity

The membrane waterproofing must be placed continuously over the entire horizontal plane that is to be protected. A plaza deck surface may be interrupted by many features such as walls, curbs, islands, planters, etc. that protrude from the structural slab onto the surface above. These protrusions tend to interrupt the plaza deck waterproofing system. The plaza deck system must be designed giving due consideration to these elements. Most importantly, these protrusions should not disrupt the continuity of the underlying waterproofing membrane. The surface areas not covered by the membrane tend to become sources of potential performance problems (see Figure 13-15). In addition, membrane terminations and transitions become potential sources of water leakage,

Although this is a very simple concept, this basic rule is often lost during the development of the design documents. All kinds of reasons and arguments are presented to disregard this fundamental rule of waterproofing. Just remember that, inevitably, there is much more to lose and very little, if anything, to gain by violating this rule.



(a)



(b)

Figure 13-15: Membrane continuity is important to avoid plaza deck performance problems: (a) Discontinuous. (b) Continuous.

13.5.4 Structural characteristics

Plaza deck systems can be installed on all types of floor slab systems. It is necessary to recognize the characteristics that will affect the performance of the plaza deck system with each of the structural systems. Some floors slabs are relatively more flexible than others and will deflect more under live and dead load application. These relatively flexible structures include concrete two-way flat slab, pan-joists, precast prestressed elements, structural steel, truss and bar-joist floor slab systems. Cast-in-place post-tensioned structures do not deflect as much under load application.

The important structural system deflection characteristics are as follows:

- Deflection under dead and live loads. Due consideration should be given to introducing horizontal slip planes between the individual components of the plaza deck in relatively flexible structures. The movement of the plaza deck elements above the membrane may damage it.
- Differential deflections or movement between adjacent members or structural systems.
- Impact on the drainage profile due to structural member deflections. Heavy dead loads such as soils, planters and pools on a plaza deck can alter the floor slab drainage profile. The drainage profile needs to be checked for instantaneous as well as long-term deflections. The long-term deflections can be two to three times the instantaneous deflection. These large deflections can very easily alter the originally designed drainage profile and

can then lead to sub-surface ponding and plaza deck performance problems.

13.5.5 Temperature and movements

The components of the plaza deck element can experience differential movements under service conditions. This differential movement can damage the underlying membrane. Also, the plaza deck wearing surface will undergo large thermal movements since it is directly exposed to the elements. Some of the considerations related to thermal movements are included in Sections 13.4.2 and 13.5.1.

13.5.6 Special Membrane Details

Special membrane details are necessary to address conditions that require more attention and additional treatment. These conditions are generally the primary avenues for potential sources of water leakage through the plaza deck membrane. If the moisture gets beneath the membrane, it can undermine the effectiveness of the entire plaza deck system. Selected samples for some of these special conditions are shown in Figures 13-16 through 13-20. Most membrane manufacturers provide guidance and details for these special conditions. Special details are required for the following conditions:

- Terminations
- Transitions
- Penetrations
- Cracks and joints

13.5.6.1 Terminations

The membrane has to be terminated at the boundaries of the area that is protected by the plaza deck system. Some of the basic considerations for developing the termination details include:

- Extend the membrane beyond the limits of the boundary.
- Terminate at the high points of the structure so that the membrane is sloped away from the termination point.
- Provide flashing or pressure strips at terminations.

- Provide membrane continuity with flashing of intersecting vertical elements.

13.5.6.2 Transitions

Transitions are horizontal to vertical membrane applications. Transitions represent membrane discontinuities. These discontinuities must be avoided within the boundary of the area that is to be protected. However, transitions are very commonly seen at termination points of the membrane. The transitions are high stress points, and membrane failure can easily occur at these locations. Considerations that go into development of transition detail include the following:

- Increase membrane thickness and fabric or other form of membrane reinforcement, when possible.
- Provide a fillet at the corner to smooth out the transition.
- Slope membrane away from the transition.

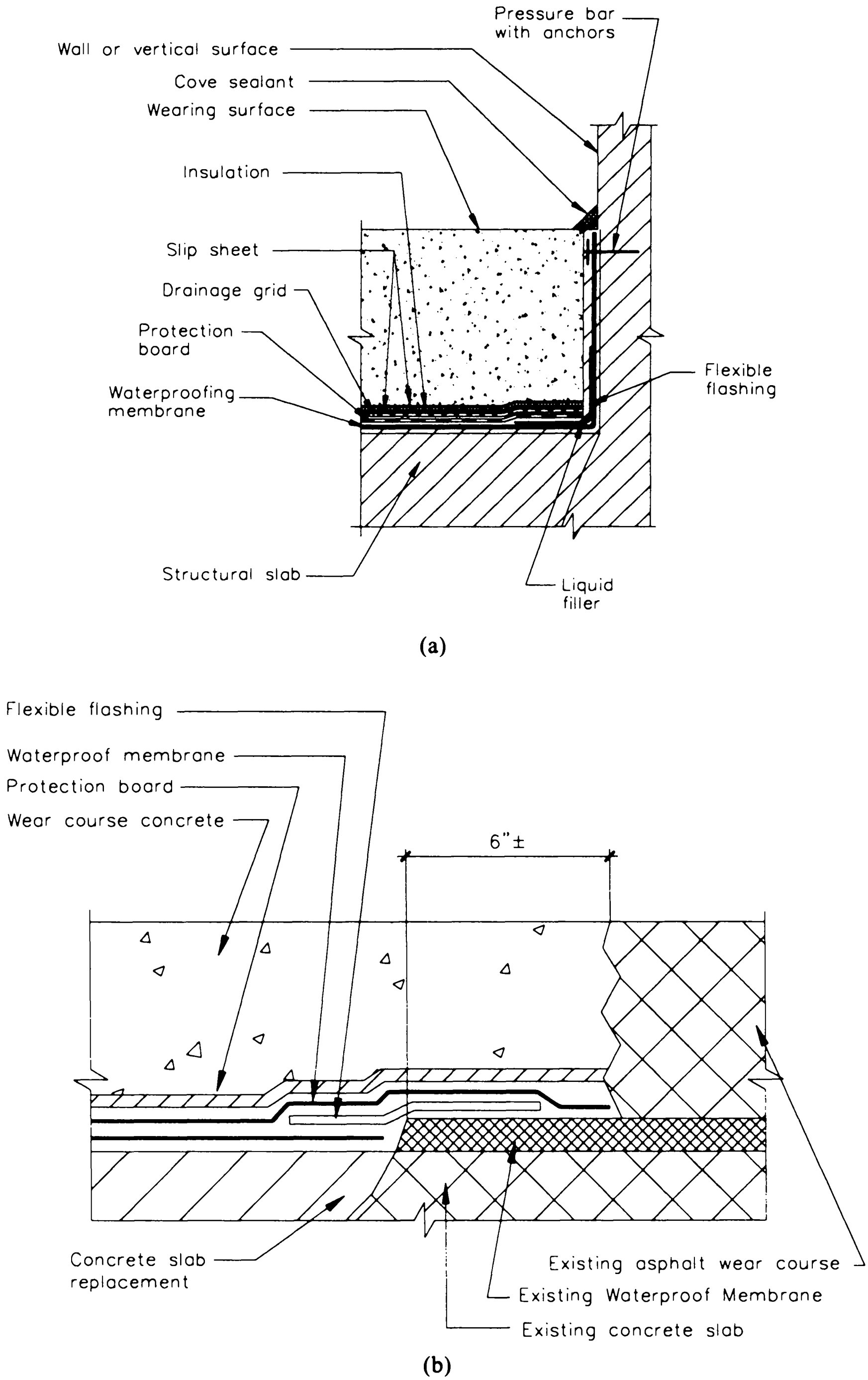


Figure 13-16: **Membrane termination (a) At exterior perimeter. (b) At existing bituminous concrete.**

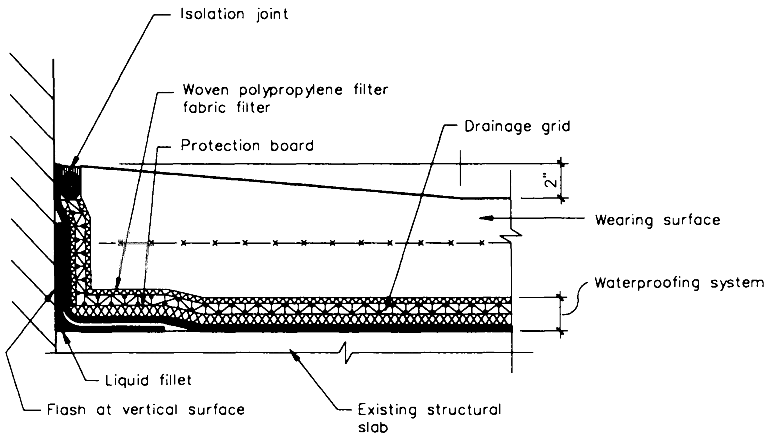


Figure 13-17: Transition detail.

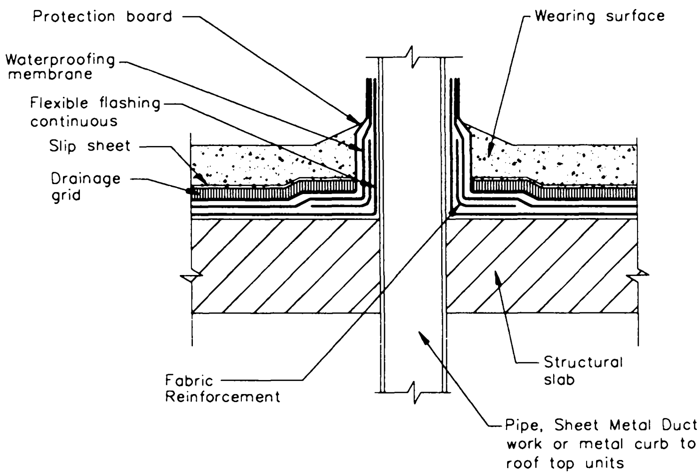


Figure 13-18: Penetration detail.

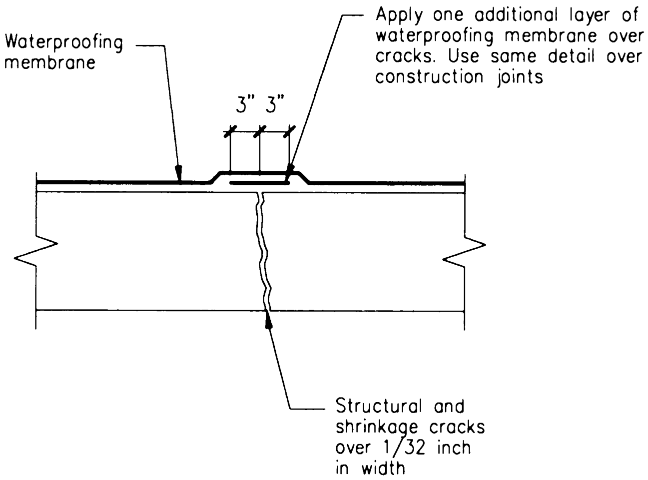


Figure 13-19: Crack treatment detail.

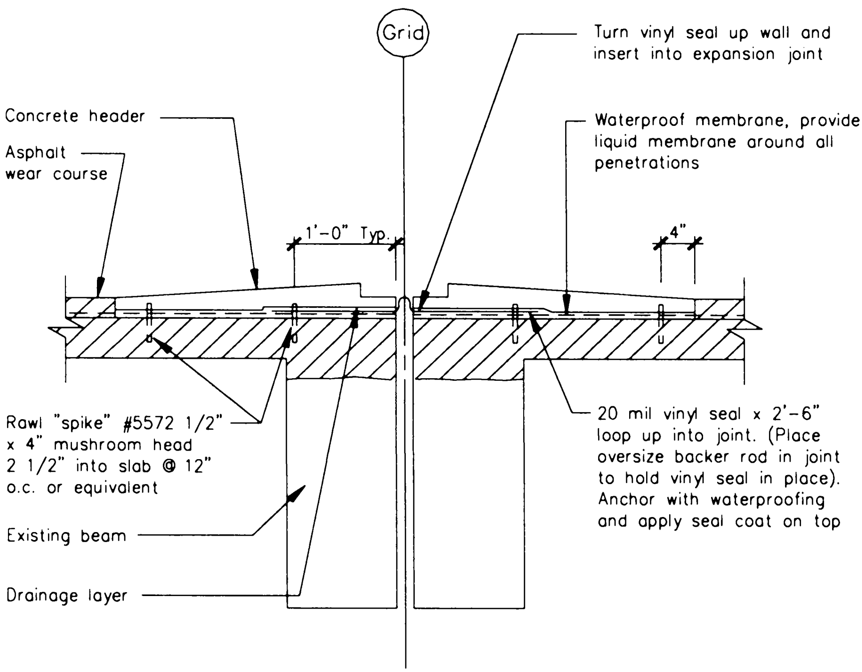


Figure 13-20: Expansion joint detail.

13.5.6.3 Penetrations

Penetrations are very similar to transitions. Every penetration also requires the membrane to be terminated. The basic considerations for detailing the penetrations are covered in the Sections above related to membrane terminations and transitions.

13.5.6.4 Cracks and Joints

Cracks and joints in the structural slab require special attention to avoid membrane failures. The membrane is stretched and stressed at cracks and joints due to vertical and horizontal movements. If the membrane is overstressed then the membrane will fail and cause water to leak through.

Expansion joints tend to experience the most movement and the most problems. Conversely, construction and isolation joints do not experience as much movement. For joints with little or no movement, the detailing considerations for the membrane are similar to that discussed for the transition and termination.

The basic consideration for treatment of cracks and joints in the structural slab are as follows:

- Increase membrane thickness and strengthen with additional membrane reinforcement, when possible.
- Slope the membrane away from isolation and expansion joints.
- Maintain membrane continuity through expansion joints.

13.6 SUMMARY

Plaza deck systems are expensive to build and extreme care and consideration must be given to reduce the potential for performance problems. Properly designed, detailed, and built, plaza deck systems will provide a long service life with little maintenance. However, there are some very basic practices that must be followed. Poor attention to these practices will result in reduced service life and premature failures. It is very disruptive and costly to repair plaza decks. Quite often, removal and replacement is the only cost-effective remedy.

CHAPTER 14

SEISMIC DESIGN

Mohammad Iqbal

14.1 INTRODUCTION

The subject of seismic design can easily fill several volumes. Wind and seismic loads have been the topics of countless research projects, and complete texts deal with the calculation of these loads. Interest in the design for earthquake effects has increased substantially in the light of experience obtained in the San Fernando earthquake of 1971 and other recent earthquakes. A great deal of time and effort has gone into the development of better methods of design. This result is a greater knowledge of earthquakes in conjunction with a better understanding of the forces they exert on buildings. New concepts have been developed concerning the earthquake resistance of buildings as determined by their ability to absorb the energy input from ground motion.

In design for seismic effects, the primary concern is safety of the occupants. A secondary concern is economics. The current philosophy is to prevent non-structural damage in minor earthquakes; allow some repairable damage in moderate earthquakes; and prevent total collapse in major earthquakes. References 1 through 3 provide extensive bibliographies of the design and research studies done to date, and state-of-the-art design methodologies. References 4 through 9 are some of the codes, commentaries and design aids available for structural design of building and parking facilities located in seismic regions of various risks. This chapter briefly summarizes basic concepts of seismic design and reviews design considerations as applicable to the design of parking facilities.

Earthquakes cause loss of life and property. The earthquakes that struck in Turkey and Taiwan in 1999 left extensive destruction. Tragically, the human cost was enormous. Tens of thousands of people were killed in both earthquakes. In fact, it is estimated that as many as 45,000 people may have lost their lives in the Kocaeli, Turkey, quake. No one knows for certain where the next earthquake will occur or how big it will be, but it is well

A. P. Chrest et al., *Parking Structures*

known that several parts of the United States, such as California, are prone to an earthquake and the resulting damage. For example, in the 1994 Northridge earthquake, several parking facilities were destroyed or suffered disproportionately heavy damage.[10] A sample of such damage is shown in Figures 14-1 through 14-4. It is therefore important that the parking facility structural designer understands the nature and causes of the earthquakes and building response to the earthquake or seismic waves.

An earthquake originates on a plane of weakness or a fracture in the earth's crust, termed a "fault". Faults vary in length, direction, origin, formation and activity. Maps of known active faults near source zones have been documented.[11, 12] Slippage along the fault occurs suddenly. It is a release of stress that has gradually built up in the earth's crust. Although the vibrational movement of the earth during an earthquake is in all directions, the horizontal components are of primary importance to structural engineers. Because the ground motion in an earthquake is vibratory, the acceleration and force exerted on a structure reverses direction periodically, at short intervals. An example is shown in Figure 14-5.

14.2 CAUSES OF STRUCTURAL FAILURE

Earthquake engineering is experience-driven. Certain structural design concepts that work well in non-seismic areas perform poorly when subjected to earthquake motions. Earthquakes reveal the shortcomings and deficiencies in the design. We learn what earthquakes can do, and we can study their engineering effects.

Based on experience derived from observation of structural collapses caused by prior earthquakes around the globe, engineers have been able to determine the causes of structural failures. The observed causes of collapse in reinforced concrete structures applicable to parking facilities in high seismic regions are:

a. Poor or incomplete load path
b. Strong beams and weak columns
c. Soft (weak) first stories
d. Poor layout of structural walls
e. Inadequate spacing between adjacent structures
f. Column shear failures
g. Inadequate confinement of column core
h. Biaxial loading, particularly at corner columns
i. Failure of beams and beam-columns connections
j. Failures of structural walls

The first item is particularly applicable to precast concrete construction where a major issue is proper connections between the various components of the structure in order to establish a load path from the floor masses to the foundation. There are numerous examples of failures of precast and tilt-up construction during the Northridge earthquake, due to inadequate connections between the different components of the structure.[2, 10]

(a)

(b)

Figure 14-1: CSU parking facility, Northridge, California collapsed as the diaphragm caved in. (Photographs by S. K. Ghosh and Associates, inc.)

Figure 14-2: Complete collapse of a 3-story precast parking facility, Northridge, CA.
(Photographs by S. K. Ghosh and Associates, inc.)

Figure 14-3: Complete collapse of a 3-story post-tensioned parking facility, Northridge, CA.
(Photographs by S. K. Ghosh and Associates, inc.)

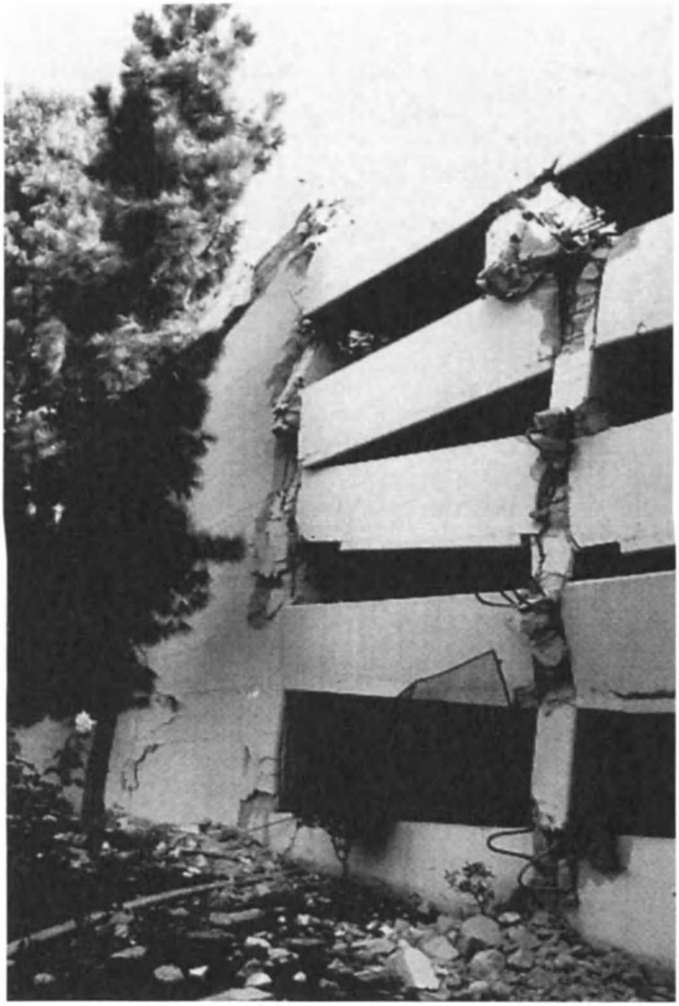


Figure 14-4: Complete collapse of a 3-story cast-in-place reinforced concrete parking facility due to lack of confinement reinforcement in columns. (Photographs by S. K. Ghosh and Associates, inc.)

Diaphragm flexibility and the transfer of diaphragm forces to the lateral-force-resisting system were two major problems with precast parking structures that suffered partial or total collapse during the 1994 Northridge earthquake.[2] As shown in Figure 14-2, the shearwall in the background remained virtually undamaged while the structure collapsed due to inadequate diaphragm connections between the diaphragm components, as well as the connections between the diaphragm and the shearwall.

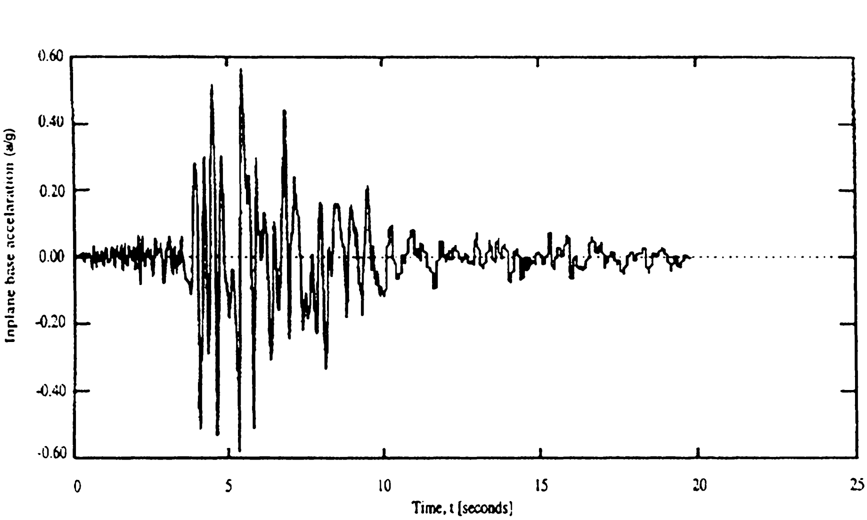


Figure 14-5: Newhall East-West Component of Base Acceleration for the Northridge Earthquake

14.3 CODE DESIGN PHILOSOPHY

In designing a structure to withstand earthquake forces, there are two basic options:

1. Make the structural resistance high so that the structure will remain elastic, or
2. Permit the structure to deform inelastically while insuring adequate ductility and energy absorption capacity.

For the latter, the structure can be designed for a considerably lower force than would be required for the former. Because it is typically uneconomical to design a structure to resist a major earthquake elastically, building codes require lower lateral forces by implying that the structure would be able to deform inelastically, exhibiting ductility. Although code seismic coefficients have undergone a series of major revisions in the last thirty years, the code philosophy has remained unchanged.[13,14] With this philosophy, the primary concern in design is whether or not the structure will have adequate ductility and energy dissipation capacity during a strong ground motion.

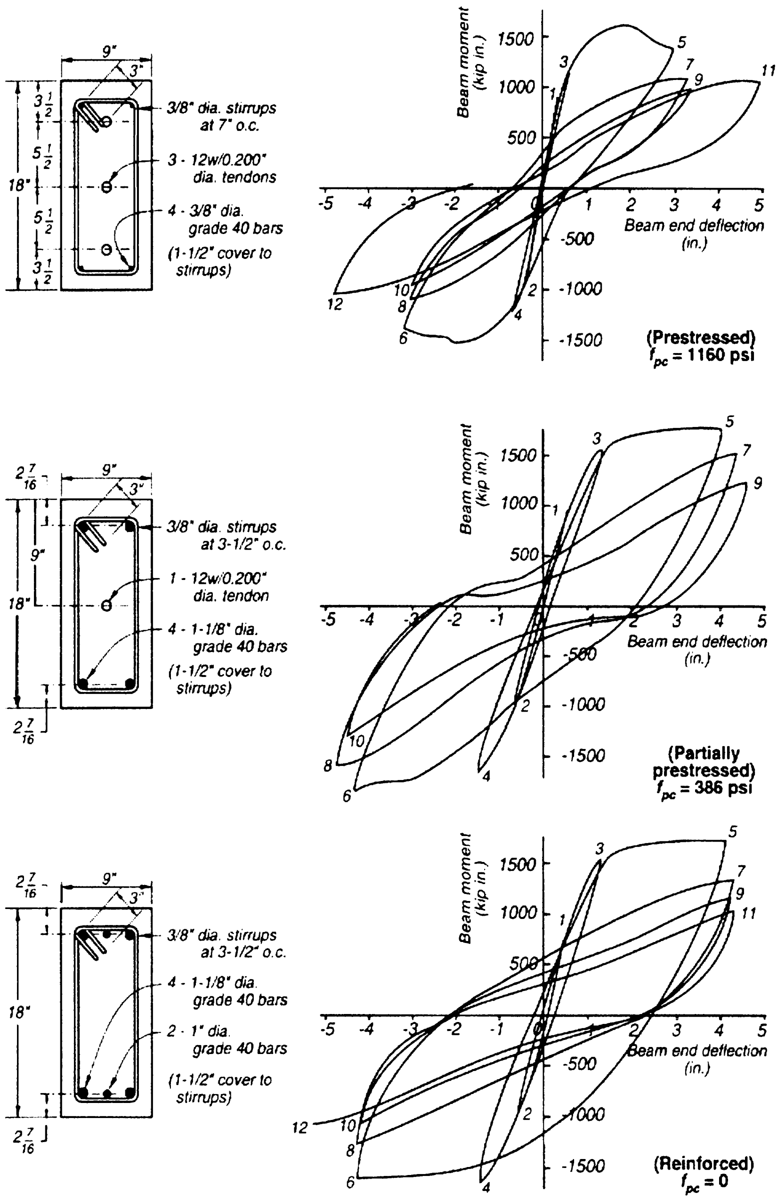
Ductility is important in seismic design because it allows the structure to redistribute forces, insuring a gradual rather than a brittle failure. Thus, ductile behavior provides a warning to occupants before collapse. Factors affecting ductility include the yield strength of reinforcing steel, longitudinal reinforcement index, transverse reinforcement, concrete strength, concrete core confinement and shear stresses on the section.[15-19]

In the case of prestressed and post-tensioned structures such as parking facilities, the effects of anchorage, bond, transfer lengths, grouting, characteristics of high prestressing steels and level of prestressing are additional parameters affecting ductility. Since prestressing steel does not have a definite yield point, there has not been a consistent definition of yield deformation and associated ductility.[20] Traditionally, codes have insisted on the use of ductile non-prestressed steel as the sole reinforcement and have not permitted the use of prestressing steel in ductile moment frames.[4] This requirement is because the prestressing may result in component hysteresis that is markedly different from that for non-prestressed reinforced concrete components. Figure 14-6 shows results of tests performed on reinforced and prestressed beams. In this study, three concrete beam types were tested: reinforced, partially prestressed and fully prestressed. The beam cross-section was kept constant and amount of prestressing was varied from zero to high. In the partially prestressed and fully prestressed beams, the reinforcement was so proportioned that all three beam types would develop similar strength. See Fig. 14-6 for reinforcement patterns. The test results show that the energy dissipation (area enclosed within the force-deformation hysteresis loops) of prestressed concrete beams is lower than that of reinforced concrete beams designed to develop similar strengths. However, between the two types of beams, the partially prestressed members showed a marked improvement over the fully prestressed beams. Based on the test studies, the National Earthquake Hazard Reduction Program (NEHRP) issued provisions stipulating that a prestressed concrete beam behaves in a manner equivalent to a non-prestressed beam when certain conditions are satisfied.[4]

14.4 LATERAL LOAD-RESISTING COMPONENTS

The purpose of the parking facility structural system is to carry all loads safely to the foundation, to prevent excessive deflections and vibrations, and to ensure the comfort and safety of the users and occupants as stipulated in the governing building code. Structural systems can be made up of one or more basic components or sub-systems.

The structural system consists of horizontal or sloping floors and vertical elements that perform the dual function of resisting gravity and lateral forces on the structure. As such, the elements and subsystem contributing to seismic or wind load resistance are termed a lateral load-resisting system. This section describes some commonly used components and subsystems that comprise lateral load-resisting systems employed in modern parking facilities.



Sample Load-Deformation Relations for Prestressed, Partially-Prestressed, and Reinforced Beams

Figure 14-6: Effect of Prestressing on Ductility

14.4.1 DIAPHRAGMS

While the primary function of the floor and ramp system is to resist gravity loading, it may perform two additional functions:

1. The floor system usually provides the in-plane stiffness required in order to maintain the plan shape of the structure, and distributes horizontal forces to the vertical load carrying system.
2. It provides the flexural stiffness that is an integral and necessary part of the lateral load-resisting system.

Floor systems that can perform the two functions are called diaphragms. Parking structures are commonly analyzed for lateral loads by assuming that the floor system acts as a diaphragm, infinitely stiff in its own plane, which distributes horizontal forces to the lateral load-resisting elements. Whether or not a diaphragm can be assumed to be rigid depends on several factors, such as span-to-depth ratio of the slab plan dimensions relative to the location of the lateral load-resisting elements, slab thickness, locations of openings and discontinuities in the slab, and the type of floor system used. This assumption is not valid for all configurations and geometries of floor systems. This situation occurs because analyses taking into account the floor system in-plane flexibility show a very different distribution of horizontal forces among the various elastic lateral resisting elements than that obtained using a structural model that assumes the floor rigid.[21]

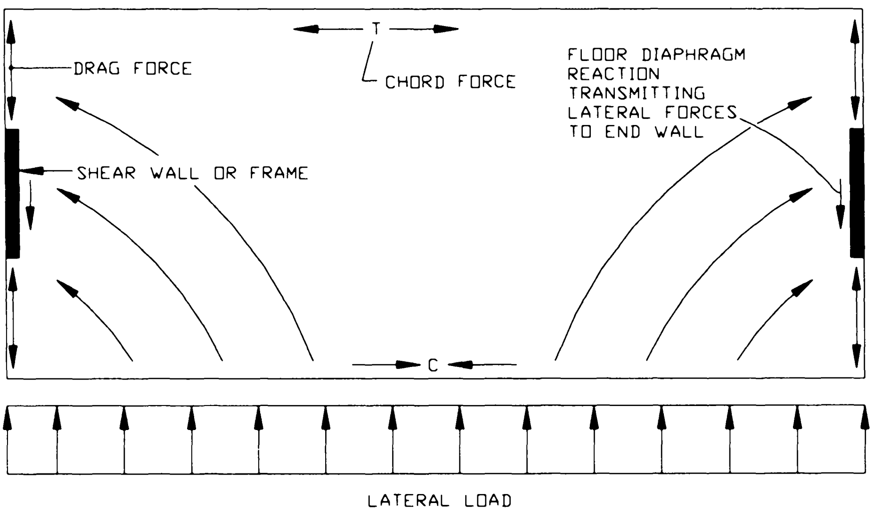


Figure 14-7: Diaphragm Action

A diaphragm may be regarded as a horizontal beam with unique features. As shown in Figure 14-7, it acts like a beam composed of web and flange elements. The web, or shear-resisting element, is provided by the floor system. The chord or boundary members serve as flanges to resist the axial tension or compression resulting from flexural action due to lateral forces. Also like a beam, it transfers horizontal (in plane or web) loads to its supports (vertical load-carrying elements). Drag or collector members are added to a diaphragm along lines where vertical bracing elements exist for a portion of the diaphragm length. The purpose of a collector member is to collect shear from the diaphragm shear web and drag or transfer that shear to the vertical bracing element.

The diaphragm may function as a very stiff element, a very flexible element or somewhere between, depending upon its physical properties and those of the vertical load-carrying system. Therefore, it is necessary to determine the diaphragm deflection relative to the deflection of the associated lateral-load-resisting elements. Likewise, knowledge of diaphragm total drift is necessary to achieve drift control and reduce damage potential.

Deformations of the lateral load-resisting elements also affect those parts of the structure that have not been designed to contribute to lateral load resistance. This is important in the design of facilities located in high seismic zones, particularly when the designer assumes ductility of the lateral load-resisting system. A structure designed to respond inelastically under severe design conditions could experience considerably higher lateral drift than that corresponding to elastic response. A floor system designed to remain elastic in this situation must be designed to accommodate the expected ground motions.[4] The designer must check that the ramp or floor slabs and vertical load-carrying elements can tolerate the out-of-plane deformations associated with several times the lateral deflection calculated for the design forces.[21,22]

The chord and drag reinforcement is required to transfer diaphragm forces into the lateral load resisting system. The development of chord and collector or drag reinforcement is a critical detailing requirement. Horizontal chord and collector reinforcement in the diaphragms must be carried far enough into the lateral force resisting elements to resist the drag force. Furthermore, the reinforcement must be continued beyond that section for a distance equal to its tension development length. Alternatively, a mechanical anchorage must be provided that is capable of developing the strength of the reinforcement without damage to the concrete.

When a parking structure has one or more sloping ramps, the diaphragm can be divided into several sub-diaphragms. As shown in Figure 14-8, the diaphragm consists of three sub-diaphragms for the lateral load in the direction shown. Each sub-diaphragm should be designed separately so that it can resist its share of the load. The Uniform Building Code (UBC 1997) approach to designing floor diaphragms is quite simple.[4] A step-by-step procedure is described in several texts such as references 7, 8, 9, 23,24,and 25.

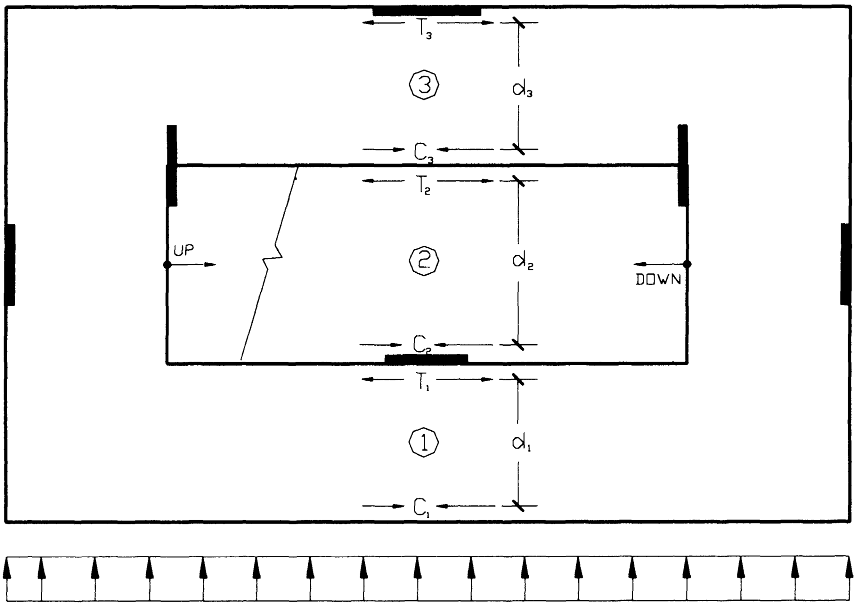


Figure 14-8: Sub-diaphragms in a Parking facility

14.5 FLOOR AND RAMP SYSTEMS

Selection of the floor system significantly affects a structure's cost, durability and performance of its lateral load-resisting system. Several floor and ramp systems may be used. A brief summary of commonly used systems in modern parking facilities is described below.

14.5.1 One-way Slabs on Beams and Girders

This common system consists of one-way slabs on beams and girders. The one-way slabs are supported on the beams. The beams are supported either on columns or on girders that, in turn, are supported on columns. In general, slabs, beams and girders are post-tensioned concrete. This system provides a satisfactory shear diaphragm, and is suitable for use in facilities located in all seismic zones. The diaphragm is assumed to be rigid or very stiff. Adequate flexural ductility can be obtained by proper detailing of the edge beam, curb or girder reinforcement. The designer must carefully examine the tension and compression forces in the diaphragm caused by lateral forces, acting in conjunction with the vertical loads.

14.5.2 Precast Double-Tees

Precast double-tees are commonly used as a one-way system supported on precast beams, precast bearing walls, or cast-in-place beams. Welded connections are normally used to transfer in-plane shear forces between the double-tee precast units and their supports. Because precast double-tees are individual units interconnected mechanically, the ability of the assembled floor system to act as a shear diaphragm is affected by connections between double-tees. The designer must critically examine such connections. Boundary reinforcement is generally required, particularly when the lateral load-resisting elements are far apart.

A concrete topping bonded to the precast double-tee flanges improves the ability of the slab system to act as a shear diaphragm, and is required in high seismic areas.[23]

14.5.3 Two-way Slab Systems

The two-way slab system is generally used in multi-use facilities where parking is located in the lower floors and the column spacing from the upper floors is carried through the parking floors. The two-way floor system may consist of cast-in-place concrete flat plates, flat slabs or waffle slabs. Two-way systems may be with or without column capitals, drop panels, or edge beams. Two-way systems may be of reinforced concrete or of post-tensioned concrete. Because of the relative thickness of the slab and distribution of reinforcement, this system normally works well as a diaphragm. Although the flat slab and supporting columns are not always considered by design engineers as a part of the lateral load-resisting system, their contribution to stiffness and strength can be significant. Further, ignoring this contribution may give rise to an overstress at the slab-column joints. Given proper attention to proportioning and detailing, flat slab or flat plate frames can have considerable ductility and strength. However, lateral load-resisting systems consisting only of flat slab or flat plate frames, without ductile frames, structural walls or other bracing elements, are not permitted in areas of high seismic risks.[4, 26]

Composite Beam and Slab Systems

This floor system consists of a one-way cast-in-place slab system supported on beams or joists. The slabs are generally post-tensioned. Shear connectors are incorporated at the beam or joist-slab interface to ensure composite action. Two commonly used examples of this type of slab system are:

1. Steel beams supporting a cast-in-place reinforced or post-tensioned concrete slab, using steel shear connectors at the beam top flanges.
2. Precast concrete beams or joists with steel shear stirrups between the top of the beams or joists and a cast-in-place concrete slab. The concrete beams or joists are normally designed to support temporary formwork for the cast-in-place slab. In this system, the beams or joists are supported on walls or columns.

This floor system provides a good diaphragm action, provided that the connections are carefully detailed for sufficient strength, stiffness and structural integrity during strong ground motion.

14.6 RAMP TRUSSES

In a continuous ramped parking structure where floors slope and form a truss, the lateral resistance can be achieved by truss action. As shown in Figure 14-9, the sloping ramp acts as a diagonal or web member and the columns act as chord members. A well-defined load path is required to properly transfer the load to the underlying ground. In this regard, it is essential that the sloping ramps be connected at the lowest extremity of the structure, by proper detailing, to transfer the load to the underlying ground base.[28,29]

Such truss action can be helpful when specifically designed to carry lateral forces to the ground. However, care should be taken so that it does not cause an unanticipated volume change restraint. Truss action cannot occur if the ramp is interrupted by an expansion joint.

14.7 MOMENT FRAMES

A frame consists of vertical column elements and the foundations to which columns are connected, horizontal beam elements, and connections between the beams and column. The term "moment frame" or "frame" also denotes a rigid-jointed structure that resists gravity and lateral loads through the flexural and axial strength of beams and columns.

Frames can be concrete or steel. Each material offers its own advantages and disadvantages in terms of strength, stiffness and ductility. Steel frames can be classified either as moment frames or braced frames. Due to the tremendous popularity of concrete frames, the discussion in this section is limited to concrete frames. The concrete frames employed in modern parking facilities are generally classified into the following categories:

1. Cast-in-place (CIP) reinforced concrete frames
2. CIP Post-tensioned concrete frames
3. Precast concrete frames

In a moment frame structure, lateral displacement consists of two parts: bending of the columns and beams along with local joint deformations and axial deformations of the columns. The effect of column axial deformations is normally quite small in parking facilities due to the low height-to-width ratio of the structure. Lateral drifts may be significantly increased by foundation deformations, yielding in the frame members, and P-Δ effects. The P-Δ effects in a given story are due to the horizontal offset or eccentricity of the gravity load above that story. Referring to Figure 14-10, if Δ is the story drift due to lateral forces, the bending moments in the story would be augmented by an amount equal to Δ times the gravity load above the story. This P-Δ effect must be considered in the evaluation of overall structural frame stability.

When constructing a mathematical model of the structure, note that the amount of drift in a lateral force analysis is very sensitive to the assumptions made for the stiffness of the force resisting elements. When the stiffness is overestimated, the period of the vibration shortens and the displacements reduce. However, a shorter period may possibly attract higher forces and may increase the member sizes. When the stiffness is underestimated, the fundamental period lengthens, lateral displacements increase, and lateral forces may be reduced. Therefore, it is recommended that several mathematical models be used in the lateral force analysis. As a first step, gross section properties are considered appropriate for modeling the stiffness of reinforced concrete members. This model must also include the effects of accidental eccentricity and diaphragm rotation. The second mathematical model, assuming cracked section properties, is used to determine the maximum drift of the reinforced concrete parking structure.

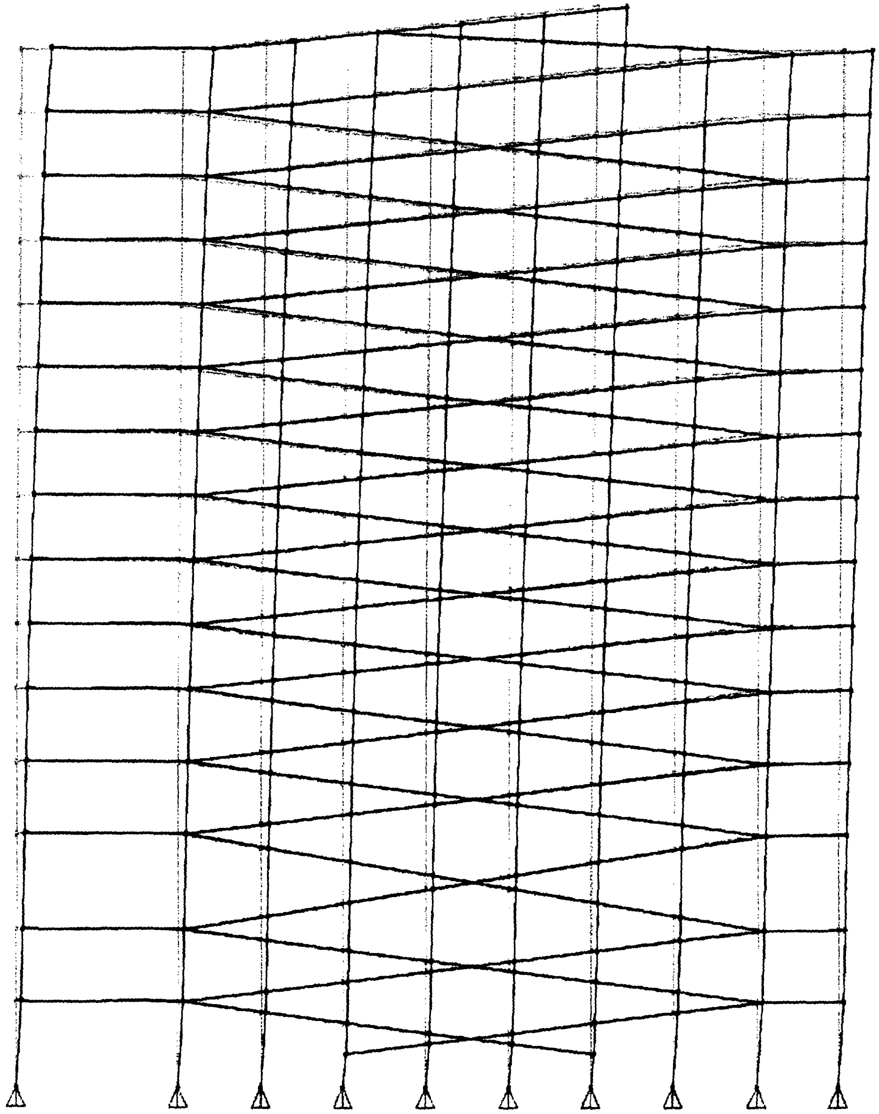


Figure 14-9: Ramp Truss Action

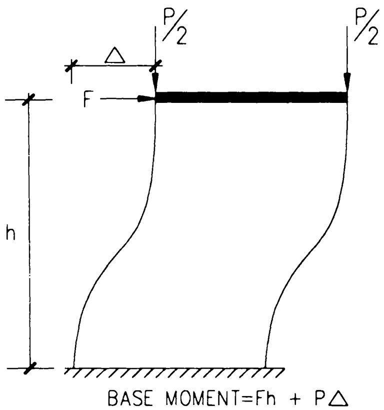


Figure 14-10: P-Δ effects in frame

Because the ductility demand depends on the seismic risk at the site, not all systems qualify in all seismic zones. Based on its ductility capacity, concrete moment frames are categorized as:

1. Ordinary moment frames
2. Intermediate moment frames
3. Frames not part of lateral load resisting system
4. Special or ductile moment frames

The design of all frames except the ductile frame is quite straightforward. Some design aspects of ductile frame are discussed below.

14.7.1 Ductile Moment Frames

Ductile moment frames are invariably of reinforced concrete with non-prestressed ASTM A-706 steel reinforcement. Other grade 60 steel reinforcement, high strength prestressing strands or tendons are not allowed. Beam elements do not have significant axial loads, and hence are designed for flexure and shear. However, special transverse reinforcement is required at beam-ends to permit plastic hinges to form there. Column elements are designed for a combination of axial load, bending moment and shear. If the columns are made stronger than the beams, yielding will tend to occur in the beams, ideally resulting in a beam sway mechanism in which beams yield throughout the structural height. On the other hand, if the columns were weaker than beams, yielding would tend to concentrate in a single story, leading to a column sway mechanism. Both mechanisms are shown in Fig. 14-11. Building codes require that the designer ensure that plastic hinges, when required, form in the beams rather than in the columns. This "strong column – weak beam" philosophy is based on the need to avoid the formation of plastic hinges at both ends of all columns in a single story or in the structure as a whole, which usually results in a column sway mechanism followed by collapse. Since hinges in the columns cannot be completely prevented, it is preferred to use adequate confinement reinforcement throughout the column height. Beam-column connections must be designed for a combination of tension, compression and shear forces, and should be proportioned to prevent excessive bond degradation of reinforcement passing through the joint.[4,26]

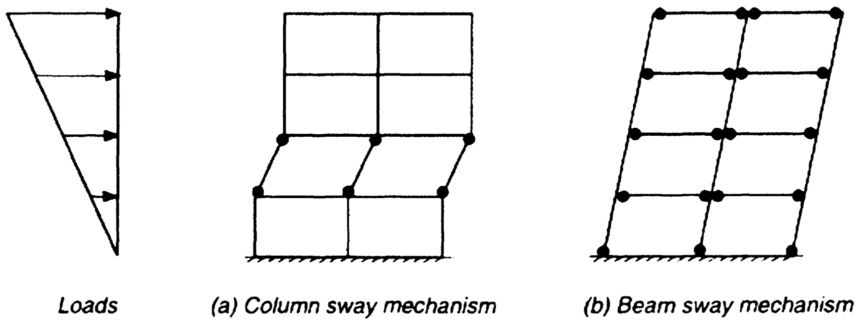


Fig. 14-11: Failure Mechanisms of reinforced Concrete Frames

The Uniform Building Code requires that ductile frame systems employed in zones of high seismic risk conform to the ductile moment-resisting frame design provisions for cast-in-place concrete.[4] Because the frames are relatively flexible, large structural deformations can occur during a major earthquake, if plastic hinges form in a significant number of beams in the frame. Exceeding the allowable drift limits should be approached with caution and with an understanding that major earthquake ground motion can cause deformations substantially larger than those resulting from the design forces. Further, under cyclic loads, frames can exhibit undesirably large lateral drifts accompanied by excessive stiffness degradation. The P-Δ effects can lead to frame instability after a few cycles if story drift ratios exceed about two percent of the story height.

14.7.2 Post-tensioned Concrete Moment Frames

Until recently, building codes did not allow post-tensioned frames to be treated as ductile frames. Consequently, post-tensioned frames were not considered to contribute to the lateral load resisting system. This concept required shearwall, braced frame, or ductile moment frames to provide full lateral load resistance. UBC-1997 allowed partially post-tensioned frames to be employed to provide lateral force-resistance if the amount of post-tensioning was limited to 350 psi over the short rectangular dimensions of the beam. For a 16 x 32 T-beam commonly used in parking facilities, the 350-psi stress translates into six beam tendons. Because most parking structures require long span beams, considerably more tendons are required to resist gravity load and for deflection control. Also, combining the limited post-tensioning with predominant non-prestressed steel reinforcement has been found uneconomical. Therefore, parking facilities have not been able to use this code provision.

UBC-97 contains a provision that "all members not part of the lateral force resisting system must be capable of resisting actions induced by the inelastic distortion of the structure in addition to actions caused by gravity loads." This requirement applies to post-tensioned frames, since the frames are not considered to be the part of lateral force resisting system. Therefore, the post-tensioned frames must be designed so that the frames can withstand the amplified displacements.

On the other hand, field observations have shown that post-tensioned frame structures performed well during a recent earthquake.[27] In light of this and other relevant data, the NEHRP 1994 provisions stipulate that the post-tensioned frames may be considered ductile provided the following conditions are met:

1. The post-tensioning stress is limited to 700 psi or 1/6 of the beam concrete strength calculated for the beam's rectangular dimensions.
2. The post-tensioning tendons shall not provide more than one quarter of the strength of both positive and negative moments at the beam-column joint.
3. The tendon anchorages are located outside the beam-column joint.

With acceptance of these criteria by governing codes, post-tensioned frames may replace reinforced concrete ductile frames in certain cases.

14.7.3 Precast Concrete Frames

In precast moment frames, precast beams and columns are jointed together at ends by either "dry" joints or "wet" joints.[3] The behavior of a precast frame subjected to seismic loading depends, to a considerable degree, on the characteristics of the connections. Because of the concerns regarding progressive collapse of precast structures, until recently they could be built in high seismic regions only if it were demonstrated by experimental evidence and analysis that the proposed system would have strength and toughness equal to or exceeding those provided by a comparable monolithic reinforced concrete structure.[28]

At present, the 1994 NEHRP Provisions adopted by UBC-97 provide two alternatives for the design of the precast concrete lateral force resisting system. One alternative is emulation of monolithic reinforced concrete construction. The alternative is the use of the unique properties of precast elements predominantly interconnected by dry joints. A connection between precast panels is called "dry" if it does not qualify as a wet connection. A wet connection is one that uses one of the approved splicing methods to connect precast members and uses cast-in-place concrete or grout to fill the splicing closure.

According to NEHRP Provisions, a precast frame can be designed using either monolithic "wet" connections or "strong" connections. A connection is considered "strong" if it remains elastic while the designated nonlinear action regions undergo inelastic response under the "Design Basis Ground Motion."[4] Considerable freedom is given in locating the strong connections and the non-linear action zones (plastic hinges) along the length of the precast member. However, the hinges must be separated from the connection by a distance of at least three-fourth of the member's depth. Wet connections are permitted at the strong connections but not at the hinge locations.[1] A commentary on the background of the connections is given in reference 28. Connection details can be developed that ensure satisfactory performance under seismic loading, provided that the designer pays particular attention to ductility requirements and positive confinement of concrete in the joint area. Welding procedures must be followed that avoid locally brittle conditions.

It is often difficult to satisfy ductility criteria for strong earthquakes when plastic hinges must occur at connections made on-site, such as at beam-column joints. To overcome this difficulty, it is preferable to locate connections in precast assemblies in areas of low moment demand, where elastic behavior can be assured during earthquake response. Plastic hinge regions can then be designed and detailed as for monolithic, cast-in-place structures.

14.7.4 Hybrid Precast Frames

Recently, a precast hybrid frame system has been developed that uses precast beams and columns. High-strength, post-tensioned steel cables and 3-ft. non-prestressed steel rods join the columns and beams. The cables run through ducts installed in each beam and are then post-tensioned. It is expected that during an earthquake the cables will stretch slightly, diffusing lateral forces by allowing the beams and columns to sway. After the event, the cables will contract, pulling the beam and column back to their original alignments. Since the cables can be up to 200-ft long, they can easily absorb the deformations caused by an earthquake. Further tests are underway.[29]

14.8 Shearwalls

The term "shearwall" or “structural wall” is used to identify walls designed to resist gravity loads and lateral forces in the plane of the wall. Shearwalls act as vertical cantilevers, supporting gravity and lateral loads. Shearwalls can have many different cross-sections such as rectangular, L-shaped, channel-shaped, and even circular. Figure 14-12 shows a circular wall supporting a helix ramp. Shearwalls can be solid or contain openings. Shearwalls may be coupled by thin flexural elements or deep shear elements resulting in considerable variation in the behavior of the coupled wall system. Shearwalls may be of reinforced, precast or post-tensioned concrete.

Shearwalls with a height to length ratio of less than two are called short shearwalls. Such walls are generally designed to behave like shear brackets. Reinforcement of these walls generally consists of evenly distributed horizontal and vertical steel. Shear walls with a height to horizontal length ratio greater than two can be designed as beam-column elements subjected to axial load, moment, and shear. Reinforcement can consist of evenly spaced vertical and horizontal bars. Part of the flexural reinforcement may be concentrated at wall ends, where a boundary element may be formed for the purpose of section stability and confinement. When analysis shows that large concrete compressive strains may be required to develop the intended ductility of the wall, the wall ends should be confined over the length of the plastic hinge.[4] Longitudinal reinforcement in the web contributes to the flexural strength of the wall, and should not be ignored. The design must also consider overturning resistance provided by the foundation. To ensure ductile response, the foundations of a wall must be capable of resisting the actions generated in the wall, with allowance for the development of overstrength at the base of the wall.

In high seismic regions, the building codes require that the shearwalls exhibit ductility. Such behavior is governed primarily by flexure, and the area of flexural reinforcement should be small enough so that flexural yielding occurs before shear failure begins. With proper attention to axial load level, confinement of concrete, splicing of reinforcement, treatment of construction joints and prevention of out-of-plane buckling, acceptable ductility can be obtained.

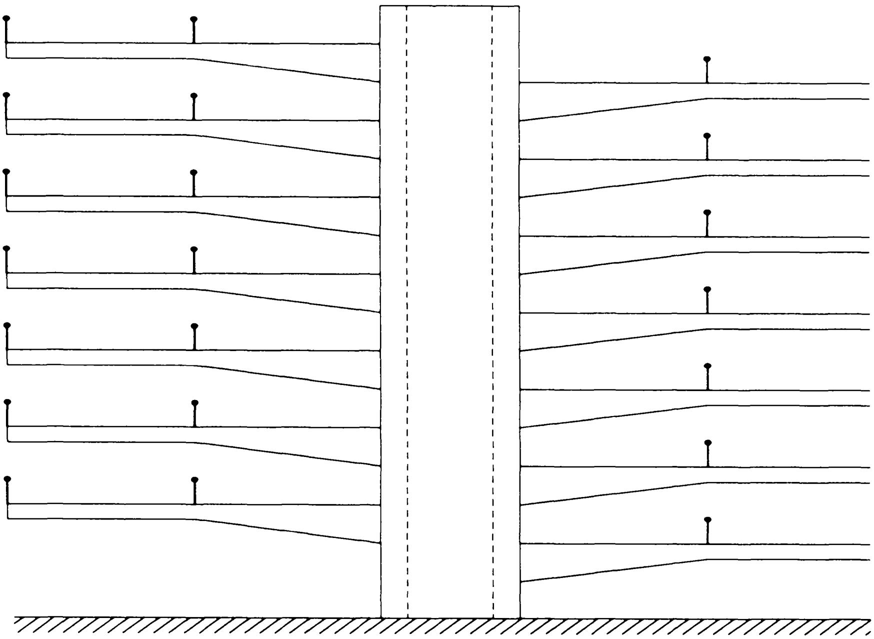


Figure 14-12: Circular cantilever corewall supporting a Helix Ramp at Seattle Tacoma International Airport Parking Facility.

14.8.1 Coupled Shearwalls

Coupled walls are divided into two categories based on the depth of coupling beams. In parking structures, coupled walls with shallow coupling beams are rarely used. However, when the central elevator/service core is pierced by small openings for doors or mechanical ducts, the result is a series of walls connected by deep, short-span link beams. Due to their stiffness and strength, the deep link beams cannot be ignored in the coupled wall analysis. High axial forces can be developed in the coupled walls, and should be considered to avoid brittle failure of the walls. High shear forces can also be developed in the coupling beams, requiring heavy reinforcement. Depending on their span to depth ratios, deep link beams must often be designed as deep beams. In seismic zones, where high ductility is desirable, greater ductility can be achieved using main reinforcement running diagonally from corner to corner, confined by spiral reinforcement and designed to resist flexure and shear directly.[4]

14.8.2 Precast Shearwalls

Precast concrete walls are used in parking facilities to carry gravity loads as well as to help resist lateral forces. The walls may be used on the exterior facade or in the interior. When used on the exterior, the walls provide an appearance of a residential or office building. Interior solid or perforated walls are widely used in precast parking facilities. Such wall construction offers economy and speed of construction by eliminating the precast beam and column elements. However, if the wall openings were not properly provided, the inner parking bays would lose much needed natural light and airflow.

In planning a parking facility with precast wall panels, avoid significant discontinuities in mass, stiffness and geometry. Wall panels should be located close to the center of the mass in order to avoid excessive volume change restraint and should preferably be symmetric in plan, to counteract torsion effects due to lateral loading. See Sections 12.3.3.2 and Figures 12-22,23, and 24. According to NEHRP Provisions, precast shearwalls are allowed in high seismic regions provided that emulated monolithic behavior is demonstrated.[1] The use of wet joints to connect wall panel in areas of high seismic risk is well accepted. Although, "dry" joints are quite popular in low and moderate seismic zones, allowing “dry” joints in such panels in high seismic regions is an open issue. The requirements for precast walls with strong connections are not presently available and will be developed in future.[28]

14.9 STRUCTURAL SYSTEM SELECTION

The subassemblies, subsystems or components described in the previous section form structural systems for parking structures. Sometimes only one type of the subassembly is used, while at other times, two or more types of subassemblies are combined to form a lateral load resisting system. A structural system is considered efficient if its premium for height is minimized. In other words, the premium is considered low if the member sizes required for carrying gravity loading only need not be increased appreciably to also resist the combined effect of gravity and lateral loading.

Three types of structural systems are used in parking facilities to resist lateral loads from winds and earthquakes. These are:

1. Moment Frame Systems
2. Shearwall Systems
3. A Combination of the above two, as discussed in subsection 14.9.4.

14.9.1 General Considerations

The selection of a lateral load resisting system for a parking facility is strongly influenced by parking layout, internal flow pattern, volume change, openness requirements, architectural considerations, and the intensity and types of lateral loading. Seismic loading depends upon the site where the parking facility is located. Probabilistic maps, such as the one shown in Figure 4-13, are available in the codes. Further, the maps can be downloaded from an Internet site.[12] A structural system is most efficient when loads are transferred as directly as possible to the foundation, without large torsion effects induced by plan asymmetry and without abrupt changes in member stiffness.

Damage to and reparability of the structure should be a consideration in the selection of the structural system. Thus, it is appropriate for the engineer to consider these concerns and increase the level of loading, stiffness, and detailing requirements if it is desirable to control the amount of damage and/or decrease repair costs.

14.9.2 Redundancy

UBC-97 recommends that the lateral force resisting system be made as redundant as possible. Multiple lines of resistance are preferable to a single line of resistance only, and multiple bents of resistance in each bracing line are much more desirable than a single bent. Good torsion rigidity is also essential. The objective is to create a system that will have its inelastic behavior distributed nearly uniformly throughout the plan and elevation of the system, and to have such a degree of redundancy that softening or failure of a particular element can result in load redistribution to the associated redundant elements, without the possibility of collapse.

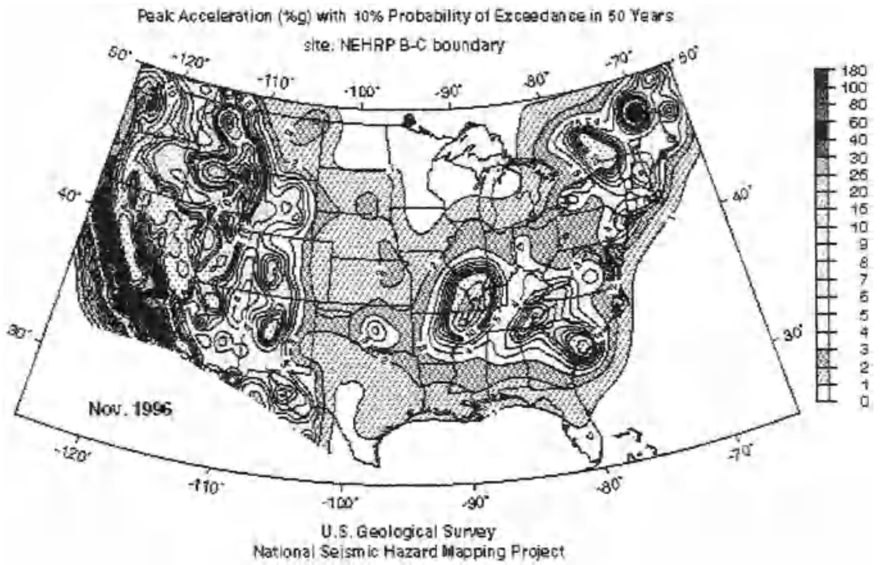


Figure 14-13: Probabilistic map of 0.2-sec spectral response acceleration with a 10% probability of exceedance in 50 years.[1,12]

14.9.3 Load Path

Regardless of which structural system is selected, keep in mind that an earthquake motion is transferred from the ground up into the building, and the forces generated by this motion must flow back to the ground. In an earthquake, the forces will try to reach the ground by the most direct route. Therefore, the load path must be as direct as possible. Once the forces from the diaphragm enter the walls, they should remain in the walls until the footing is reached. If discontinuity occurs, an adequate transfer system must be created to transfer the force to another lateral load-resisting element.

14.9.4 Dual System

A dual system consists of two or more basic lateral load resisting components or subsystems. The combination is chosen to achieve specific response characteristics, particularly with respect to the seismic behavior. The wall-frame system is an example.

In a wall-frame system, frames and isolated or coupled shearwalls can be combined to produce a structural system with the gravity load-carrying efficiency of a rigid frame, and the lateral load-resisting efficiency of a shearwall.[30] Wall-frame interaction is due to the different characteristic lateral deflected shapes of these two elements. The degree of interaction is dictated principally by geometry and relative stiffness. Wall overturning moment and lateral drift are both greatly reduced by wall-frame interaction. In strong ground motion areas, wall-frame systems are superior to isolated walls or frames acting alone because of their structural redundancy, which permits the structure to be designed for a desired sequence of yielding under strong ground motion. Beam elements can be designed to experience significant yielding before inelastic action occurs at the bases of the walls. Because of the feasibility of controlling the hinging sequence, and the relative economy with which beams can be repaired, wall-frame structures are appropriate for use in high seismic zones. However, designers should be aware that in wall-frame structures, the variation of shears and overturning moments over the height of the wall and frame is very different under inelastic response conditions than under elastic response conditions. The difference between elastic and inelastic response is much greater for wall-frame systems, than for systems composed of walls or frames alone.

14.9.5 Mixed Concrete-Steel System

Although previous sections have been written with an all-concrete construction in mind, the strength, stiffness and ductility requirement of seismic design in a parking structure may dictate a hybrid structure in that a combination of a concrete floor system is employed in the structure along with steel moment frame or braced frame. Since such mixed concrete-steel systems may be competitive in certain market conditions, their feasibility should be studied, particularly for large projects. Although steel erection is generally speedy, it should be noted that since the erection of steel and concrete involve different building trades and equipment, mixed construction may involve scheduling problems and economic penalties.

14.9.6 Base Isolation

A parking structure may be isolated (usually at its base) from excessive seismic forces. Elastomeric pads or other devices may be used to increase the fundamental period, thereby reducing the elastic seismic response of the structure to earthquake motions.[31,32] However, this type of base isolation offers little return for two reasons. First, there are many columns in a parking structure. Second, for base isolation to work, the slab-on-grade has to be a structural slab.

Figure 14-14: McCarran Airport Parking facility, Las Vegas, Nevada

14.10 CASE HISTORIES

This section presents several parking facilities recently built in various seismic zones ranging from mild to severe. The structural systems described in section 14.8 are employed to satisfy the functional needs.

14.10.1 McCarran Airport Parking Facility, Las Vegas, Nevada

This 6,000-car facility, which has a 6.5 acre footprint, contains nine parking levels and is integrated with the existing four-level 1,600 space parking structure above the Baggage Claim Building. Pedestrian connections with power walks link two levels of the new facility for patron convenience. A one-way post-tensioned slab, beam and girder system with a 36-ft. x 54-ft. structural bay is employed to help create patron security and visibility. Precast concrete spandrels with architectural features are used at the exterior of the facility. As shown in Figure 14-14, a unique circular helix is used to achieve vertical auto flow.

Built according to UBC-1991, and located in a moderate seismic zone, the lateral load-resisting system consists of post-tensioned concrete frames in the two orthogonal directions. The building is divided into several structural modules with seismic expansion joints separating the modules.

14.10.2 BJC Hospital Parking Facility, St. Louis, Missouri

This cast-in-place post-tensioned concrete parking facility has eight levels. The 1,612-car facility offers one-way traffic flow using a double helix with two flat bays for circulation. Built without an expansion joint, the facility has a plan footprint of 295 ft. x 229 ft. The parking facility is built with three elevators and has the space for another elevator. As shown in Figure 14-15, the exterior is a brick façade complementing the hospital campus. A pedestrian bridge allows staff to efficiently move to and from the facility.

Figure 14-15: Barnes Jewish Hospital Parking facility, St. Louis, Missouri

Located in an intermediate seismic region, the structure was designed for $A_v = 0.12$ per the 1992 BOCA code. The floor system is one-way post-tensioned slabs and beams. To resist seismic loading, shear walls are provided in the long direction. In the short direction, the post-tensioned frames resist the seismic forces. The shearwalls are located between the sloping ramps to allow maximum light and airflow in the facility. The wall construction followed the floor construction to allow for post-tensioning and related volume changes.

14.10.3 Judicial Center Parking Facility, Carol Stream, Illinois

The Parking Structure has 2,040 spaces. The Structure provides 5-level parking for employees and visitors to the Judicial Center. Segregated parking for judges and designated staff is an important design feature of the facility. As shown in Figure 14-16, the superstructure is a total precast concrete system. Cantilevered planters are equipped with automatic sprinkler and drainage systems.

The floor system utilizes 10-ft. double-tees, ledger beams, spandrels and precast columns. Located in a low seismic region, precast frames were used in both directions. The C-shaped and I-shaped prefabricated concrete elements were jointed together in column mid-height locations. Splice sleeves with high strength grout were used to connect the precast subassemblies. In addition to economy of construction, the precast concrete was selected to allow construction to continue in winter.

Figure 14-16: DuPage County Judicial Center Parking facility, Wheaton, Illinois.

14.10.4 Sixth Ave. and Cherry Street Parking Facility, Seattle, Washington

The Sixth Ave. and Cherry Street parking facility is an 8-tier post-tensioned structure. The facility is two bays wide. One-way post-tensioned slab, post-tensioned beams and cast-in-place columns carry the gravity loads. Located in a high seismic region, the seismic forces in east-west directions are resisted by reinforced concrete ductile frames. As shown in Fig. 14-17, the ductile frames are exposed concrete and act as bumper guards as well. Shearwalls are used to resist the north-south seismic forces at the interior grid line to allow natural light and air flow. Reinforced concrete auger-cast piles comprise the foundations.

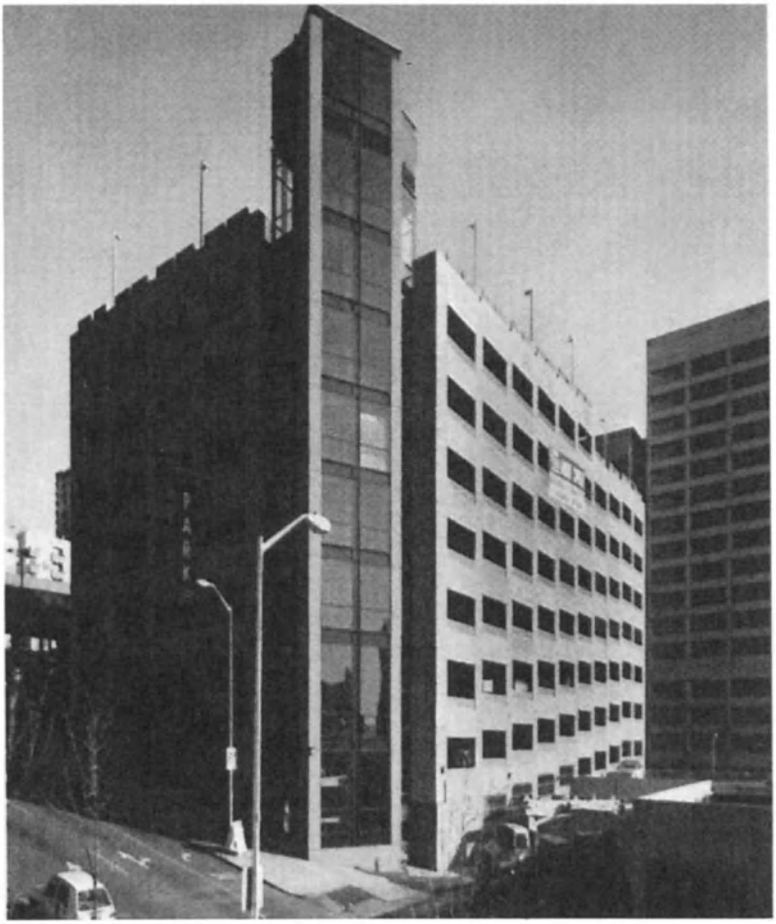


Figure 14-17: Sixth Street and Cherry Ave, Seattle, Washington

14.10.5 Luis Munoz Marin International Airport Parking Facility, San Juan, Puerto Rico

This 4,000 space, 6-tier, parking facility serves the expanding needs of the airport. In addition to serving hourly and daily parkers, it also contains rental car "Ready/Return" areas. This design-built facility is a post-tensioned concrete structure with a bay size of 23 ft x 53 ft. To allow for natural light and air circulation, an air well is provided at the interior of the facility. An expansion joint separates the footprint into two parts to allow for volume changes. See Figure 14-18. Shearwalls are provided to resist high seismic forces in both directions. Architectural concrete panels clad the exterior and integrate it with on-site landscaping.

Figure 14.18: Luis Munoz Marin International Airport Parking Facility, San Juan, Puerto Rico.

14.10.6 San Francisco International Airport Parking Facility, San Francisco, California

Completed in 1999, the parking facility is an 8-tier cast-in-place post-tensioned structure with 1722 car spaces and plan dimensions of 220 ft. x 320 ft. See Figure 14.19. Located in high-seismic zone, it was built according to UBC-94. Reinforced concrete ductile moment frames are used in two orthogonal directions to resist the seismic forces. Due to soft soil encountered at the site, a pile foundation system was used with grade beams tying the pile caps together for additional stability.

Figure 14.19: San Francisco International Airport employee parking facility, San Francisco, California

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Chapter 15

DESIGNING FOR DURABILITY

Anthony P. Chrest

15.1 INTRODUCTION

You will have seen from Chapter 12 that with parking structures, structural design and durability design go hand-in-hand. One depends on and directly affects the other. For organizational purposes, this chapter will address construction material use that will improve the useful life of your structure. At intervals tables have been inserted to summarize the discussion of a material or to close a major section.

Parking structures deteriorate more rapidly than other building types, simply because they are more exposed to attack. Exposure conditions, even in climates like those found in southern North America, can be severe, and require proper protection.

The cost of protection systems varies widely. Some measures are almost free. Others are uneconomical except as a last resort, or because the project involves more than just the parking structure. For example, consider an office building with parking in its lower floors. The structure of the parking segment supports that of the office segment above. If the parking structure deteriorates to the point where it is unsafe, the entire building would have to be condemned; this example has already happened.

The discussion of why some concrete deteriorates and some does not appears in Chapter 19. There you will also find an explanation of why it is a good idea to keep road salt and water out of your concrete.

This chapter classes protection systems as internal or built-in and external or applied. With a few exceptions, internal measures are relatively inexpensive, while external systems are usually more expensive. In sections 15.2 and 15.3, the alternatives presented range from least to most expensive. Use any system with proper care, or it will be a waste of money. Another caution - do not expect the impossible from a product; each has limitations and none will work miracles.

A. P. Chrest et al., *Parking Structures*

For example, we were once consulted on a project in New England because the protective sealer was not working. A review of the construction records showed that the concrete quality was poor and that floor deflections exceeded acceptable limits. The result was floor cracking. No sealer can bridge cracks in concrete. The cheap fix desired was not successful, not because the sealer was poor quality, but because of ignorance of its capabilities.

As a final introductory note, when considering one element of durable design, do not forget to look at its impact on the total design. For example, increasing reinforcement cover may increase cracking, unless crack widths and tensile stress levels are checked and adjusted if required.

15.2 BUILT-IN PROTECTION SYSTEMS

15.2.1 Drainage

While proper drainage is not an ingredient of concrete, build it in. If we do not allow chloride-carrying water to collect anywhere in a structure, we reduce considerably the opportunities for chloride attack. Minimum pitch for drainage should be one percent, with 1-1/2 percent preferred. Size the drains to handle anticipated runoff volume. Include a sediment bucket (to reduce chances of clogging the piping) and corrosion protection.

Don't be misled by the brevity of treatment of drainage here. It is your first line of defense against corrosion. For more discussion of drainage in new structures, see Chapter 12. For remedial measures to drainage in an existing structure, see Chapters 19 and 20.

15.2.2 Concrete

Look at the basic ingredients of a good quality concrete first - cement, water, and aggregate. As basic as they are, these materials are not always selected properly, so take nothing for granted.

15.2.2.1 Cement.

Any Type I cement conforming to ASTM C150 should be acceptable, providing that local experience records show that it will perform well. Depending on the project area requirements, special-use cements such as sulfate-resistant cement, high-early-strength cement, or quick-setting cement may be needed. Different brands of cement will produce different results, so it is wise to specify that only one brand be used throughout the project. Be more careful about cement selection when you are designing for 28-day yield strengths exceeding 7000 psi, or when concrete color is important.

15.2.2.2 Water.

Water must conform to ASTM C94, which requires drinkable quality water. Chloride content must be such that total chloride content of the mix does not exceed the limits given in the next section.

15.2.2.3 Aggregate

Both coarse and fine aggregate must conform to ASTM C33. For coarse aggregate, use crushed and graded limestone, or an acceptable local equivalent. For fine aggregate, use natural sand having the preferred grading shown for normal weight aggregate in Table 4.2.1 of ACI 302.1R, *Guide for Concrete Floor and Slab Construction.*

Aggregate gradation is important. Too many small particles will increase the water requirement, leading to a high water-cement ratio and consequent shrinkage cracking. There will be more information on water-cement ratio later in this chapter. Gradation may have to be different for pumped concrete. See ACI 304, *Guide for Measuring, Mixing, Transporting, and Placing Concrete.*

Another important but easily overlooked characteristic of an aggregate is its chloride ion content. Check this quantity through the laboratory making the trial concrete mixes. According to ACI 318, the total mix water-soluble chloride ion content, including all ingredients, should not exceed 0.06% chloride ions by weight of cement for prestressed concrete. The corresponding figure for reinforced concrete is 0.15%. See ASTM C 1218, "Sampling and Testing for Water Soluble Chloride Ions in Concrete and Concrete Raw Materials."

15.2.3 Additives

15.2.3.1 General

In this context, the term "additives" will include compounds added in relatively small amounts to the ingredients already mentioned. In Section 15.2.4 we will address ingredients like fly ash, silica fume, and ground granular blast furnace slag, which may be used to replace some of the cement in the concrete mix.

Prohibited additives are calcium chloride or additives containing more than 1% chloride ions by weight of additive. Additionally, each additive must not contribute more than 5 ppm, by weight, of chloride ions to total concrete ingredients. We arrived at these limits after discussion with additive manufacturers. Interestingly, we found that chloride percentages of additives, even from the same manufacturer, varied greatly.

The engineer must approve all additives in writing before use. Use all additives according to the manufacturers' instructions. Prudent practice requires all additives to be furnished by the same manufacturer. Require a statement of additive compatibility from the manufacturer (see Section 15.2.4.4).

15.2.3.2 Air Entraining Agents (AEA)

These materials must conform to ASTM C260. AEAs give the concrete resistance to freezing and thawing. Without an AEA, concrete in a cold climate will deteriorate quickly, as highway engineers discovered early in this century. Concrete mixed and placed using conventional practice will have 1-3% entrapped air. Entrapped air is air trapped in relatively large pockets distributed randomly in the mixture. Entrapped air does not help freeze-thaw resistance. Entrained air is distributed uniformly throughout the mixture in millions of tiny bubbles. The bubbles relieve the pressure generated by water becoming ice, thus preserving the concrete integrity. To be effective in climates where freeze-thaw damage may occur, air entrainment should be in the 5-7% range in the placed mix for ¾ in. nominal size aggregate. (See ACI 301 for entrained air requirements for other aggregate sizes.) Transportation, handling such as pumping, over-consolidation, and over-finishing will all reduce the air content. How do you know how much entrained air is in the hardened concrete? See Chapter 17. A fringe benefit of air entrainment is that it improves the workability of concrete. Air-entrained concrete segregates less easily and handles better than non-air-entrained concrete.

15.2.3.3 Water-Reducing Additives (WRDAs)

In most regions, use these additives to reduce the water content of a mix while retaining workability and slump. The result is a lower water-cement ratio, which leads to stronger and more durable concrete without adding cement.

Normal range WRDAs should pass ASTM C494, Type A. High range WRDAs, usually called superplasticizers, sharply reduce the water needed for a mix. Or, they dramatically increase slump, or both, depending on dosage amount and water volume. Dosage must be kept within the manufacturer's limits. High range WRDAs should meet ASTM C494, Type F or G. Use must not change the specified requirements for:

Maximum allowable water-cement ratios
Minimum allowable concrete strength
Minimum allowable air content
Minimum allowable cement content.

15.2.3.4 Corrosion Inhibitors

Certain proprietary products containing calcium nitrite as their main ingredient slow corrosion of unprotected mild steel reinforcement. Calcium nitrite reacts with ferrous ions to protect steel reinforcement. With continued addition of chloride ions from outside sources, the calcium nitrite supply ends and chloride ion corrosion starts. As with most other forms of protection described here, corrosion is delayed, not stopped. Whether or not corrosion inhibitors will be cost-effective for your project is something only value engineering and life cycle cost analysis will indicate. Table 15-1 contains a summary for calcium nitrite.

Table 15-1. Calcium Nitrite Summary

Characteristic	Favorable Aspect	Unfavorable Aspect
Effectiveness	Internal-not susceptible to traffic wear and abrasion. Barrier extends completely through member.	Must be designed and built into structure. No barrier to concrete contamination. May not protect rebar for structure design life.
Life	25-40 years, depending on dosage rate	Field performance data limited to 20± years.
Effect on Plastic Concrete Properties		May accelerate concrete setting time.
Initial Cost	Less expensive, now that there are several suppliers	
Maintenance Cost		May require additional protection against corrosion.
Surface Texture		Finishing may be adversely affected by accelerated setting time

15.2.4 Admixtures

15.2.4.1 General

The admixtures described here are used in superstructure concrete to replace some of the cement in the original mix. Except for fly ash and ground granular blast-furnace slag, cost considerations tend to limit their use to certain elements within a parking structure. Silica fume may be used in beam, column and slab concrete and in slab toppings. Because of its relatively high cost, latex is commonly used only in slab toppings.

15.2.4.2 Fly Ash

Fly Ash is the finely divided residue resulting from the combustion of ground or powdered coal. It is a material with cementitious properties used as a partial replacement for cement. When properly used, it will improve workability and final strength. It may improve impermeability; however, fly ash-rich concrete will gain strength more slowly than a comparable mix with none, even though final strength may be greater.

Fly ash should meet ASTM C618, Class C or F; test according to ASTM C311. Use trial mixes to be sure that the proposed fly ash does not cause variation in specified strength or entrained air content by more than the specified tolerances.

15.2.4.3 Ground Granular Blast-Furnace Slag (GGBS)

This material is a processed byproduct of steel manufacturing. It is used as an additive or as an ingredient in two types of blended cement, Types IS and ISM. ACI 301 limits GGBS to no more than 50 percent of the total weight of cementitious material and requires that it conform to ASTM C989. GGBS will lighten the color of cured concrete, which is often desirable. This characteristic is useful in lightening the color of concrete containing silica fume, as silica fume darkens the color of cured concrete. The other effects of GGBS on concrete are similar to that of other pozzolans. If you have no experience with it, rely heavily, via your project specifications, on the manufacturer's representative, and specify a large-scale sample panel (Chapter 17) to practice on. It is far less costly to lose a 20 ft square piece of slab on grade concrete than the same area of supported slab.

15.2.4.4 High-Reactivity Metakaolin (HRM)

HRM is a manufactured white powder conforming to ASTM C618, Class N pozzolan specifications. HRM particle size is much smaller than cement, but larger than silica fume. While new in the construction marketplace, HRM's properties should bring it into increasing use in the future. Concrete made with

HRM has properties similar to concrete made with silica fume (See section 15.2.4.5.), at less cost. Properties include high strength, low permeability, good air void system, and excellent freeze-thaw resistance. In addition, cured HRM concrete is lighter in color than silica fume concrete and less superplasticizer is needed to produce adequate workability. The latter property should ease the curing and finishing difficulties often associated with silica fume concrete.

15.2.4.5 Silica Fume

Silica fume, also called microsilica, is another finely divided by-product of industry which has properties helpful to concrete. When added to a concrete mix in the right proportions, the silica particles fill some of the spaces between cement particles and react chemically with the cement. The result is a concrete with much improved strength, impermeability and electrical resistivity. These properties make the concrete considerably more durable than a comparable mix without silica fume. Finishing and curing procedures require careful attention.

By the time the silica fume concrete is one year old, the impermeability of the concrete reaches a value comparable to that of concrete coated with a protective sealer. (See the section under Exterior Protection for more on sealers.) You need not seal silica fume concrete of a proper mix design after it is over a year old. Because it does take a year for the full impermeability to develop, initial protection will be needed for silica fume concrete. There then will be no first cost savings for not sealing silica fume concrete, but maintenance costs will be lower. To reduce first cost, consider using a sealer with a shorter expected life, instead of a more expensive, longer lasting one that will be more than is needed. The first coat of sealer will be the last. Comparable concrete without silica fume will require sealer application every one to three years, depending upon traffic loads.

Proprietary silica fume products may contain a retarder. Require a statement from the manufacturer that the product is compatible - will not react deleteriously - with the other additives. Silica fume will usually darken the color of the cured concrete. Adding white cement or GGBS to the concrete mix will lighten the darker color, if objectionable (see section 15.2.4.3). Table 15.2 contains a summary for silica fume.

Table 15-2. Silica Fume Summary

Characteristic	Favorable Aspect	Unfavorable Aspect
Effectiveness	In concrete-not susceptible to traffic wear and abrasion. Can by itself provide barrier to chloride and moisture. Barrier extends completely through member. Increased electrical resistivity of concrete reduces corrosion rate.	Must be designed and built into structure. Does not bridge cracks. Does not prevent leakage through cracks. Performance data limited to last 10-15 years.
Life	25-40 years estimated	
Effect on Plastic Concrete Properties	Concrete bleeding during finishing reduced-conducive to not over-finishing	Finishers must be trained properly to work with silica fume concrete. Difficult to finish if addition rate >7% by weight of cement. Susceptible to cracking during hot and/or windy weather.
Effect on Hardened Concrete Properties	Significant reduction in concrete permeability	Concrete requires water curing during first 7 days to reduce potential for cracking
Cleaning	Normal wash-down in spring and fall	
Structural Maintenance	Sealer need not be reapplied after initial application. Sealer can be lower quality.	Chloride ion monitoring program necessary to evaluate performance and need for additional protection against corrosion
Initial Cost	Moderate	
Maintenance Cost	None	
Appearance	Usually darker than Portland cement concrete	
Surface Texture		Finishers must be trained properly to work with silica fume concrete.

15.2.4.6 Latex

Latex is a water emulsion of synthetic rubber obtained by polymerization. It is used in place of water to produce latex-modified concrete (LMC). LMC shares many of the properties of silica fume concrete, though for different reasons, since strength does not improve. LMC is relatively more expensive than either ordinary Portland Cement concrete, HRM, or silica fume concrete. For that reason, it is commonly used only as a topping for new or rehabilitation work. Finishing can be troublesome because the fresh surface tears easily. Curing must be done with care to prevent excessive surface cracking. Choose your contractor with care. You need an experienced specialty contractor; make sure your project is not the contractor's first LMC project.

15.2.4.7 Other Admixtures

There are a number of polymer admixtures, such as methyl methacrylate, which will produce improved concrete. Characteristics usually include improved impermeability, high early strength, and thin layer installation, as thin as 3/4 in. in some products. These products are all relatively expensive and are used to repair structures.

15.2.4.8 Summary

Table 15-3 summarizes concrete ingredients.

Table 15-3. Concrete Ingredients

Ingredient	Reference	Requirement	Reason for Use
Cement	ASTM C150	≥6 sacks	Strength, durability, freeze-thaw resistance
Water	ASTM C94	w/c ≤0.40	Durability
Aggregate	ASTM C33	Varies	Strength, durability, pumpability, alkali-aggregate reactivity avoidance
Chlorides	AASHTO T260	≤0.06%for P/S, otherwise ≤0.15%	Durability
Entrained Air	ASTM C260	Varies w/ climate	Freeze-thaw resistance, workability
Water Reducers	ASTM C494, Type A	Varies	Durability, workability
Superplasticizers	ASTM C494,	Slump ≤ 6 in.	Durability, workability

Ingredient	Reference	Requirement	Reason for Use
	Type F or G		
Accelerators	ASTM C494, Type C	Varies, but chloride free	Cold weather concreting
Retarders	ASTM C494, Type B	Varies	Hot weather concreting
Corrosion Inhibitors		Varies	Durability
Fly Ash	ASTM C618	$\leq$25%	Economy, handling, low heat, impermeability
Ground Granulated Blast-Furnace Slag	ASTM C989	$\leq$50%	Economy, lighten concrete color, impermeability
High-Reactivity Metakaolin	ASTM C618	$\leq$25%	Strength, lighten concrete color, impermeability
Silica Fume	ACI 226	$\leq$5 to 7%	Strength, durability, impermeability
Latex	ACI 548R	Varies	Impermeability

15.2.5 Reinforcement

15.2.5.1 Cover

ACI 318 recommends increased cover over reinforcement in corrosive environments such as those in parking structures. ACI is referring to reinforcement that is not epoxy coated. Increase cover over code requirements to allow for cover loss through traffic abrasion. Our practice in floor structures is to specify a minimum of 2 in. cover over all reinforcement exposed to the weather which is not epoxy coated. We prefer, however, to epoxy coat all reinforcement within 3 inches of the floor surface, and provide 1-1/2 in. cover, minimum, or 3 bar diameters, whichever is greater. See Figures 15-1 and 15-2 for examples involving sloping floors. This discussion applies to floors in regions where pavements are salted for snow and ice removal.

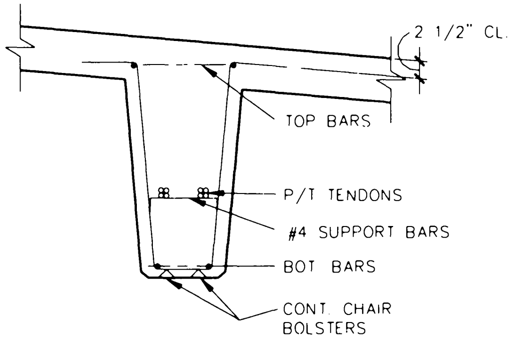


Figure 15-1. Cast-in-place post-tensioned concrete beam cross section – open stirrups.

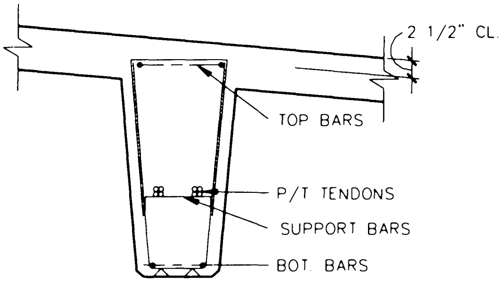


Figure 15-2. Cast-in-place post-tensioned concrete beam cross section – closed stirrups.

15.2.5.2 Epoxy-Coated Reinforcement

This heading refers to welded wire fabric, non-prestressed reinforcing bars, and high strength prestressing strand. Welded wire fabric and reinforcing bars may be epoxy coated to reduce the opportunities for corrosion. Epoxy-coated pretensioning strand is available. Present practice in most regions is to epoxy coat only the strand reinforcement used in pretensioned precast concrete, when additional protection is needed, if fire protection of the epoxy coating is not a problem. Protect the strand reinforcement used in post-tensioned concrete with a coating of grease and a plastic sheath. Epoxy-coated strand for post-tensioning use is also available. See Chapter 17 for more information on post-tensioning strand protection. Protected reinforcement is worth the investment in climates where pavements are salted for snow and ice control. Note that ACI 318 requires longer anchorage and development lengths for epoxy-coated reinforcement than for uncoated reinforcement. Epoxy-coated tensioning use is also available. See Chapter 17 for more information on post-tensioning strand protection. Protected reinforcement is worth the investment in climates where pavements are salted for snow and ice control. Note that ACI 318 requires longer anchorage and development lengths for epoxy-coated reinforcement than for uncoated reinforcement. Epoxy-coated bonded strand needs grit embedded in the epoxy coating to develop bond. Table 15-4 contains a summary for this section.

Table 15-4. Epoxy-Coated Reinforcement Summary

Characteristic	Favorable Aspect	Unfavorable Aspect
Effectiveness	Provides barrier at reinforcement. Internal to concrete-not susceptible to traffic wear and abrasion.	Not a barrier to concrete contamination. Must be designed and built into the structure. Defective coating will reduce protection. May not protect rebar for structure design life. May contribute to increased cracking and wider cracks.
Life	Should add 10-15 years	Field performance data available only over last 20± years.
Initial Cost	Moderate in most regions, but expensive in some	
Structural Performance		Requires increased development length

Most designers will be aware of the controversy surrounding epoxy-coated rebar that arose in the early 1990s. As of this writing, several state Departments of Transportation in the US prohibit epoxy-coated rebar in some or all types of structures. These prohibitions occurred because severely corroded epoxy-coated rebars were found in structures that were but a few years old. Research at the same time showed that there was no way to predict the durability of a specific piece of epoxy-coated rebar. Contributing to the problem were perceptions, fed by marketing hype, that epoxy-coated rebar would last forever. The controversy has abated somewhat. Now we know that epoxy coating rebar will extend its life in a corrosive environment 10-15 years, not 50. Also, standard specifications for coating application have been made more stringent, and coating manufacturers have developed higher-performance coatings. Like many other situations, this one proves that the way to quality in construction is not always through technology, but careful, informed workmanship and quality control.

15.2.5.3 Galvanized reinforcement

Field studies do not support laboratory studies indicating that galvanized reinforcement does not work long term in the corrosive environments commonly found in parking structures. Galvanizing is sacrificial protection; therefore, in a corrosive environment, it too corrodes. The corrosion products occupy more space than do the uncorroded galvanizing. The resultant pressure exerted on the surrounding concrete will spall or crack it. Laboratory and field test results conflict, but we do not specify galvanized reinforcement.

15.2.5.4 Other Types of Non-Prestressed Reinforcement

Stainless steel and non-metallic bars are available, but expensive. Their use in parking structures is overkill.

15.2.5.5 Prestressed Reinforcement

Prestressing high strength steel reinforcement puts concrete structural elements into compression before it is loaded by its own weight and service loads. Prestressing a floor slab or beam will result in that member's remaining in compression or at a low level of tension under self and service loads. No or little tensile stress in the concrete means little cracking of the kind usually found in nonprestressed reinforced concrete.

In most precast concrete parking structures, the pretensioned precast elements are of simple-span construction, which means that the top fibers of those elements are always in compression. Further, the pretensioned reinforcement is below the centroid of the concrete section. In the case of a typical 24 in. deep double tee, that reinforcement is likely to be protected by a foot or more of concrete cover above it. So long as there are no cracks in the precast concrete through which moisture can penetrate, the pretensioned reinforcement will be adequately protected from corrosion by the concrete alone. Also, since the entire length of the top fibers of the member are in compression, any cracks which do form will be kept closed by that compression.

In most cast-in-place post-tensioned concrete parking structures, the post-tensioned concrete elements are of continuous span construction, which means that the member top fibers will be in tension at supports and in compression at midspans. The post-tensioned reinforcement must therefore be close to the member top surface at the supports. Not only is the protective concrete cover for the reinforcement less at the supports, but if there is sufficiently high tensile stress in the negative moment area at a support, flexural cracks may open, providing a path for surface moisture from the floor to reach the post-tensioned reinforcement. It is necessary, then, to provide additional protection for the post-tensioned reinforcement.

The first layer of protection around the post-tensioned reinforcement strand is a coating of corrosion-inhibiting grease, which also lubricates the strand to reduce friction when the strand is tensioned. The second layer of protection is a continuous, seamless plastic sheathing extruded around the greased strand. The grease must completely fill the annular space between the strand and the sheathing. This sheathing keeps moisture away from the strand. At the ends of the strand, the anchor assemblies are completely encapsulated and the joint between strand sheathing and anchor encapsulation is made watertight.

Stressing pockets are very susceptible to water penetration. The joint between the pocket and the pocket fill may form a path for water penetration. Provide sealants or bonding agents at pockets. Also provide a sealed, tooled joint and epoxy coated nonprestressed reinforcement at each construction joint to minimize water penetration through slabs and to provide structural redundancy should tendon integrity be breached. For more information, see Chapter 16.

15.2.5.6 Fiber Reinforcement.

Fiber reinforcement may be steel or plastic. The fibers, when mixed uniformly throughout the concrete in the manufacturer's recommended proportions (usually 1 lb of fibers per cu yd of concrete), improve its crack-resistance during finishing and curing. Claims have been made that fiber can be used instead of bars for shear reinforcement. Though research indicates that these claims are true for much higher dosages, fiber reinforcement should not be substituted for bars unless and until recognized by building codes. We use them for concrete where, because of location or place in the construction sequence, cracks can be frequent. Examples are the cast-in-place pourstrips at the ends of pretopped double tees and at temporary isolation joints. Both are long, narrow placements that tend to crack due to plastic shrinkage and drying shrinkage-induced stress, due to neglect of proper curing. Further, concrete at these locations is commonly placed late in the project when schedules press. With the best of intentions, workmanship may deteriorate. If the standard quality control procedures are not effective, reduce cracking at these locations by using fiber-reinforced concrete. An evaporation retarder may also be effective, but neither measure will replace simply following correct placing and curing practices.

15.2.6 Construction Practices

15.2.6.1 Mixing, Transporting and Placing Concrete

It is hard to know where to stop educating when concrete is the subject; there are so many pitfalls for the unprepared. ACI has a number of publications which will help guard against the many mistakes which will lower concrete quality. For a start, read ACI 304 through 306.1. Next arrange a concrete preinstallation meeting with the owner, general contractor, ready-mixed concrete supplier, concrete pumping contractor, finishing contractor, forming contractor, testing agency, design professionals, and anyone else whose work will affect concrete quality. Define procedures and agree on them. The outcome of this meeting (more than one may be necessary) should be a written procedure outlining every major step in the process. It must address producing, delivering, placing, finishing, testing, and curing each type of concrete on your project. Everyone involved must sign off on the written procedure. There is more on these topics in later sections of this chapter and in Chapter 17.

15.2.6.2 Formwork for Concrete

Aside from suggesting that formwork be built tightly enough to prevent paste loss from the concrete, resulting in honeycombing repairs, and that formwork be kept clean (cigarette butts, paper, and sawdust are not acceptable admixtures in concrete), we recommend ACI SP-4 on formwork; the subject matter is well covered there.

15.2.6.3 Consolidation

Properly done, consolidation reduces the quantity and size of air voids, improving the end-product concrete. Most of the time, consolidation is done with vibrating screeds for thin slabs and overlays. Internal vibrators are used for thicker slabs and other members. Too little vibration will produce voids. Visible voids cost money to repair. Hidden voids will reduce strength and durability. Too much vibration will drive entrained air out of the plastic concrete and will bring too much paste to the surface. Both these effects will make the concrete less durable, though the loss of entrained air in the final product will be important only in colder climates where freeze-thaw damage is a concern. Premature surface deterioration because of too much cement paste at the floor surface is a concern in any climate. Good inspection will help prevent over-vibration. Using ACI 309, *Guide for Consolidation of Concrete,* to educate the vibrator operators will be better prevention.

15.2.6.4 Finishing

Finishing is another operation that can improve or damage the final product. As with many procedures, it is easier to do wrong than right. In the mistaken belief that more is better, finishers will overwork the concrete surface, bringing paste and fines to the top and reducing entrained air. The result is a weakened surface susceptible to scaling.

The best finish for floors with vehicle and pedestrian traffic consists of these operations - screed to the specified elevations and profiles. A vibrating screed will reduce the internal vibration needed. Wait until bleed water has evaporated or remove it. Bullfloat, then final finish with a light broom perpendicular to the direction of traffic. The term "light broom finish" in this context means a textured finish achieved with a soft broom where the amplitude between adjacent grooves and ridges is between 1/32 and 1/16 in. The surface must not be too smooth. A typical sidewalk finish is too smooth. If the finish is too rough, it will be a tripping hazard. Be careful not to drag aggregate from the surface.

If a traffic-bearing membrane is to be installed on the slab, be sure obtain finish requirements from the membrane manufacturer; then specify them. Include specification wording requiring that the finish conform to the membrane manufacturer's requirements wherever the membrane is to be installed.

Some finishers like to add water to the surface as they work. This practice produces a thin surface layer which is weak and permeable. Again, inspection will help prevent this practice. Education via the concrete preinstallation meeting mentioned earlier is better and will work even when the inspector isn't around. Keep the same finishing foreman throughout the project to maintain a consistent finish quality.

15.2.6.5 Curing

Curing is the important last step in the concreting process, but is sometimes ignored or done carelessly. Using a curing compound is often the preferred method. Curing compounds do not perform well on rough surfaces like the light broom finish discussed above. Specify a wet cure; it is proven to produce the best results. The cost is higher than other methods, but the results are worth it.

Pay special attention to ACI 305, *Hot Weather Concreting*, ACI 306, *Cold Weather Concreting*, and ACI 306.1, *Standard Specification for Cold Weather Concreting*. Some practices to avoid should be well-known, but every so often they reappear, so we will mention them. In cold weather, heaters may be needed to maintain proper curing temperature in the concrete. Be sure to vent the combustion products of the heaters to the outside air, not onto the concrete surface. If the combustion products come in contact with curing concrete, carbonation occurs. Carbonation produces dusting of the surface which is impossible to stop. As cold weather approaches in northern climates, do not seal concrete; it will not continue to loose moisture as it should and damage will result when the water in the concrete freezes. Also, sealers are not effective on high-moisture concrete.

In hot weather, especially on windy days, plastic shrinkage cracking is a real danger. Windbreaks, fogging, and application of an evaporation retarder will reduce the chances of it occurring.

15.2.6.6 Summary.

Table 15-5 summarizes construction practices.

Table 15-5. Construction Practices

Activity	References
Mixing	ACI 304
Transporting	ACI 304
Placing	ACI 304, ACI 304.2
Formwork	ACI 347, ACI SP-4
Consolidation	ACI 309, ACI 309.1R, ACI 309.2R
Finishing	ACI 302.1R
Curing and Protection	ACI 305R, ACI 306.1, ACI 308

15.3 EXTERIOR PROTECTION SYSTEMS

15.3.1 General

Systems under this heading will range from least to most expensive. Remember, though, that no external protection can make a silk purse out of a sow's ear. In other words, if the underlying concrete is not of good quality, no external protection system, no matter how expensive, will work for long. To emphasize the point yet one more time - spend your money on good concrete - then you will not have to waste it later on applied protection that should not have been necessary.

15.3.2 Sealants

There is sometimes confusion between the terms *sealant* and *sealer*. A *sealant* is a viscous material applied in fluid form, hardening somewhat to provide a long-term flexible seal which adheres to the surrounding concrete. In the next section, we will cover *sealers*.

In parking structures use sealants to keep water out of joints. These joints may be gaps inches wide between members. They may be grooves tooled into the plastic concrete to provide weakened planes for crack control. Whatever the joint width, a good sealant will keep water and water-borne salts out of the joint, extending its serviceability. Water and water-borne salts attack both the concrete and any unprotected ferrous metals in the joint.

Always specify that the edges of joints to be sealed be tooled, not sawn, then ground to remove concrete laitance. Next, the joint should be primed. Both practices will greatly improve the bond between sealant and concrete.

Though some engineers and architects prefer a two-part sealant to a one-part sealant, there are pluses and minuses for each. We have never had a problem with the one-part sealants that we specify. We have had problems occasionally with installer mistakes in proportioning or mixing two-part sealants. See Chapters 12 and 21 for more on proper joint design and sealants.

Sealant joints between precast double tee flanges can be troublesome. The usual connection detail involves field welding together steel embedments spaced at 4 to 8 ft on centers along the flange edges. Often too much heat is generated by the welder, cracking the flange concrete adjacent to the weld. The cracks are hairline, invisible until after the joint is sealed. With time and volume changes, the cracks widen and leak. The result appears to be a failed sealant joint, but the real cause is an improperly welded connection.

15.3.3 Sealers

Sealers are protective coatings applied over a concrete surface to prevent water and water-borne salts from penetrating that surface. A good sealer penetrates into the concrete surface, but allows vapor to escape. A good sealer may extend the service life of a sound concrete surface, but will not bridge cracks.

A good sealer will not stop deterioration, but will slow it and will reduce future maintenance costs. There are two sealer groups: film-formers and penetrating sealers. Film-formers wear quickly in a parking structure so are worthless. A good penetrating sealer will not be abraded off quickly, providing that it does penetrate. Only silane and siloxane sealers penetrate concrete. Because the silane molecule is smaller than a siloxane molecule, silane penetrates better. Higher solids-content silane sealers penetrate deeper and perform better than other products. For example, a 100% solids silane performs about fifty percent better than a 40% solids silane and one hundred percent better than a 20% solids silane.

Among the film-formers that will not withstand abrasion are acrylics, epoxies, silicones, and stearates. Avoid them. Among the penetrating sealers, avoid silicates and siliconates. Siloxanes are less expensive than silanes, but are also less effective. Even a 100% solids silane will not penetrate much more than 2.5 mm. That's a tenth of an inch.

Unfortunately, much deception is present in the sealer market. It's a buyer-beware situation. A summary of penetrating sealer characteristics appears in Table 15-6.

Table 15-6. Penetrating Sealer Summary

Characteristic	Favorable Aspect	Unfavorable Aspect
Effectiveness	Provides a barrier at top surface. Makes concrete less permeable. Silane more effective than siloxane. Higher solids content more effective.	Susceptible to wear from tire abrasion. Eventually allows salt and moisture to enter the concrete. Unable to bridge active or wide cracks to prevent leaks.
Life	Silanes penetrate better, so resist wear better.	Siloxanes penetrate less, so do not perform as well.
Ease of Reapplication	Easy to apply with few disruptions	Reapplication every 3-5 years necessary, depending on wear.
Cleaning	Normal wash-down in spring and fall	No protection of concrete from difficult-to-remove grease and oil stains
Structural Maintenance	Delays need for maintenance.	Chloride ion monitoring program necessary to evaluate effectiveness, reapplication frequency, and need for additional protection against corrosion
Initial Cost	Relatively inexpensive	Many reapplications necessary during structure service life
Maintenance Cost	Relatively inexpensive	Will require additional protection against corrosion during structure service life
Appearance	No change to concrete surface	Concrete surface can be stained by grease and oil
Surface Texture	No change for silanes and siloxanes	Other sealer types remain on the surface and may reduce skid resistance and/or become slippery

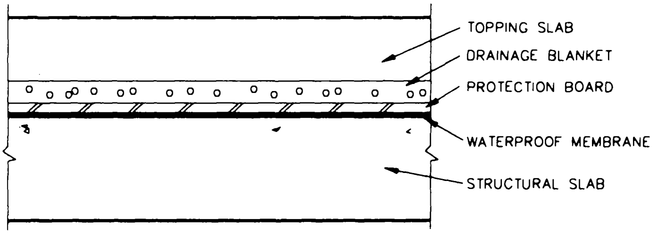


Figure 15-3. Example section view of a non-traffic-bearing membrane system.

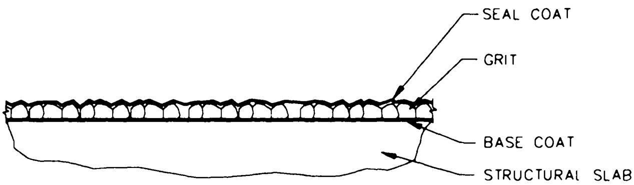


Figure 15-4. Example section view of a traffic-bearing membrane system.

15.3.4 Membranes

We classify waterproof membrane systems (sometimes called traffic toppings) for parking structure pavements into two kinds - those applied over the pavement as a traffic-bearing surface and those which must be protected by a wearing course. See Figures 15-3 and 15-4 for illustrations of each. Note that the protected membrane installation has more components than the traffic-bearing type. The protection and drainage systems for the protected type are often difficult to install correctly. Protected systems are more expensive than traffic-bearing systems. Finding a leak in a protected membrane can be difficult. Repairing that leak means removing some part of the protection layer, fixing the leak, and replacing the protection layer. If the protection layer is made of brick or concrete pavers, the removal and repair operations are not particularly difficult, but if the protection layer is cast-in-place concrete, removal and repair operations are more difficult. On the other hand, protected membranes are not subjected to traffic wear or to deterioration from the ultraviolet rays in sunlight.

Traffic-bearing membranes typically come in four wear grades. The first is for zones in which wear is low, such as in parking spaces or pedestrian areas. The second is for flat, straight driving aisles. The third is for places where high wear is likely. Examples are turns, steeper slopes, ramps, and locations where stopping and starting will occur, as at gates or ticket dispensers. The fourth grade is not really a grade at all.

It can be any of the other three grades, except that it has a light-colored top coating. It should contain an aliphatic compound, to increase its resistance to ultraviolet light. This grade is for locations exposed to sunlight.

Traffic-bearing membranes are relatively easy to repair. Service life varies with abrasion wear received. Turns or locations where frequent starts and stops occur may need repairs every 2-3 years. Parking spaces may need repairs only after 10 years or so. At this writing, there are no data available relating membrane wear to traffic volume.

Like good sealers, good membranes keep water and water-borne salts out of the underlying concrete while letting vapor out. Unlike good sealers, good membranes will bridge narrow cracks which may develop in the underlying concrete after the membrane is in place. (For specification information, see Chapter 16.)

If a traffic-bearing membrane is to be used over a precast double tee floor, use field-topped tees, not pretopped. The differential camber between pretopped tees will produce a number of ridges in the floor. When these ridges are coated with the membrane, the ridges will remain, presenting and edge off of which traffic will quickly wear away the membrane. For a summary of traffic-bearing membranes, see Table 15-7.

Table 15-7. Traffic Bearing Membrane Summary

Characteristic	Favorable Aspect	Unfavorable Aspect
Effectiveness	Provides impermeable surface barrier to moisture and chloride. Protects occupied space below from moisture above. Bridges active cracks.	Susceptible to traffic abrasion and wear. Proper application by experienced contractor essential. Application will not stop corrosion in already-contaminated concrete. Maintenance required.
Life	Quality initial application may last 10-15 years. Topcoat reapplication extends life another 10± years.	Buys only 5-10 more years if applied over already-contaminated concrete. UV from sunlight reduces life.
Ease of Reapplication	Few disruptions in most areas. Easy to repair damaged areas.	More frequent disruptions in heavy traffic locations like turns, entries, exits, ramps, and any locations with frequent stops and starts. Requires rubber-edged snowplow blade to reduce damage to membrane. Studded snow tires will damage membrane.
Cleaning	Oil stains easily removed. Clean annually.	Requires special sweeper and scrubber
Initial Cost		Relatively high initial cost.
Maintenance Cost		Cost can vary considerably depending on the actual traffic patterns and intensity. Heavily used areas may need recoating every 3-5 years. Complete replacement required after 25± years. Life cycle cost is 2-3 times the cost of any other combination of comparable systems designed to protect against corrosion for service life of structure.
Appearance	Provides neat, uniform appearance	UV from sunlight will discolor. Black or dark colored membrane reduces light levels and tends to conceal locations made slippery with grease or oil.
Texture	Can improve surface skid resistance	Heavily used locations require more frequent repairs to maintain skid resistance

15.3.5 Overlays

15.3.5.1 General

Except for cast-in-place overlays on precast concrete, overlays are not often used in construction of new parking structures. Their use, particularly of the more exotic materials, is more common in restoration work. For further discussion, see Chapter 19. For the sake of completeness, here is a brief discussion.

Topping on precast concrete is commonly used to provide a level, even wearing surface which compensates for the unevenness in the tops of the precast members caused by differential camber. It may also be used to provide drainage difficult to achieve with pretopped tees alone. At the same time, the topping reinforcement may also serve to transfer lateral loads to the structural framing. Further, the topping can be used to conceal connections between precast members. Keep in mind that the joints between the precast pieces beneath a topping will reflect up through that topping. Tool and seal the topping above all joints between precast pieces.

On a few recent projects, owners have requested that we specify a non-composite sacrificial topping over already pretopped precast double tees.
Several different types of concrete overlays will be presented here. Though they will all fulfill the functions listed in the above two paragraphs, they do differ in durability and in expense, and are listed in order of increasing degree of expense. These overlays also vary in minimum recommended thickness. The densities of the overlays listed below are all around 145 lb/cu ft. So, the thinner it can be applied, the lighter that overlay will be. Extra structure weight drives up the cost of construction in both new and restoration work.

15.3.5.2 Portland Cement Concrete Overlay

This economical alternative has been used successfully as an overlay many times. Where high impermeability, low dead weight and a thin overlay are requirements, this material would not be a solution. A 3-in. thick overlay is a practical minimum. If of normal weight (145 lb/cu ft) concrete, it will weigh 35-40 lb/sq ft. If thickness and self-weight are acceptable, you could use a sealer or membrane on the new overlay to improve impermeability. The cost of such a combination will probably exceed the cost of one of the other overlays listed below.

15.3.5.3 Low Slump, Dense Concrete Overlay (Iowa Method)

This alternative has the same attributes as that above. However, its lower water-cement ratio makes it more durable and less permeable. It has been used extensively on new and repaired highway bridge decks.

15.3.5.4 Silica Fume Concrete Overlay

Density is a little higher than that of the two alternatives above. Its much higher strength makes a 1-1/2 to 2 in. thickness practical. Impermeability is quite high. See Section 15.2.4.4 for more information on this material.

15.3.5.5 Latex-Modified Concrete (LMC) Overlay

Similar in performance to silica fume concrete, but significantly higher in cost and of lower strength. Thickness may be less. See Section 15.2.4.4 for more information.

15.3.5.6 Other Overlays

Combinations of materials and protection are not uncommon. Fiber-reinforced overlays and overlays with covered or exposed membranes are not unusual. See Section 15.2.5.6 for more information on fiber reinforcement.

15.4 SUMMARY

See Table 15-8 for a summary of exterior protection systems, and Table 15-9 for a summary of recommended combinations of protection measures.

Table 15-8. Exterior Protection Systems

System	Usual Application	Relative Cost[1]
Sealants	Waterproof control, construction, and isolation joints	Lower
Sealers	Keep out chlorides	Lower
Membranes	Keep out water and chlorides; bridge cracks	
traffic bearing	Parking structures	Lower
non-traffic bearing	Pedestrian plazas	Higher
Overlays	Durability, protection	
Portland cement concrete		Lowest
low slump, dense concrete		Lower
silica fume concrete		Higher
latex-modified concrete		Highest

[1]Costs are relative only within a system category.

Table 15-9. Durability Measures

Element	Basic Protection	Added Protection
Surface	Finishing, curing, sealer	Traffic topping
Concrete	Mix design, low w/c ratio, entrained-air, superplasticizer, etc.	Fly Ash, Silica fume, GGBS, HRM
Reinforcement	Cover, epoxy coating	Corrosion inhibitor, stainless steel
Design	Drainage, prestressing, detailing for volume change	

Chapter 16

SPECIFICATIONS

Anthony P. Chrest

16.1 INTRODUCTION

This chapter is primarily directed at project managers, designers, and specification writers, though it may interest others. The chapter scope will be limited to presenting some general information, and discussing sections of specification Divisions 3 and 7 as they relate to parking structures. These Division 3 and 7 sections cover technical areas of concrete, reinforcement and waterproofing systems and are the heart of parking structure specifications. They represent areas of continually changing technology and are often the basis of disputes, so should be written with care. Be sure to define all terms. Enforce the specification at all stages of construction. Unfortunately, enforcement is often lacking. Determined long-term education of project field staff is the only practical way to improve enforcement.

16.2 COMMUNICATION

Make it your business to talk to suppliers of all types. Ask them to review your specifications and discuss their views with you. You will soon know who is genuinely helpful and who is just promoting a product or service. These reviews will improve your specifications. More importantly, they will build good communications, respect, and trust between the supplier and you. If suppliers know that you are approachable, they may help you prevent some of the inevitable problems that arise during construction. Supplier familiarity with your specifications will produce lower bid prices.

Some designers will be reluctant to invite review discussions. They will feel uncomfortable because they will think such action will betray ignorance. Such a view is short-sighted and self-defeating in today's competitive market. Think about how you react when a stranger asks you for directions. Your first reaction is likely one of pleasure at being asked to share your knowledge. Everyone likes

A. P. Chrest et al., *Parking Structures*

to be thought helpful, so don't waste time worrying about how a supplier will take your request; just do it.

16.3 PERFORMANCE SPECIFICATIONS

A performance specification states *what* is wanted, not *how* to get it. As an example, a performance specification for concrete might list required strength, water-cement ratio, air-entrainment range, maximum slump, and minimum cement content. It will not list required ingredient proportions or give directions as to how to achieve the results.

A prescription specification states both what *and* how. In the example above, the prescription specification would require the same results, but would continue with details as to how to proportion, mix, transport, place, consolidate, finish, and cure the concrete. Most specifications today are a combination of the prescription and performance approaches.

As much as possible, we use a performance specification approach. Prescription specifications can lead to headaches for the designer, especially in product areas where new developments are rapid. Within reason, we really do not care about product ingredients, so long as the product meets our requirements. A good performance specification must contain requirements that are measurable quantitatively by standard testing methods such as those of ASTM. Pass/fail limits must be set for each test required. If a particular product is not listed in a specification, its vendor should be able to find all the performance requirements for the product category in the specification.

Make sure that your specifications contain the flexibility to deal with local or regional conditions -- more reason to communicate as suggested above.

If there is an industry-accepted requirement for a product, such as ASTM C 260 for air-entraining agents for concrete, it is sufficient to list that requirement only. If there are no industry-accepted requirements for a product type, then listing acceptable products by name, followed by the corresponding performance specification, reduces questions during bidding and construction and limits time spent with prospective vendors.

We make changes to our master specifications as needed, but only rarely make exceptions to them. The exceptions are only for trials of a new product. Exceptions may help one vendor, but they are unfair to everyone else. When we explain to a vendor that an exception on the project at hand might lead to an exception for a competitor on the next, the vendor will not persist in a request for an exception.

16.4 SPECIFICATION PRODUCTION

Computer Assisted Specifying (CAS) has been available for several years. The National Institute of Building Standards, the American Institute of Architects (through ARCOM), the Construction Specifications Institute, the military, and firms such as Sweet's provide CAS systems. Re-examine your present specification production system in light of these developments. There may be little reason to maintain your current methods. Our firm's experience is a good example.

For nearly thirty years we have maintained our own specification, tailored to our specialized market. We updated some part of our in-house specification every month. This specification has worked well for us. Within the past two or three years, however, several factors have combined to cause us to re-evaluate our specification. First, several clients required us to use the American Institute of Architects (AIA) MasterSpec© master specification for their projects. Second, our market has changed. Parking structures are becoming more complex. They often contain features requiring architectural specification sections that our in-house document never had or needed. Third, we had no full-time specification specialist to develop and maintain new sections.

We examined two "industry standard" master specifications at some length, deciding to adopt and adopt the AIA document as our new standard. The AIA document is weak in Division 3, Concrete, where our in-house specification is strong. Conversely, our in-house document was weak in the architectural divisions, 6-10. We concluded that we could easily strengthen AIA's Division 3, while acquiring strengths we did not have in other sections. The other master specification document we reviewed seemed weaker in both architectural and engineering sections, so we considered it no further. Acquiring the AIA MasterSpec© permits us to transfer some of our specification development effort and much of the maintenance outside the firm. All in all, adopting the AIA document has been a positive step for us.

The AIA documents are updated quarterly. The material provided for each section includes:

- Section text, with editing advice
- A cover sheet, outlining the revisions to the new edition of that section
- Advice on how to coordinate that section with project drawings
- Advice on how to coordinate that section with other sections of the project specification

- The Evaluations: extended editing notes and background information on the subject matter

With advances in word processing software and printers, producing an easier to edit and read project specification has become easier.

16.5 DIVISION 1

16.5.1 Section 01330, Submittal Procedures

In the AIA MasterSpec©, a provision requires that there will be one subsequent visit by the designer to recheck punch list items previously noted as unfinished. Further visits necessitated by unfinished work will be at the expense of the general contractor. The prudent designer will include a similar provision for shop drawing checks in the case where a shop drawing is marked, "Revise and resubmit." Designers should not provide unlimited checks of such drawings.

16.6 DIVISION 3

16.6.1 Section 03300, Cast-in-Place Concrete

In bidding, bidders often neglect to read specification requirements. For example, concrete specified with a 28-day strength of 4,000 psi *and* a water-cement ratio of 0.40 will cost appreciably more than that specified with the strength requirement alone. If the bidder sees the first requirement but not the second, the profit margin may be reduced enough to cause the bidder, and you, problems downstream.

Example:

Required:	4,000 psi compressive strength at 28 days 0.40 water/cement ratio 3 in. slump
Water Demand:	Concrete requires approximately 275 lb (33 gal) of water per cu yd to achieve a 3 in. slump.
Cement Factor:	water/cement = 0.40

cement = 275 lb/0.40 = 687.5 lb/cu yd

Problem: If the strength requirement is shown as 4000 psi at 28 days, the ready-mix concrete producer often bids on this information, but misses the maximum water/cement ratio that governs. A cement factor of 550 lb/cu yd is usual for 4000 psi compression strength. The 137.5 lb of cement per cu yd increase (687.5 - 550) necessitated by the water/cement ratio is a significant extra cost to the ready-mix producer if not included in the bid.

Result: The mix design may be "adjusted" to meet the specification. The cement factor included in the bid may be used with a fictitious water content in order to conform to the maximum water/cement ratio of 0.40.

Listed Water Content = Cement Factor x 0.40
= 550 lbs x 0.40
= 220 lbs/cu yd (26.4 gal)

Concrete cannot be mixed at this water content. If you include a short caution under the "Scope of Work" heading in Section 03300, Cast-in-Place Concrete, it might prevent this problem.

Example:

Work Included: Specification specifies cast-in-place concrete, including formwork, reinforcing, mix design, placement procedures, finishes and other miscellaneous items related to cast-in-place concrete.

Concrete Supplier:	Concrete specified here requires high strength, entrained air, low water-cementitious materials ratio, and superplasticizer.

However, don't expect this notice to be read by bidders. No one reads specifications until there's a problem, so recognize this fact of life by addressing this and other important issues in a prebid conference. Address it again at the pre-construction and pre-concrete conferences. Note that ACI 318 Chapter 4 commentary begins by emphasizing the need for strength and water-cement ratio to be consistent.

16.6.2 Entrained Air.

Correct entrained-air content in concrete improves workability and protects the hardened concrete from freeze/thaw damage. Other common additives will improve workability, but few others will provide freeze/thaw protection -- none as inexpensively.

Entrained-air content requirements to provide adequate protection vary widely depending on climate. Requirements in North America typically vary from a range or 5-7% in northern latitudes to 4% or less farther south. State or Provincial Department of Transportation requirements for entrained air for bridge construction are reliable guidelines if you have no experience in a locality.

If requirements are set, the next question is, where should the air content be measured? If the concrete leaves the ready-mix plant with x% entrained air, chances are that the in-place concrete will have 1/2x% entrained air or less. Transportation, pumping, consolidation, and finishing all tend to remove entrained air from plastic concrete, particularly the latter two.

Check air content at the truck. Also check it after screeding. Air content is the most difficult concrete ingredient to control. Expect problems with it and be prepared for them.

16.6.3 Finishing.

Improper finishing is usually over-finishing. The best finishing is that accomplished with the least effort.

For a parking structure, the finish itself should be rough enough to provide traction for car tires and to prevent slipperiness when wet. It must not be so rough as to become a tripping hazard for pedestrians. Suggested finish is light broom.

Examples from our section 03300 specification:

A. Flatwork in Parking and Drive Areas (BROOM Finish, ACI 301):

1. Bullfloat immediately after screeding. Complete before any excess moisture or bleed water is present on surface (ACI 302.1R, Article 7.2.3).
2. After excess moisture or bleed water has disappeared and concrete has stiffened sufficiently to allow operation, give slab surfaces coarse transverse scored texture by drawing broom across surface. Texture shall be as accepted by Engineer from sample panels.

[Editing Note: See ACI 117, paragraph 4.5.7, choose the dimensional tolerance you want for your project and insert it below.]

3. Finish tolerance: ACI 301, Paragraph 5.3.4.2 and ACI 117, paragraph 4.5.7: The gap at any point between the straightedge and the floor (and between the high spots) shall not exceed 0.5 in. In addition, floor surface shall not vary more than +/- 0.75 in. from elevation noted on Drawings anywhere on floor surface.

[Editing Note: Always use test panels. Contractors have had some problems with uneven surfaces developing in plastic concrete after final finishing, even on level slabs. Use the test panels to fine tune the mix design and work the bugs out of placing, finishing, jointing (particularly if using a "Soff-Cut" saw), and curing. When surface is dry and interior of concrete slab is not set, finishing operation may cause waver on slab surface. Uniform setting will minimize potential for wavy surfaces].

4. Before installation of flatwork and after submittal, review, and approval of concrete mix design, Contractor shall fabricate two acceptable test panels simulating finishing techniques and final appearance to be expected and used on Project. Test panels shall be minimum of 20 ft. by 30 ft. in area and shall be reinforced and cast to thickness of typical parking and drive area

wearing surface in Project. (Maximum thickness of test panels need not exceed 6 in.) Test panels shall be cast from concrete supplied by similar concrete batch, both immediately after addition of superplasticizer or water-reducing admixture, and at maximum allowed time for use of admixture supplemented concrete in accordance with Specifications. Intent of test panels is to simulate both high and low workability mixes, with approximate slump at time of casting of test panels to be 6 in. and 3 in., respectively. Contractor shall finish panels following requirements of paragraphs above, and shall adjust finishing techniques to duplicate appearance of concrete surface of each panel. Finished panels (one or both) may be rejected by Engineer, in which case Contractor shall repeat procedure on rejected panel(s) until Engineer acceptance is obtained. Accepted test panels shall be cured in accordance with Specifications and may be incorporated into Project. Accepted test panels shall serve as basis for acceptance/rejection of final finished surfaces of all flatwork.

5. Finish all concrete slabs to proper elevations to insure that all surface moisture will drain freely to floor drains, and that no puddle areas exist. Contractor shall bear cost of any corrections to provide for positive drainage.

[Editing Note: Our usual finish for parking and drive areas is rough swirl texture. However, sometimes we have had difficulty getting it. You may choose the "broom finish" paragraph or "swirl finish" paragraph. Delete one or the other. See editing notes above where applicable.]

B. Flatwork in Parking and Drive Areas (SWIRL Finish, ACI 301):

1. Begin bull floating after bleeding of water through surface of concrete has been completed and water sheen has disappeared from surface of concrete and concrete has stiffened sufficiently to allow operation (ACI 302.1R-80, Article 7.2.9).
2. Give slab surfaces rough, swirl texture finish. Swirl ridges shall not be allowed to exceed 0.25 in. in height. Texture shall be as accepted by Engineer from sample panels. No refloating required.
3. Finishing tolerance: ACI 301, Paragraph 5.3.4.2 and ACI 117, paragraph 4.5.7: The gap at any point between the

straightedge and the floor (and between the high spots) shall not exceed 0.5 in. In addition, floor surface shall not vary more than +/- 0.75 in. from elevation noted on Drawings anywhere on floor surface.

4. Before installation of flatwork and after submittal, review, and approval of concrete mix design, Contractor shall fabricate two acceptable test panels simulating finishing techniques and final appearance to be expected and used on Project. Test panels shall be minimum of 20 ft. by 30 ft. in area and shall be reinforced and cast to thickness of typical parking and drive area wearing surface in Project. (Maximum thickness of test panels need not exceed 6 in.) Test panels shall be cast from concrete supplied by similar concrete batch, both immediately after addition of superplasticizer or water-reducing admixture, and at maximum allowed time for use of admixture supplemented concrete in accordance with Specifications. Intent of test panels is to simulate both high and low workability mixes, with approximate slump at time of casting of test panels to be 6 in. and 3 in., respectively. Contractor shall finish panels following requirements of paragraphs above, and shall adjust panels finishing techniques to duplicate appearance of concrete surface of each panel. Finished panels (one or both) may be rejected by Engineer, in which case Contractor shall repeat procedure on rejected panel(s) until Engineer acceptance is obtained. Accepted test panels shall be cured in accordance with Specifications and may be incorporated into Project. Accepted test panels shall serve as basis for acceptance/rejection of final finished surfaces of all flatwork.

5. Finish all concrete slabs to proper elevations to insure that all surface moisture will drain freely to floor drains, and that no puddle areas exist. This Contractor shall bear cost of any corrections to provide for positive drainage.

16.6.4 Curing

Curing is often slighted. That's unfortunate, because the curing process, if properly done, can improve concrete quality. If done incorrectly, it might as well have not been done at all. The excerpt below, taken from our specification section 03300, gives some advice on curing and curing materials. Some of the curing compounds listed in the excerpt are marketed as "curing and sealing compounds," giving the impression that they both cure and seal. Not so; they cure only. Do not be misled into assuming that because one of these products is used on your project, you need not apply a penetrating sealer.

Curing Materials

[Editing note: Evaporation retarder below temporarily reduces moisture loss from concrete surfaces waiting finishing in hot, dry, and windy conditions. Evaporation retarders are not curing compounds. Beware of overuse by the finishers. Evaporations retarders are mostly water, so be sure that they are sprayed on the plastic concrete with a properly operations sprayer, not drizzled or poured.]

A. Evaporation Retarder: Waterborne, monomolecular film forming, manufactured for application to fresh concrete.

[Editing note: Select curing aids and materials from paragraphs below, retaining optional materials if applicable.]

B. Absorptive Cover: AASHTO M 182, Class 2, burlap cloth made from jute or kenaf, weighing approximately 9 oz./sq.yd. dry.

C. Moisture-Retaining Cover: ASTM C 171, polyethylene film or white burlap-polyethylene sheet.

D. Water: Potable.

[Editing note: Below are clear, solvent-based, membrane-forming curing compounds that meet the federal requirements for volatile organic compounds (VOC) of 700 g/l. retain if lower-VOC emissions are required. Verify curing compounds meet maximum emission limits of authorities having jurisdiction. Nondissipating-type products have generally been listed.]

E. Curing Compound (VOC Compliant, 700 g/l): Liquid type membrane-forming curing compound, clear styrene acrylate type, complying with ASTM C1315, Type I, Class B, 25% solids content minimum. Moisture loss shall be not more than 0.40 Kg/m^2 when applied at 300 sq. ft/gal. Manufacturer's certification is required. Subject to project requirements provide one of the following products.

1. Super Rex Seal, The Euclid Chemical Company.
2. Masterseal 30, Master Builders.

[Editing note: Below is a clear, waterborne, membrane-forming curing compound which meets 350 g/l VOC requirements of several states, notably New York, New Jersey, California, Texas, etc. these compounds have a minimum solids content of 25%.]

F. Clear Curing Compound (VOC Compliant, 350 g/l): Liquid type membrane-forming curing compound, clear styrene acrylate type, complying with ASTM C1315, Type I, Class A 25% solids content minimum. Moisture loss shall be not more than 0.40 Kg/m^2 when applied at 300 sq. ft./gal. Manufacturer's certification is required. Subject to project requirements provide one of the following products:

   1. Super Diamond Clear VOX, The Euclid Chemical Company.
   2. Masterkure 100W, Master Builders.

G. Products; Subject to compliance with requirements, provide one of the following:

   1. Evaporation Retarder:

      a. Cimfilm; Axim Concrete Technologies.
      b. Aquafilm; Conspec Marketing & Manufacturing Co., Inc.
      c. Eucobar; Euclid Chemical Co.
      d. E-Con; L&M Construction Chemicals, Inc.
      e. Confilm; Master Builders, Inc.
      f. SikaFilm; Sika Corporation.
      g. Sure-Film (J-7): Dayton Superior Corporation.

16.6.5 Section 03410, Structural Precast Concrete-Plant Cast.

Whether you use a performance specification, with some or all of the piece design assigned to the precaster, or you provide full structural design services, the success of any project with sizeable quantities of precast elements is in the precaster's hands. While even the best precaster cannot produce a good project from a poor design, a poor precaster can certainly spoil a good design. Your best defense is to work with precasters whom you have come to trust. If you are working in a locale new to you, use well-written prequalification requirements to exclude questionable performers. Require PCI plant certification. Keep in mind, though, that no industry standards will protect you from dishonesty by any vendor. Sometimes your only defense may be to refuse to work with a vendor who has cheated on a previous project, even if it means losing the current project.

16.7 KEEPING CURRENT

Treat your master specification as a living document. We update some part of ours every month. What you see in this chapter was current when it was written. By the time this book is published, several months will have elapsed. We guarantee that some part of the quoted sections will have been superseded, during the intervening months, because of new experiences, changing technology, and new product research.

16.8 SUMMARY

Specifications are one of the two principal means to communicate project requirements from the designer to the builder. As such, specifications must be clear, complete and fair. We have discussed some of the likely trouble spots in a typical parking structure specification and have included excerpts and sections from our master specification. Finally, no matter how watertight the specification, without communication to reinforce and enforce the specification at the jobsite, the specification will be worthless.

Chapter 17

CONSTRUCTION

Anthony P. Chrest

17.1 INTRODUCTION

This chapter is for owners, designers and builders. The construction process should involve all of you. When it does not, problems arise. All too often relations between owner, designer and builder become adversarial shortly after construction begins. They stay that way for the rest of the project. Instead of working *with* each other, the team members waste most of their energy working *on* each other. This sorry state does not have to be. Imagine how much less time a project would take if only half the disputes and "cover your tail" paperwork could be eliminated. It can be done, because it has been done. Trust is the key; however, trust is not free; it must be earned. Earn trust by fair treatment, clear communications in every step, and clear communications *before* every step. All this will take unaccustomed effort. It also may initially require behavior that makes you uncomfortable, but the resulting savings in time and hassle will be worth it. Give it a chance.

17.2 COMMUNICATION

17.2.1 Plans and Specifications

The lifeblood of the construction process is communication - clear, concise, and constant. It must begin well before construction begins -- during drawing and specification preparation in the designer's office. At this point the owner and designer must communicate. The owner must make clear its intentions for

A. P. Chrest et al., *Parking Structures*

the project. The designer must achieve that intent while keeping the project within the owner's total budget. Trade-offs during this process are likely.

Repetition through different modes of communication will make the message clearer. It is usually best to follow up spoken messages with written confirmation of one party's understanding of what was said. Invite corrections before a stated deadline. If the deadline passes with no corrections received, the ground rules must say that the written message stands. Memories are short, especially in disputes where what really happened conflicts with what we would like to have happened. During the preparation of plans and specifications, designer and owner should review the documents together, signing off as they go. This practice, if followed, will bring the project to completion with few detours. Keep in mind though, that some arguments will happen and may even make for a better project.

Drawings must clearly give the prospective builder enough information both to estimate a construction cost and to build the project.

Quality control during drawing production is important. Drawings for a recent project, for which we were consulted as an expert witness, showed an obvious conflict between column vertical bars and slab dowels, yet the conflict was not noticed until construction, when the dowels pulled out of the columns. When questioned, the response from the Designer of Record was, "The draftsman showed it that way." The response betrayed both lack of quality control and lack of knowledge of what was on the drawings.

Another issue that has arisen on some projects is the reluctance of some sub-consultants to communicate with the lead consultant. While the issue may seem minor, lack of intra-design-team communication can impede construction and cause needless friction between parties. With all the communications tools available today – telephone, fax, e-mail, and project web-sites – there is no excuse for poor communication practices.

Enough has been said elsewhere on the subject of unclear documents. Unfortunately, there are still designers who contract for document preparation at a fee so low as to prevent doing a complete job. What results is a project with many problems, an unhappy owner and lawsuits. Any owner savings resulting from the low design fee will be eliminated by higher construction costs. A higher design fee may produce a lower total project cost. Owners must learn to look at the total cost of the project: design cost *and* construction cost. Owners, ask the design firm you are considering hiring for its track record of self-caused construction change orders. If no such record is forthcoming, how can you estimate the total cost of your project? If an designer quotes you - an owner - a fee that seems too good to be true, it probably is, and it will likely cost you more in higher bids and construction change orders than you saved in design fees.

17.2.2 Understandable Specifications

Too many design professionals believe that a good specification must be full of legalese. A review of proprietary master specifications such as the AIA (ARCOM) "MasterSpec©" or the Construction Specifications Institute "Master Specification" shows that the briefer, the better. Specifications must be clear, concise, and no longer than necessary. Look for ways to shorten your specifications while still stating your message clearly.

17.2.3 Bidding or Negotiating

Common bidding procedures often work against good communications during this critical phase in a project's life. Adversarial relationships may begin at this stage because information that one party, usually the bidder, wants is not available.

Let's define a successful bidding process as one that produces a bid by a trustworthy contractor that is within the owner's budget. Bringing the bidding process to a successful conclusion has to begin early. Recognize potential pitfalls and plan to avoid them. A rigorous prequalification procedure is critical to successful bidding, particularly if the owner is a public entity such as a municipality or airport authority. A good prequalification procedure will eliminate the poor contractors that public work attracts. Such a procedure should include verification of bonding capacity, financial stability, and references.

Use a prebid conference during the bidding period to emphasize to bidders what you want them to understand, particularly those items unique to parking structures or to your specification. Though a prebid conference is common practice, our experience has been that meaningful questions are not often asked. Bidders, being competitors for the project, will not say too much for fear of giving away a real or imagined advantage. The understandable result is little worthwhile communication.

Another problem with bid jobs is there may be little control over who may bid and therefore, who gets the work. Unless prequalification procedures (mentioned above) are used, the owner may have no control over to whom it gives its hard-earned money. Even then the successful contractor may not be the owner's first choice. So, bidding may result in a forced marriage. How many of those work?

Step one in successful construction price negotiating is the owner's selection, with designer advice, of a reputable builder with demonstrated success in parking structure construction. Check the prospective builder's financial stability too, even (and especially) if the builder is a friend or has worked with you before. In negotiating, the parties must talk. Make available the opportunity for give and take on both sides. All three sides must win the negotiation. Fairness is the key. Mutual trust and a spirit of working *with*, not *on*, one another will begin here. The negotiated price may be more than the bid price might have been. However, the price at the end of the project will not be more than obtained through negotiation, because there will be a better understanding of what is included in the project by all parties. The fewer construction change orders that result will produce a lower final cost. And, the owner's increased control over who does the construction work stacks the deck for just such an outcome.

17.2.4 Preconstruction

Before the initial euphoria of signing the construction contract wears thin, begin preconstruction planning. The owner, designer and builder must meet with all the major players in the construction process, such as:

Concrete supplier
Concrete placer
Concrete finisher
Concrete curer
Concrete inspector
Concrete tester
Precaster supplier
Precast erector
Others

"Others" includes contractors, suppliers, and professionals who are involved in almost any multilevel building construction. Examples are excavators, elevator contractors, roofers, geotechnical engineers, and painters, to name a few. Since concrete is the single most important and expensive component of most parking structures, we emphasize it. It is advisable to hold more than one preinstallation meeting for different parties and/or during different phases of construction. Example: why discuss painting until the builder schedules that work?

The outcome of a concrete preinstallation meeting, one of the preinstallation meetings to be held, must be a written procedure that spells out who will do exactly what and when. This written procedure must be reviewed, discussed, and signed by every party involved in the work for the items listed:

Mix design(s)
Mix design submission
Mix design approval
Proportioning and mixing
Transportation
Placement method(s)
Consolidation procedures
Finishing procedures
Weather protection procedures
Curing procedures
Testing procedures, locations, and frequency
Testing personnel qualifications
Inspection requirements
Inspector qualifications
Test and inspection reporting
Repair criteria and procedures
Conflict resolution
Acceptance criteria
Criteria for reduced payment
Suppliers' quality control
Subcontractors' quality control
General contractor's quality control
Designer's site quality control

Every party must keep a copy of the agreed-upon procedure on hand, particularly at the site. The above list may seem too long, but every item listed has been disputed among some of the parties involved in construction. Several examples of common disputes follow. You can avoid most of them by reaching agreement on the list above before construction begins, not after the problem occurs. It's far better to resolve disputes in advance around a table in a comfortable room than to try to do it in the heat of the battle.

First example: On several projects a year, we'd receive a frantic call from the builder, "We're ready to pour footings. The truck is here. Is the mix design okay?" To which we'd reply, "What mix design?" because we had not received it. Builder: "Well, can we pour anyway?" We always say no, making sure that the issue will never again arise on that project.

Second example: Another dispute may arise just after the first compression test cylinder reports come in, showing that some concrete is under strength. Next, the builder alleges that the testing agency's site person took, stored, handled, and transported the test cylinders wrong. Besides, the person was just some kid who didn't know which end was up anyway. The testing agency stoutly denies all these ridiculous claims. The important point, whether or not the concrete is really under strength, is left unresolved.

Third example: The project specification clearly states that provisions must be ready to protect fresh concrete from rain and snow. The first time it rains, no protection is ready. Once more, blame is tossed back and forth while the real problem is obscured. The unacceptable concrete surface will still be there, and will have to be repaired.

Fourth example: Opportunities for mistakes abound during the finishing process. Since the slab finish is exposed to the weather, it has to be durable. The best finish is therefore one that can be produced with the least possible working of the surface. It also must be roughened somewhat so that it's not too slippery for tires or shoes. The best way to define the finish: take the finishing crew foreman to another project. Show the foreman what you want. Spell out the finishing requirements in the project specification and review them with the foreman too. For these requirements, see Chapters 15 and 17. Take the time to explain why you want what you want. We've found that few designers take the time to give explanations for what they want. When we do, it really makes an impression. The craftsmen appreciate our concerns and cooperate.

Fifth example: If you see a concrete finisher with a bucket of water doing anything other than cleaning tools with it, get rid of the bucket. Some finishers do not feel they have done a good job unless they add water to the surface as they work. This practice does make finishing easier, but results in a weakened surface that will deteriorate quickly. Avoid this potential problem with a good concrete pre-installation meeting.

Sixth example: Non-conforming test results are overlooked, causing severe problems when and if they're found later, when the non-conforming concrete is buried in the structure. Require that all non-conforming test results are faxed to the designer, and that all paper copies of such results are printed on colored paper. Such simple procedures will prevent complex problems.

If the project includes precast concrete, a pre-installation meeting with a similar result is necessary for:

Precast concrete mix design(s)
Precast concrete mix design submission
Precast concrete mix design approval

Reinforcement and accessories submission
Reinforcement and accessories approval
Shop drawing submissions, including schedule
Shop drawing approvals
Design requirements (if applicable)
Design submission (if applicable)
Design approval (if applicable)
Manufacturing tolerances
Testing procedures
Inspection procedures
Testing personnel qualifications
Inspector qualifications
Test and inspection reporting
Precaster's quality control
Fabrication, curing, storage, and handling procedures
Erection plan
Shipping plan
Handling procedures at the site
Erection procedures
Erection tolerances
Erector's quality control
Engineer's site quality control
Repair criteria and procedures
Acceptance criteria
Criteria for reduced payment

The following four paragraphs illustrate issues of potential dispute. You can avoid them through good communication in a preconstruction meeting.

Most precasters would prefer that the engineer not check their shop drawings. The checking process delays the start of production even if all drawings are correct. More delays occur if the engineer finds mistakes or makes changes. These delays intrude into the already tight schedule, completely filling the time between precast concrete contract signatures and erection of the first piece. Yet if no one checks the shop drawings, serious mistakes will carry through to fabrication, erection and the final structure. We know of two recent structures where members were made with insufficient reinforcement. The result in both cases was partial dismantling of the structures and replacement of the defective pieces.

Improper storage practices in the precaster's holding yard can result in damaged pieces. You might caution the precaster about support points and stacking heights, even though these issues are not your responsibility.

Other potential trouble spots are erection tolerances that affect connections, and the sequence of erection and connections. The Precast/Prestressed Concrete Institute (PCI) has adopted erection tolerances, but you may have to adapt them, or add more to fit your project requirements. Before you add new tolerances, check with the prospective bidders to get a consensus of what's realistic. Then try to work from that information. Most erectors will want to make permanent connections as late in the erection process as they can. Doing otherwise interrupts and delays erection, costing expensive crane time. However, C-clamps and other temporary connections are not as strong as permanent ones. Frame stability may be temporarily reduced. With the serious construction collapses of the past, the last thing anyone needs is a collapse waiting to happen. Agree on some middle ground so that permanent connection installation does not lag much behind erection.

Another pre-installation meeting must be held for those involved with concrete reinforcement, especially if post-tensioned (P-T) reinforcement will be used:

Materials submissions
Materials approvals
Shop drawing submissions
Shop drawing approvals
Design requirements
Placement tolerances
Stressing procedures
Stressing record keeping
Stressing record submission
Stressing record approval
Tendon cutoff procedures
Stressing pocket fill and seal procedures
Repair criteria and procedures
Acceptance criteria
Contractors' quality control
Inspection procedures
Inspector qualifications
Engineer's site quality control

Note the number of items in the list involving stressing P-T tendons. That's because there are usually problems. Too often the stressing records submitted are too neat and the recorded elongations are exactly the same. We do not trust such reports. Another point: we do not allow the post-tensioner to cut off tendons and fill the stressing pockets until all tendon-elongation discrepancies are resolved.

17.2.5 Construction

Whether you are the owner, builder or designer, if you laid the groundwork properly during the pre-construction phase, you will have fewer communications problems during the construction phase. Do not relax, though; answer questions from the other two major parties quickly and completely. Concentrate on building and maintaining trust. Achieving mutual trust is not easy. It requires setting your own ego second to the success of the project. Whether or not you are covered against any eventuality is not all that important. What is important is the completion of the project according to requirements - including being on schedule and under budget.

Some years ago, to sort out some ongoing construction disputes, the design and construction management firms met. At the end of an inconclusive meeting, one designer's principal announced that he was leaving before the general contractor joined them for the next meeting. His comment, "I do not want to talk to contractors." The project finished with poor quality, behind schedule and over budget. The lawsuits went on for several years, but the principal's ego was protected.

Do not approach construction problems by ignoring them in the hope that they will go away or get better. They will not.

17.3 BUILDABLE DETAILS

Designers, do not contribute to construction problems by detailing items that have to be built like a watch. Our firm requires all design engineers to spend at least six months on a construction site so they can see first hand which details work and which do not.

One situation that may arise is the case when a detail that works well with precast concrete is translated into a cast-in place detail; it may have little chance of proper execution. Consider the detail shown in Figure 17-1. This detail is not uncommon in precast parking structures. It shows a beam-column sliding joint. A few years ago a contractor called us in for help with a construction dispute. The plans showed this detail, but in cast-in-place concrete. Note the construction sequence required.

First, form the column and place it to the top of the haunch. Next, form and place the portion of the column above the haunch, then strip the column form.

Install the lower slide-bearing assembly so that it will not be displaced during subsequent steps; form the beam. The end of the beam bottom form must be left open to allow the upper slide-bearing assembly to bear directly on the lower assembly. Install the upper bearing assembly so that it too will not be displaced during later steps. Seal between the upper bearing assembly and the beam form so that the cement paste will not leak out, leaving voids. Install the congested beam end and main reinforcement. Place the beam concrete.

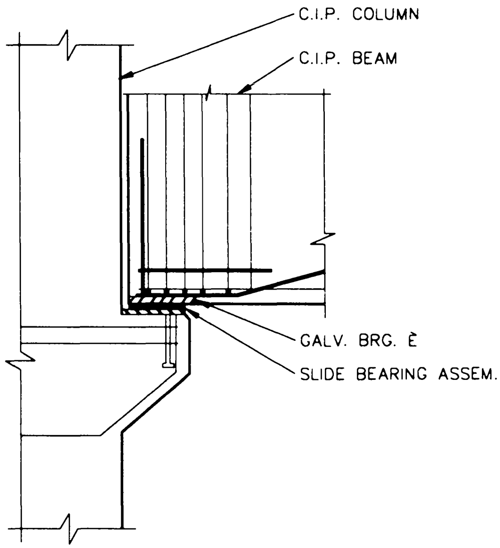


Figure 17-1: Beam Slide Bearing.

Figure 17-2 illustrates a similar detail for a slab bearing and sliding on a beam. While not as difficult to build as the Figure 17-1 detail, it is easier to build it wrong than right.

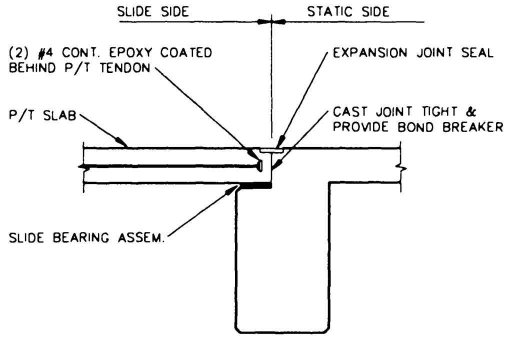


Figure 17-2: Slab slide bearing.

Rather than use details like those shown in Figures 17-1 and 17-2, use only details that are easy to build in the particular structural system. Simply put, avoid opportunities for error. With but a few specific exceptions, we recommend avoiding slide bearings unless no other solution works. Avoiding slide bearings may result in having to add a column to replace a group of beam slide bearings, but the extra initial cost will be recouped with lower maintenance costs. The only condition where we use slide bearings is illustrated in Figure 12-30. There the vertical load on the bearing is low, producing low friction forces on the bearing surfaces. The anticipated movement is small because of the location of the joint in the structure and the fact that only one side of the joint is free to move.

We were engaged as expert witnesses on a project built some years ago. One of the owner's complaints was that a large number of post-tensioning tendons had little or no cover and were becoming exposed. The contractor had been instructed by the structural engineer to maintain a top cover of between one-half and three-quarters of an inch. Conscientious workmen can maintain a vertical tolerance of plus or minus four-tenths of an inch in placing reinforcement. Within that tolerance, the tendons would be placed with covers ranging from one-tenth to one and fifteen-hundredths inches. The lower figure is just about what the engineer got. Why criticize the contractor?

17.4 CONSTRUCTION SEQUENCE

The task of building a structure with floors that slope continually brings with it a few problems that may not be apparent to one whom has never built such a structure before. Obviously, the floors are not discrete segments, but form a continuous ribbon of concrete from bottom to top and back again. While the engineer will suggest a construction sequence and may give certain constraints, the builder must decide for itself what the best arrangement of construction joints and concrete pours will be. Figure 17-3 shows an example of a suggested construction sequence. The numbers in smaller circles indicate the order of concrete placement. The figure numbers, in larger circles, show selected details.

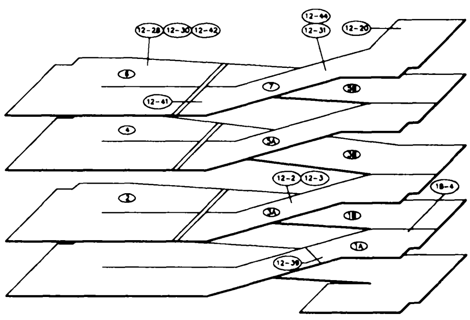


Figure 17-3: Example of a suggested concrete placement sequence. Numbers in the smaller circles show pour sequence. Hyphenated Figure numbers in the larger circles indicate selected details.

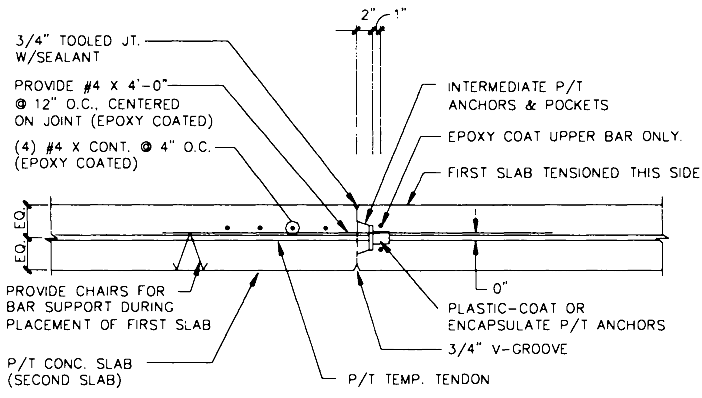


Figure 17-4: Section view at a slab construction joint

17.5 SITE VISITS

17.5.1 General

Designer, set the tone for all future visits with your first. Answer all questions promptly and completely. If you do not know an answer, say so instead of trying to come up with a statement that you may have to retract later. Do get a response back to the questioner quickly if you cannot answer at the site. *Listen* to the project superintendent. You can learn a lot, if you're willing; the superintendent may have been working in construction before you were born.

Do your best to maintain good relations with the builder's people, but hold your ground on important requirements. We believe that the best way to approach a construction project is to have clear requirements in the contract documents. If, on a project, a requirement cannot be fully satisfied after the construction contract has been signed, there must be a trade-off to compensate the owner for getting less value than the contract required. The trade-off could be a credit to the owner, a reduction in the originally-agreed upon construction time, or enrichment in some other aspect of the project. Whatever the eventual agreement on the particular requirement, record it. If the owner does not receive fair value, you, the designer, have not performed.

If the contract documents give you the right to remove a contractor's or subcontractor's superintendent for nonperformance or incompetence and such turns out to be true, don't hesitate to assert your right. Life is too short to continue to buy trouble.

17.5.2 Before Supported Cast-in-Place Concrete Floor Placement

Rarely will a concrete parking structure floor receive a floor covering later. The only protection for the structural reinforcement is the concrete itself. Proper cover is therefore critical. Check to see that all reinforcement - non-prestressed and post-tensioned - is placed correctly. Ensure that post-tensioning tendons are free from kinks. Check for cover and alignment of tendon anchors. See that tendon sheathing is continuous and intact from anchor to anchor. Get all sheathing tears repaired according to the procedure specified below.

Sheathing repair procedure:

1. Restore tendon corrosion preventive coating in damaged area.
2. Coat with corrosion preventive coating outside of sheathing length of damaged area, plus 2 in. beyond each end of damage. Example: If sheathing tear is 6 in. long, then corrosion preventive coated area will be 10 in. long, centered on tear.
3. Place piece of slit sheathing around corrosion preventive coated tendon. Slit shall be on side of tendon opposite tear. Length of slit sheathing shall overlap corrosion preventive coated area by 2 in. at each end. Example: If corrosion preventive coated area is 10 in. long, then sheathing will be 14 in. long, centered on tear.
4. Tape entire length of slit sheathing, spirally wrapping tape around sheathing to provide at least 2 layers of tape. Taping shall overlap slit sheathing by 2 in. at each end. Before taping, sheathing shall be dry and free of corrosion preventive coating. Example: If slit sheathing is 14 in. long, then taped area will be 18 in. long, centered on tear.

Ironworkers often tie sheathed tendons to support chairs or bars so tightly that the sheathing is crimped. The crimp provides a place for moisture, already inside the sheathing, to condense. This condensation is the first step toward tendon corrosion. Get all too-tight ties redone. Better yet, work with the foreman and crew before they start. Explain to them what you want and why. You will likely find them pleased with the time you took and quite cooperative. If the ironworker foreman does not cooperate, get one that will.

Likewise, work with the concrete finishers and placement crew to be sure that they understand that you want the absolute minimum working of the concrete floor surface necessary to achieve the desired finish - screed, bullfloat, broom or float. (See 17.5.3 for requirements.) Be certain that everyone involved in the concreting operation understands that *no* water may be added to the concrete surface during finishing.

17.5.3 During Supported Cast-in-Place Concrete Floor Placement

Do not permit vibrators to be used to move concrete, even if it is superplasticized. Guard against over-vibration, which will drive out entrained air and bring paste to the surface. Both results reduce durability; under-vibration results in honeycombing.

The typical placement (pour) in a parking structure is rectangular in plan. Place the concrete beginning at one of the shorter ends of the rectangle and bring the pour face forward toward the opposite shorter end in the direction parallel to the two longer sides. Always keep the pour face parallel to the shorter sides, will result in the open or forward face of the pour being kept as short as possible. You should not have to advise a builder to reduce risk by maintaining a short pour face. However, for the good of the project, we have had to do so.

Watch for post-tensioned tendon sheathing tears, dislodged reinforcement, and crushed support chairs. Get these items repaired or replaced before they are covered by concrete. In long-span construction with relatively shallow members, there is little tolerance for misplaced or damaged reinforcement.

17.5.4 Field Observation Guidelines

17.5.4.1 Cast-in-Place Post-Tensioned Structure

We prefer to have a project resident on site full time during all cast-in-place post-tensioned concrete construction to help guard the owner against deviations from the contract documents. If the project budget renders a full-time resident infeasible, then we like to have one on-site at least the day before each slab and beam pour to review non-prestressed and post-tensioned reinforcement. We also want the resident on-site during the pour itself to guard against reinforcement being displaced and post-tensioning system protection being damaged. The resident should also review all the concreting, finishing and curing operations, as well as concrete quality control testing.

One person can usually handle these tasks satisfactorily for each pour. If two or more pours occur simultaneously, more people will be needed.

Appendix 17-1 contains a guideline, which could easily be converted into a checklist for the resident, for reviewing the items that must be checked for cast-in-place post-tensioned concrete prior to each pour.

17.5.4.2 Precast Structure

Field observations for precast concrete structures are confined to concern with erection and connection of the precast pieces.

There will be some cast-in-place concrete work, for instance, at the ends of the double tees for a pretopped double tee structure, or over the entire tee for site-topped double tees. Treat that work as you would any other cast-in-place work, but recall the cautions about topping work in Chapter 12.

Watch for conformance to specified erection and connection sequences. Appendix 17-2 contains a guideline that could be converted into a checklist for the resident's use each day or each site visit.

17.6 PRECAST CONCRETE PLANT VISITS

Visit the plant supplying your project during fabrication of the first few pieces of each piece category. Check for proper placement of reinforcement and cast-in assemblies such as connection hardware. If welding of non-prestressed reinforcement is detailed, spot check the welds. Review concrete test results. Visit the storage yard to see if members are stacked to prevent damage. Revisit the plant at appropriate intervals.

Appendix 17-3 contains a checklist for use for each visit to the precast concrete fabrication plant.

17.7 SUMMARY

We have discussed the overriding need to establish good communication among members of the project team during the construction phase. Concentrate on prevention of common problems before they occur. The president of a large construction company once told us, "You are going to have problems on any job." The implication was that problems cannot be avoided. With good communications, many problems - admittedly not all - can and will be avoided. Along that line, we discussed using buildable details to help ensure proper execution of contract documents. A well-planned construction sequence is another preventive measure. Finally, we offered some help with site and precast plant visits during construction. During construction, the designer's most important task is to guard against unplanned departures from the intent of the contract documents. What was designed must be built.

17.8 TRANSITION

Sometimes, providing a maintenance program for the new parking structure is part of the agreement between owner and designer for professional services. Sophisticated owners will recognize the prudence of funding a maintenance budget and providing programmed maintenance from the beginning. In other cases, maintenance is not considered until the need becomes obvious. Chapters 18 and 19 review parking structure maintenance needs.

APPENDIX 17-1

Guidelines for Field Observation for a Cast-in-Place Unbonded Post-Tensioned Concrete Parking Structure

A. P-T Tendons - general
   1. Sheathing thickness.
   2. Tears repaired.
   3. Proper amount of grease.
   4. Encapsulation system.

B. Slabs
   1. Main tendons:
      a. Number
      b. Drape profile
   2. Temperature tendons:
      a. Number
      b. Location at center of slab
      c. Straight placement
      d. Properly supported so that they do not affect main tendon profiles
   3. Plates at ends:
      a. Correct position
      b. Truly vertical
      c. #4 Bars behind plates
      d. 1-1/2 in. minimum / 2in. maximum cover for dead end
      e. Epoxy coating
   4. Non-prestressed Reinforcing:
      a. At slab midspan
      b. At slab supports
      c. Epoxy coated?
      d. Epoxy coated chairs, tie wires?
   5. Expansion joint:
   6. Bumper wall steel placement / size
   7. Stainless steel, plastic tipped or plastic chairs for slabs with bottom exposed.

C. Beams
   1. Stirrup number and spacing
   2. Non-prestressed bars

a. Top
b. Bottom

3. Hook at ends of top and bottom steel to outside face of column in line with column steel.
4. Tendons:
   a. Number
   b. Location at midspan
   c. Location at ends
   d. Spot-check at 1/4 points and at 3/4 points
5. P-T plates:
   a. Correct location
   b. Extra ties at each side of plate
   c. Rebars behind plates
6. Expansion joint:
7. Steel from adjacent beam in place if required
8. Other

D. Columns
1. Vertical bars:
   a. Number
   b. Location
   c. Splices
2. Ties:
   a. Number
   b. Location

E. Miscellaneous
1. Provisions for future construction
2. Provisions for precast fascia connections
3. Provisions for expansion joint: structural, electrical, mechanical
4. Joints at stairtowers
5. Electrical boxes and conduits in proper position
6. Forms to be clean: free of cut bars, tie wire, debris, etc. before pour
7. Cylinders for P-T concrete - leave open on site and cure with the members
8. Undue slab and frame restraint
9. Check drain number and locations

F. Possible problem areas
1. Forms shall not be removed before tensioning.
2. Stressing shall be performed according to specifications.

3. Vertical elevations to be checked before and after pouring and prestressing.
4. Ensure that removal of forms at pour strips is according to notes on structural drawings.
5. Contractor should be aware that the structure is going to shorten upon prestressing. (May be accomplished by the Project Manager at preinstallation meetings.)
6. Use a reference point on the ground to check plumbness and elevations for all levels. Do not use the previous floor as a reference.
7. Check edges of structure to ensure cover for reinforcing and anchor plates.
8. Slab plates shall be vertical and shall not project above pour.
9. Tendons shall be straight in a horizontal position.
10. Be sure bottom of reinforcing cage is such as to have proper concrete cover.
11. If in your judgment, pour should not be allowed, inform project manager immediately.

APPENDIX 17-2

Field Observation Guidelines for a Precast Concrete Structure

A. Connections
   1. Column / column
      a. Column base grout
      b. Column/column splice
   2. Beam / column
      a. Exterior L beam
         1. Coil rods / rebars
         2. Pockets grouted
         3. Bearing pads.
      b. Interior L beam
         1. Coil rods/rebars
         2. Pockets grouted
         3. Bearing pads
      c. Interior inverted tee beam

1. Coil rods / rebars
2. Bearing pads

d. End spandrel
1. Coil rods / rebars
2. Pockets grouted
3. Bearing pads

3. Tee / beam
   a. Exterior / interior "L" beam
      1. Coil rods
      2. Weld plates
      3. Bearing pads
   b. End spandrel beam coil rods
4. Tee / tee
   a. Flange connections
   b. WWF in topping / pour strip
   c. Rebar at crossovers
   d. Rebar at pour strips / topping
5. Wall panel / tee
   a. Wall panel / beam
   b. Wall panel / column

B. Precast pieces
1. Finish
   a. Columns
   b. Tees
   c. Beams
   d. Walls

C. Miscellaneous
1. Provisions for future construction.
2. Provisions for light standards at top tier.
3. Provisions for expansion joint: structural, electrical, mechanical.
4. Joints at stairtowers.
5. Electrical boxes and conduits in proper position
6. Undue column and frame restraint.

APPENDIX 17-3

Checklist for Precast Concrete Plant Visit

A. Pre-visit Review
1. Reviewer has obtained permission to observe operations.
2. One authority in plant has been designated to receive reviewer's report.
3. Reviewer has not interfered with plant operations.
4. Report of review has been given to the designated authority.
5. A copy of this review report has been sent to the plant.

B. Pretensioning Strand
1. Strand is clean and free of dirt or form oil.
2. Strand is new and free of broken or nicked wires.
3. Strand is located per plans.
4. Strand mill report verifies size and strength.

C. Tensioning
1. Strand vises are clean.
2. Strand jack has been calibrated within last year. (Report is available.)
3. An initial stress of approximately 5% of the final is applied.
4. Final stress is checked by measuring elongation and jack gauge reading.
5. If strand is depressed during stressing, frictionless holddown devices are used.
6. Strand is depressed at the proper locations.

D. Concrete
1. Mix design is approved.
2. All concrete admixtures are approved.
3. Admixtures containing calcium chloride are prohibited.
4. All admixtures are properly measured.
5. Admixtures applied to mix at proper time and per manufacturers' recommendation.
6. Aggregate used is of correct size.
7. Various aggregates are properly segregated.
8. Aggregates are stored and handled in a manner that will keep them clean.
9. Moisture content of aggregate is determined twice daily.
10. Gradation of aggregate is checked weekly.
11. Mill reports are available for cement.
12. Cement is protected from moisture during storage.
13. Scales for measuring cement, aggregate and water have been calibrated in the last four months.
14. All scales are in proper working order.

15. Water in aggregate is accounted for in measuring water.
16. Cement is not allowed to free fall into mixer.
17. Mixer is free of hardened concrete.
18. Mixer blades are not excessively worn or missing.
19. Concrete is mixed for the length of time equipment manufacturer recommends.

E. Placing Concrete

1. Concrete is not allowed to segregate in transporting from mixture to form.
2. Concrete temperature is checked and maintained between 50°F. and 80°F.
3. Concrete is properly vibrated by either internal or external vibration.
4. No cold joints are allowed to form in adjacent layers of concrete.
5. If placed in layers, lower layer is still plastic when the upper layer is placed and the layers are consolidated.
6. Workmen do not move embedded items or reinforcing while placing concrete.
7. If inserts, plates etc., are placed in concrete after it is placed, the concrete is still plastic and concrete around insert, etc., is properly consolidated.
8. All pockets, blockouts, ledges etc., allow air to escape during concrete placement.
9. If ambient air temperature is below 40°F, form is preheated to above 40°F. prior to placing concrete.

F. Finishing Concrete

1. Concrete surfaces are screeded to correct dimensions prior to applying finish.
2. Surfaces receiving form finish or manual finish are as specified in plans and specs.
3. If broom finish is specified, striations are made in specified direction.
4. If rough finish is specified, a minimum of ¼ in. amplitude is maintained.
5. If steel trowel finish is specified, final finishing operation does not start until all surface water has evaporated and surface cannot be easily dented with a finger.

G. Curing Concrete

1. Concrete is covered to prevent loss of moisture.
2. If ambient temperature is below 50°F., form is heated or insulated to prevent concrete temperature from dropping below 50°F.
3. If heat is used to accelerate cure, continuous recording thermometers are used to monitor temperatures.
4. At no time is concrete temperature allowed to go below 50°F. or above 175°F. If alkali-aggregate reactivity is a factor, keep the curing temperature as low as practical. Current research for PCI suggests 73°F, maximum.

H. Concrete Testing

1. Cylinders are made per specifications.
2. Air content is checked per specifications.
3. Slump is checked per specifications.
4. Cylinder testing machine was calibrated within the last six months.
5. Cylinders are properly capped prior to testing.
6. Operator applies load to cylinder at a uniform rate.
7. Two cylinders are cured on the form in the same manner as the concrete and break at or above 3500 psi prior to detensioning strand or stripping product.
8. Twenty-eight day cylinders are tested and concrete strength is in conformance with specifications.

I. Detensioning

1. Concrete strength has reached 3500 psi strength as required by design prior to detensioning.
2. Strands are detensioned by slowly heating the strand.
3. Strands are heated simultaneously from both ends.
4. Strands are detensioned in a symmetrical pattern.

J. Quality Control

1. Plant does have a designated quality control department.
2. Quality control department supervises the tensioning, detensioning and all concrete testing.
3. The quality control department checks dimensions on all products.

4. The quality control department maintains records of all stressing, testing, mill reports, etc.

K. Storage

1. Dunnage is placed only at pick points.
2. Product is handled only at pick points.
3. Product is stored on a level plane.
4. Product is marked so it can be identified by date cast and location in the building.
5. If product is stacked more than three high, plant engineer has calculations showing he is not exceeding allowable concrete strength.
6. If product is stored at below 32°F. all inserts, sleeves etc., are sealed to prevent ice forming in them.

Precast Double Tee Inspection

Tee Forms

1. Forms are clean and free of pits, bends, bowing and uneven joints.
2. Form will provide an approved finish.
3. Form oil is applied properly per manufacturer's recommendations and no puddles are left in form.
4. Form is of correct configuration and dimensions.
5. All skews and blockouts are correctly positioned.

Tee Reinforcing

1. Shear reinforcing in stems provided per drawings.
2. Shear reinforcing held with nonferrous chairs that provide specified concrete cover.
3. End bearing plate in place and held in proper position.
4. Bearing plates have received the proper finish and have the correct reinforcing welded to them.
5. Proper preheat used in welding reinforcing.
6. Mill reports verifying size and strength of all rebar are available.
7. Flange WWF located per plans and held with non-ferrous chairs that provide specified concrete cover.
8. Extra layer of flange WWF at 2-in. flange.
9. WWF from 4-in. flange extends proper distance into 2-in. blockout.
10. Mill reports available showing proper strength and size for all mesh.

11. Flange WWF extends through floor drain holes.
12. Additional reinforcing around all flange holes.
13. Flange connectors made per plan.
14. Flange connectors properly spaced and held securely.
15. Lifting devices in 2in. flange area only.
16. All reinforcing held securely so that correct cover is maintained.
17. Flange WWF lapped at least 2 cross wires plus 2 in. or a minimum of 8 in. at all laps.

Precast Beam Inspection

Beam Forms

1. Forms are clean and free of pits, bend, bowing and uneven joints.
2. Form will provide an approved finish.
3. Form oil is applied per manufacturer's recommendations and no puddles are left in form.
4. Form is of the correct configuration and dimensions.
5. All skews and blockouts are correctly positioned.

Beam Reinforcing

1. Mill reports verifying size and strength of all rebar are available.
2. Proper preheat is used when welding reinforcing.
3. No unspecified tack welds are used on the reinforcing.
4. All bearing plates are in proper position and held securely so that they remain level during concrete placement.
5. Bearing plates have received the specified finish and have the correct reinforcing welded to them.
6. All reinforcing is correctly positioned.
7. All reinforcing is bent to specified tolerances.
8. Proper lap lengths are used for all lap splices.
9. All reinforcing has the specified concrete cover.
10. All reinforcing is held with nonferrous chairs.
11. All reinforcing is held securely to prevent movement during concrete placement.
12. All reinforcing is free of dirt, form oil, hardened concrete etc.
13. All steel that will be exposed in the final condition has received the specified finish.
14. All inserts, plates etc., that are to be patched in the final condition are recessed to provide the proper concrete cover.

15. All sleeves are lined with the specified material; PVC, steel, etc.
16. All lifting devices are so positioned that they will not be exposed in the final position.

Precast Column Inspection

Column Forms

1. Forms are clean and free of pits, bends, bowing and uneven joints.
2. Forms will provide an approved finish.
3. Form oil is applied per manufacturer's recommendations and no puddles are left in the form.
4. Form is of the correct configuration and dimensions.
5. Column corbels and beam blockouts are of correct configuration and provide for correctly sloped bearing surfaces.

Column Reinforcing

1. Mill reports are available verifying all steel is of proper strength and size.
2. Proper preheat is used when welding all reinforcing.
3. No unspecified tack welds are used on the reinforcing.
4. All main reinforcing bars are continuous without splices.
5. All lifting devices are so positioned that they will not be exposed in the final erected position.
6. All inserts, plates, etc., that must be patched in the final erected position are recessed to provide proper concrete cover.
7. Column ties are properly spaced and all extra ties specified are provided.
8. All column ties are bent to specified tolerances.
9. All reinforcing has the specified concrete cover.
10. All reinforcing is held with nonferrous chairs.
11. All reinforcing is held securely to prevent movement during concrete placement.
12. All steel that will be exposed in the final condition has received the specified finish.
13. All reinforcing is free of dirt, form oil, hardened concrete etc.
14. Sleeves for beam connections are lined with specified material; PVC, steel, etc.
15. Bearing and base plates are properly positioned and held securely so that they remain level during concrete placement.
16. Provisions for future extension of columns conform to detail.

Chapter 18

MAINTENANCE

Sam Bhuyan

18.1 INTRODUCTION

The purpose of parking facility maintenance is to assure proper and timely preventive actions to reduce premature deterioration of structural elements and equipment failures. The material in this chapter has been adapted from the maintenance manual published by the National Parking Association. The reader should refer to the "Parking Garage Maintenance Manual, First Edition," for further details related to the maintenance of parking facilities.

This chapter is directed primarily at owners or operators of parking facilities. The material will also assist architects and engineers to develop an understanding of the essential elements of parking structure maintenance. An important objective in designing new and restoring existing structures is to reduce future operating and maintenance costs.

Parking facilities experience unusually harsh exposure conditions compared to most buildings. Temperature extremes, dynamic loads, and deicer attacks are potentially destructive to all parking facilities. Premature deterioration, such as scaling, spalling, cracking and leaking can reduce the integrity of exposed concrete surfaces, especially floor slabs.

Deferred structural maintenance can lead to serious deficiencies. Premature deterioration of concrete floors is costly and, in extreme cases, can impair the structural system's integrity. Timely corrective and preventive maintenance action is needed to reduce impact and cost of structural deterioration. On the other hand, failures associated with certain operational features, such as lighting, parking equipment, or security-monitoring devices are relatively easy to correct. Preventive maintenance defers major repairs and is usually more cost effective and less disruptive to operations.

Parking facilities today are structurally more complex than ever. Challenges facing the designer include:

- Building codes and city ordinances impose design requirements not present several years ago.
- Integration of parking facility operational and structural features. Parking structures require special attention for structural maintenance in order to assure long-term structural integrity.
- Multi-use facilities or high-rise structures with integrated parking demand life expectancy well beyond 40 years.
- Quality control of materials, labor, and erection is more critical than in most buildings.
- The service environment is more severe and potentially more destructive than conventional structures are capable of withstanding effectively.

Parking facility operation programs also feel the demand of new challenges, including:

- Equipment failures that occur due to high utilization rate and sensitivity of components to adverse conditions. Automation instead of manpower is required to reduce operating costs.
- Pay facilities that are quite competitive and have little money for structural maintenance or for establishing a budget to support a maintenance program.
- Extensive salt use contaminating the concrete, allowing chloride to corrode embedded reinforcing steel, causing progressive surface spalling. Other destructive processes are structural-member cracking, leaking, floor-slab spalling, and surface scaling.
- Legal liability for code or regulatory violations and negligence to enforce security.

This chapter will address general and specific maintenance actions required to extend the life of parking structures. General maintenance is associated with operational aspects of the facility. Specific maintenance is associated with the structural system and is required periodically during the life of the structure. This chapter is intended to provide guidelines for maintaining parking facilities at a satisfactory level of service.

18.2 RECOMMENDED MAINTENANCE PROGRAM AND CHECKLIST

As shown in Table 18-1, maintenance needs for a parking facility can be separated into three broad categories:

- Structural
- Operational
- Aesthetic

Maintenance must be performed at regular intervals if the full benefit of the effort is to be realized. Irregular or incomplete maintenance will provide a marginal return on investment. To ensure that a maintenance program is functional, establish a schedule and follow appropriate maintenance procedures. Maintenance actions include:

- Routine maintenance – Routine maintenance includes repairing leaking joint sealant, clearing plugged drain lines, replacing damaged light fixtures, small area repairs to spalled or delaminated concrete, replacing expansion joint seals and other similar work. Routine maintenance also includes other housekeeping actions such as cleaning and washing down floor surfaces.
- Preventive Maintenance – Preventive maintenance includes actions that tend to extend the facility service life. These items include reapplication of surface sealers, traffic membrane, joint sealants and expansion joints. Preventive maintenance does not usually entail the major disruptions associated with structural repairs.
- Replacement – Replacement actions include replacement of structural and operational items at the end of their service lives. Items such as lighting, elevators, plumbing and parking access and control equipment are included.

When should an owner develop and implement a maintenance program? Ideally, develop and implement the program from the very first day of operation. Also, the level of maintenance for a facility is initially designed into the facility and impacted further by the quality of construction.

Table 18-1 Maintenance Category

Structural System	Operational	Aesthetics
1. Floors	1. Cleaning	1. Landscaping
2. Beams, columns, and bumper walls	2. Snow and ice control	2. Painting
3. Stair and elevator towers	3. Mechanical systems	3. General appearance
4. Joint sealant systems	4. Electrical systems	
5. Architectural sealants	5. Parking control equipment	
6. Exposed steel	6. Security systems	
7., Masonry	7. Signs (graphics) and striping	
8. Bearing	8. Inspection	
	9. Safety checks	

The first step in developing and implementing a maintenance program is a walk-through review, which is a visual inspection of the entire facility. For existing or restored structures, limited nondestructive and laboratory testing may be required to qualify construction materials and as-built conditions. The walk-through review by an experienced restoration engineer assists in developing a tailored maintenance program for a specific facility based on factors such as:

- Age and geographic location
- Structural system and the design details involved
- Quality of construction material specified
- Construction quality or deficiencies
- Existing distress in structural elements, such as spalling, cracking, scaling, or excessive deformations
- Corrosion-protection system specified or implemented
- Operational elements

Once relevant maintenance elements are identified, procedures and schedules can be set up for maintaining the structure. Regularly scheduled walk-through inspections then form the basis for implementing and monitoring the effectiveness of the maintenance programs.

The in-house maintenance staff can perform the walk-through inspections. The in-house maintenance crews should be on the alert to locate distress of structural elements in accordance with fixed schedules. The result of the visual review should be noted on plans so that they are available to a restoration specialist. Refer to Section 18.2.2.8 for recommended frequency of walk-through inspections. Sometimes it may be necessary to perform a more detailed condition review of the structure. Condition appraisals, repair methods and materials are addressed in Chapter 19 and Chapter 20.

18.2.1 Structural System Maintenance

Structural system maintenance includes floor slabs, beams, columns, bumper walls, stair and elevator towers, joint systems and exposed steel. Maintenance of structural elements consists of repairing deteriorated members, renewals of protective coatings, and replacement of joints and sealants to extend the structure service life. Maintenance actions to repair distress due to spalling, scaling, and cracking are necessary. If left unattended, such distress can contribute to accelerated deterioration of the structure. See Chapter 19 for a detailed explanation of deterioration and distress commonly seen in structural members.

Maintenance of the structure is considered very important, since neglect of structural maintenance can lead to major problems and high repair costs. In addition to the actual repair costs, lost parking revenue during repairs can be substantial. Table 18-2 presents the recommended program for satisfying structure maintenance. Structural system elements are listed and the appropriate action required specified.

18.2.1.1 Concrete Floor Slab and Surfaces.

The most significant maintenance needs are associated with the floor slab and consume the largest share of the maintenance budget. Typical conditions of deterioration that affect the floor slab are delaminations, scaling, spalling, cracking, leaking, and leaching. These conditions can contribute to accelerated deterioration of the structure and adversely affect floor slab serviceability.

Periodic application of surface sealer or elastomeric coatings can reduce floor slab deterioration by reducing water penetration. For severe climate structures exposed to road salts, an unprotected concrete surface will eventually permit chloride ions to migrate in sufficient quantity to promote corrosion of embedded reinforcement. The "time-to-corrosion" and need to protect the floor surface depend upon factors such as geographic location of the structure, concrete quality (water-to-cement ratio), the clear concrete cover of embedded steel, the permeability of the concrete, and the corrosion protection system specified. Even for mild climates structures, sealing and coating will extend structure service life. This statement is particularly true for structures exposed to airborne chlorides from large bodies of salt water.

Supported entrance and exit lanes, helix, turn lanes, and flat floor areas are subject to more severe exposure conditions. Special attention must also be given to turning areas at end bays, crossovers, gutterlines, and water ponding. The high-wear areas may require more frequent sealer application than the general parking surfaces. All areas should be closely monitored, and if deterioration develops, heavier sealer application rates or an application of elastomeric coating may be necessary.

Elastomeric coatings installed on parking floors above offices or commercial space should be examined for wear and tear. Damaged coating should be repaired as soon as possible to prevent leaking and contamination, since the integrity of the entire coating system and floor slab can be jeopardized if left unrepaired. These coating systems are usually proprietary and should be inspected and repaired by the system manufacturer's authorized representative.

Verify the ability of the sealer to reduce water absorption, screen chloride ions, and resist ultraviolet exposure by laboratory tests. The test procedures for measuring sealer effectiveness are provided in a National Cooperative Highway Research Program (NCHRP) report entitled, "Concrete Sealers for Protection of Bridge Structures, NCHRP Report 244." In addition, verify the method of surface preparation and sealer application by trial applications in selected areas of the structure. Trial applications also help to identify sealers that can "glaze" and create slip hazards.

Horizontal surfaces of a parking structure are usually subjected to traffic abrasion and wear that can reduce sealer effectiveness. Sealers that penetrate deeper into the pores and capillaries of the concrete surface perform better than sealers that cannot penetrate as much. The NCHRP test method was developed for vertical bridge deck members that are not subjected to traffic wear and abrasion.

The Alberta Department of Transportation (Alberta DOT) has developed a sealer test method that simulates traffic abrasion and wear in laboratory samples. The laboratory samples are sandblasted and the sample surface is abraded prior to testing. Test results indicate that silanes generally perform better than the other generic type of sealers currently available. The silane sealer has a smaller molecular structure, making it possible for silanes to penetrate more effectively into the concrete than other sealers. Refer to Section 20.3.2 in Chapter 20 for a summary of available test methods commonly used to evaluate sealers.

Surface sealers should be reapplied every 3-5 years. Required reapplication frequency can be verified by annually monitoring the concrete chloride content at various depths beneath the floor surface to at least the level of the reinforcement top mat. See a sample form for an annual chloride-monitoring program included in Appendix 18-1.

Table 18-2 Structure Maintenance Schedule

Item	Description	Frequency	
		Annual	As Required
1.0	Concrete slabs		
	1.1 Visual inspection	Perform	
	A. Floor		
	B. Ceiling		
	C. Floor coatings	Perform	
	1.2 Delamination testing & patching		
	A. Floor		
	B. Ceiling		a
	1.3 Protective sealer application		
2.0	Beams, columns, bumper walls, and connectors	Perform	
	2.1 Visual inspection		
	A. Columns	Perform	
	B. Beams		
	C. Bumper walls		
	D. Connections		
	E. Snowchute		
	2.2 Delamination testing & patching		
	A. Columns	Perform	
	B. Beams		
	C. Bumper walls		
	D. Connections		
	E. Snowchute		
	2.3 Protective sealer application		b
3.0	Stairtowers		
	3.1 Visual inspection	Perform	
	A. Stairs & landings		
	B. Walls		
	C. Glass		
	3.2 Apply protective sealer to landings and stairs	Inspect	c
4.0	Joint-sealant systems		d
	4.1 Visual inspection & repairs	Perform	
	A. Expansion joints		
	B. Construction joints		
	C. Control joints		
	4.2 Crack routing and sealing	Inspect	Perform
5.0	Architectural sealants	Inspect	Perform
6.0	Exposed steel	Inspect	
7.0	Masonry	Inspect	Perform
8.0	Bearing pads	Inspect	Perform

[a]Reapply every 3-5 yr. Areas that are subject to more intense and severe exposure may require retreatment annually. Testing and inspection should be performed to determine degree of exposure. A traffic coating may be more cost-effective in areas of heavy leaking or floor deterioration.
[b]Apply sealer every 3 yr. on those structural members subject to frequent leaking and saltwater splash.
[c]Sealer application should be made every 3 yr.
[d]Budget for total replacement every 10 yr.
Adapted from "Parking Garage Maintenance Manual, First Edition." Parking Consultants' Council, National Parking Association, 1982.

Liquid applied membrane systems (traffic toppings) provide more effective protection against moisture and chloride contamination than surface sealers. The membrane waterproofs the surface and allows moisture penetration only at localized imperfections, such as holes and tears. Membranes are capable of bridging some active floor systems with extensive through-slab cracking. Membranes are significantly more costly (four to six times) than surface sealers and are susceptible to wear, especially in the driving and turning aisles of the parking facility. Recoating the top layer of the membrane system is often necessary in high wear locations. However, with proper maintenance, some membranes can last well beyond 10 years

Preventive maintenance measures, such as applying a protective sealer and elastomeric coating, are most effective when applied to a floor slab that is not contaminated by road salt. When sealers and elastomeric coatings are applied to older facilities with chloride contaminated floor slabs, concrete deterioration cannot be effectively controlled due to the continuing corrosion of embedded reinforcement. Therefore, the floor-slab maintenance cost for restored facilities is relatively higher than maintenance costs associated with a new parking facility; also, older facilities require more frequent repairs.

A facility should be monitored annually for concrete deterioration. Open spalls and delaminations in floor slabs should be patched to reduce the impact of progressive deterioration and maintain serviceability. Also, open spalls and exposed reinforcement are tripping hazards. Due to time or weather constraints some spalls may have to be repaired temporarily with asphalt or prepackaged repair materials. Asphalt repair materials generally tend to trap and retain moisture that can contribute to accelerated deterioration of the underlying and adjacent concrete. For relatively permanent repair, all unsound concrete must be removed. Corroding reinforcement should be completely excavated, cleaned, and epoxy coated. The repair area should then be patched with properly air-entrained, high-quality Portland cement-based patch materials that are relatively impervious to moisture. Preventive measures and maintenance procedures for chloride-induced deterioration are fairly comprehensive, and usually help reduce other forms of concrete deterioration.

Sealing cracks and joints in floor slabs is necessary to limit ceiling deterioration. All loose overhead concrete spalls are potential safety hazards that can damage vehicles or injure facility users. Remove loose overhead spalls as soon as possible.

Ponding is also a potential slipping and skidding hazard, particularly during the winter months, due to freezing. Also, ponded areas can contribute to more rapid floor-slab deterioration and joint leakage. Eliminate isolated ponded areas by installing supplemental drains. Relatively large areas may require resurfacing to provide adequate drainage.

18.2.1.2 Beams, Columns, and Bumper Walls.

Beam and column deterioration can adversely affect the structural integrity and load-carrying capacity of floor slabs. Deterioration of these supporting members can be attributed primarily to water leakage through failed joints and floor-slab cracks. Vertical surfaces of columns and bumper walls are also susceptible to damage by salt-water splashed by moving vehicles.

Beam and columns adjacent to and below expansion joints are most susceptible to deterioration. Beam and column deterioration can be reduced by proper maintenance of floor surface joint sealant systems and sealer application on column bases and bumper walls. Water leakage can contribute to the corrosion of embedded reinforcement, freeze-thaw deterioration, rust staining, and leaching.

Concrete bumper walls can be subject to vehicle impact; the bumper walls should be monitored for cracking and spalling. Structural steel connections should be monitored for corrosion and distress due to impact. Ponded areas and gutterlines adjacent to bumper walls can contribute to the corrosion of steel connections, leaching, and rust staining. These adverse conditions generally require installing new curbs, supplemental drains, or a concrete wash.

18.2.1.3 Stair and Elevator Towers.

Without regular maintenance, leaks between the floor-slab surface and stair and elevator towers can be a problem. Quite often the leakage can be attributed to poor drainage around the towers. Drainage can be improved by providing curbs and washes, which will then tend to reduce deterioration of elements beneath, such as doors, light fixtures, electrical conduits, metal stairs, exposed structural steel members, connections, etc. In addition, rust staining, leaching, and paint peeling can be aesthetically unpleasing. Frequent inspections and repair of the damaged elastomeric expansion-joint seal between the tower and floor surface will also reduce distress caused by leaking.

Stairs and landings are exposed to salt contamination. The concrete surfaces require periodic resealing. Masonry walls should also be maintained by sealing. Stair and elevator wall cracking should be evaluated and repaired. Door and window glazing should be replaced when damaged or leaking.

18.2.1.4 Joint Sealant Systems.

Expansion, construction, and control joints in parking structures accommodate movements due to the volume change of concrete. The volume-change movement can be attributed to concrete shrinkage, seasonal temperature variations, elastic shortening in prestressed structures, and creep. The joints in the structure are sealed with flexible elastomeric sealant to reduce water leakage and accelerated deterioration of the structure. In addition to the joints, random floor-slab cracking can also contribute to leakage and to structural member deterioration. When and where appropriate, seal random through-slab cracks with flexible elastomeric sealant material. A discussion of concrete cracking, joint distress, and causes of sealant system failure is included in Chapter 19.

Joint-sealant systems have a limited life expectancy. Depending upon the structural configuration, wear and tear, exposure conditions, the joint-sealant system can be expected to provide 8-10 years of service before complete replacement. Spot-patch repair of joints is cost-effective only when less than 30% of the joint-sealant system shows deterioration. Concrete surfaces adjacent to expansion joints, construction joints, control joints, and sealed random slab cracks should be treated periodically with a surface sealer. Also, the concrete surfaces adjacent to the joints and cracks must be inspected for deterioration to maintain effectiveness of the joint-sealant system.

18.2.1.5 Architectural Sealants.

Periodically inspect the condition of architectural sealants and repair as necessary. Areas include sealants at window and door framing, in block masonry, exterior sealants in or adjacent to concrete walks, drives, curbs, and landings, at structural precast to adjacent surfaces or dissimilar structure, all control joints, and at exterior perimeters of curbs. Replace all damaged sealants.

18.2.1.6 Exposed Steel.

Exposed steel within a concrete parking facility is generally limited to structural steel connections, stairs, pedestrian railings, vehicle guardrails, and metal decking. Neglect and the chemical reaction between the metals and the corrosive environment cause premature deterioration of metal components. Monthly, check for potentially unsafe conditions due to connection corrosion. Treatment of metals with proper surface preparations and quality paint will reduce corrosion.

18.2.1.7 Masonry.

Most concrete masonry walls contain non-prestressed reinforcement. Recommendations for the inspection, cleaning, tuckpointing, and sealing of these walls are similar to those for concrete walls.

18.2.1.8 Bearing Pads.

Beams, columns, spandrels and floor members are set on bearing pads. Bearing pads may be made from steel, hardened plastics, TFE assemblies, neoprene or fiber- reinforced neoprene singly or in combination. They help ensure the correct placement of loads and partially restrain lateral movement between structural members.

Weathering, misplaced or omitted pads and excessive movement can result in the movement of pads from their original positions. As pads move or fail, the resulting deterioration, cracking, spalling and excessive deflections can affect the structure. Deterioration should be evaluated by an engineer, then repaired. Replace bearing pads that are missing.

18.2.2. Operational Maintenance

Special emphasis is placed on operational maintenance because malfunctions or breakdowns can take part, or all, of the facility out of service and/or reduce user security and safety. Operational maintenance involves regular and scheduled inspection and repair of items, such as parking equipment, elevators, electrical systems, heating and ventilation systems, security monitoring, and fire-fighting equipment. Routine cleaning, including sweeping and washdown, is also a part of operational maintenance. Snow and ice control is important where appropriate. Table 18-3 presents a recommended program for satisfying operational maintenance needs. A more detailed checklist of maintenance tasks is included as Appendix 18-2.

18.2.2.1 Cleaning Requirements.

One of the most frequently overlooked aspects of parking-facility maintenance is proper floor cleaning. Sweeping can be accomplished by using hand brooms or mechanized sweepers designed for use in buildings. The maximum weight for mechanized sweeping equipment in a parking facility is generally limited to 8000 lb. gross weight or 4000 lb. per axle.

Table 18-3 Operational Maintenance Schedule

Item	Description	Frequency Monthly	Frequency Annual	As Required
1.0	Cleaning Requirements			
	1.1 General cleaning	Perform		a
	1.2 Sweeping	Perform		a
	1.3 Remove ponded water			Perform
	1.4 Floor-surface flushdown		Perform	a
2.0	Snow removal and ice control		Perform	
3.0	Mechanical/electrical systems			
	3.1 Drainage system includes sediment trap)		Inspect	
	3.2 Elevators		Inspect	Perform
	3.3 Ventilation equipment		Inspect	
	3.4 Fire Protection		Inspect	
	3.5 General lighting		Inspect	
	3.6 Exit and emergency lighting		Inspect	a
	3.7 Emergency generator		Inspect	
	3.8 Parking equipment		Inspect	
	3.9 Security monitoring		Perform	a
	3.10 Safety checks		Perform	a
4.0	Graphics and striping			
5.0	Inspection (see structural-maintenance schedule)			

[a]More frequent performance of this task is suggested.

Remove all dirt and debris from the facility. Dirt and debris should be kept away from drain basins and pipes, as blockage may cause leaking and failure. Dirt and debris in expansion-joint systems can damage elastomeric seals.

Remove grease buildup in parking spaces with appropriate degreasers. In addition, a poultice made with limestone, sodium hydroxide solution, and trisodium phosphate (TSP) is effective in cleaning oil spills. Refer to the *Concrete Construction* magazine publication, "Removing Stains from Concrete" for more detailed information on removing stains. Excessive grease build-up is common at the entrance gate and adjacent to the cashier's booth. Regularly remove grease.

Salt accumulates during winter months and should be removed each spring by flushing floor surfaces. A flushdown with low-pressure water hoses is advisable after the facility has been swept. Flushing can be incorporated with a check of the standpipe system, which can be coordinated with the deck washing. Flushing of critical areas such as entrance and exit lanes, turn lanes, flat areas, and main drive aisles should be performed frequently during the winter whenever moderate temperatures permit. If moderate temperatures do not permit, then in-house maintenance personnel should use sponge mops or brooms to remove accumulated salt-laden slush or water. Entrance and exit lanes will benefit most from periodic removal of snow and slush.

When flushing floor surfaces, avoid washing sand into the drain system. Temporary burlap or straw filters are effective in preventing sand from plugging drains.

18.2.2.2 Snow Removal and Ice Control.

It is possible to damage the joint-sealant and deck-coating systems with abnormal and/or abusive traffic. The three most common causes of damage to the systems are:

- Dropping heavy or sharp objects onto the surface
- Dragging heavy or sharp objects across the surface
- Unprotected snow removal equipment and studded tires or tire chains

To reduce damage, implement these snow removal guidelines:

1. Clearly mark all expansion joint locations by means visible to the equipment operator when the deck is snow-covered. Place markings such as red, yellow, or orange stripes on the adjacent walls or columns at each end of expansion joints. Where walls or columns do not exist, place safety flags, properly anchored 55-gal drums filled with sand, or other means of identification at each end of joints.
2. Piling snow in corners or other locations within the facility is not recommended. Snow varies greatly in weight, but packed snow can be quite dense, and ice often forms at such piles during freeze/thaw cycles. While the structure can probably safely support most snow piles, the weight may be sufficient to crack the concrete. Such cracking could permit water (and dissolved salt) penetration of the concrete that could hasten slab deterioration. Therefore, avoid accumulation of snow piles for long periods.
3. Establish a snow removal pattern so that the snow removal equipment approaches the expansion joints at an angle not greater than 75 degrees and preferably parallel to them. This technique will reduce the chance of catching the snowplow blade on the expansion-joint system. Snowplow damage is not usually covered by the expansion-joint warranty. Snow and ice packed in an expansion-joint system can contribute to seal failure. Follow the manufacturer's guidelines and where necessary, clean snow in the expansion-joint gland to reduce seal failure chances.
4. Snow is normally plowed using a vehicle with an axle weight of 4000 lb. maximum. Snowplow blades and bucket loaders should be modified with a heavy rubber cutting edge attached to the bottom, or with "shoes" or other positive means designed to keep the steel blade from contacting the floor. It is necessary to keep the steel blade a minimum of 1/8 in., but preferably 1/2 in., above the floor to avoid damage to the concrete, deck coating, and expansion-joint sealant systems. Whenever possible, use a power brush for snow removal.
5. Snow is plowed to specific locations within the facility where a bucket loader or industrial snowblower can be used to throw the snow over the side. In congested areas, snowchutes or off-peak snow removal operation may be required to deal with heavy snowfall. Care must be taken with a bucket loader or snowblower

to avoid damage to the concrete walls, connection hardware, deck coating, and expansion joints.

6. Schedule an inspection of the deck coating, control joints, expansion joints and concrete walls in early spring to assess the winter's wear. If damage has occurred, repairs can be scheduled in the upcoming construction season.

The floor slope is designed to drain surface water as quickly as possible. However, certain areas are particularly vulnerable to freezing when water from sun-warmed surfaces drains into shaded areas. This situation occurs at transitions from top level to covered levels and at entrance/exit lanes. In-house maintenance crews must be aware of these areas and take steps to control icy conditions.

Most common chemical deicers can have significant physical effects on concrete. Several deicers are listed below with a general description of common effects on materials typically located in and around the parking facility. The effect on any single material may progressively affect the entire concrete system. It must be noted that no deicing compounds, including road salt, work in extremely cold temperatures.

Some of the common chemicals associated with ice control are:

1. *Sodium Chloride* (NaCl, halite, table salt, or rock salt), has little chemical effect on concrete, but will damage lawns and shrubs. It does promote metal corrosion. **Do not use Sodium Chloride by itself or packaged with corrosion inhibitors..**
2. *Calcium chloride* (CaCl), a major active part of many proprietary deicers, has little chemical effect on concrete, lawns, and shrubs, but does cause corrosion of metal. It is particularly hazardous to prestressed steel. Calcium Chloride has been reported to leave an oily residue, which can be tracked into buildings and is difficult to clean. **Do Not Use.**
3. *Potassium Chloride* (KCl) is a fertilizer material sometimes used as an ice-melting agent. Potassium Chloride is very corrosive. **Do Not Use.**
4. *Magnesium Chloride* (MgCl) is a hygroscopic (moisture absorbing) material used by itself or as an additive to other products. **Long-term effects on reinforced concrete have not been determined.**

5. *Ammonium nitrate or ammonium sulfate* are base materials in many fertilizers and will not harm most vegetation. However, use may lead to complete destruction of concrete because of direct chemical attack on concrete reinforcement. **Never Use.**
6. *Calcium Magnesium Acetate* (CMA*)*, a combination of acetic acid and pulverized limestone, helps break the bond between the ice and driving surface. CMA is generally used in granular form, but is also available as a liquid. CMA is more effective on ice than snow,

as it produces a slush, which can then be plowed. CMA has no known adverse affects on concrete or embedded reinforcement. It will not damage lawns or shrubs and will perform to temperatures of about 20^0 F. Other acetates, based on sodium or potassium are also currently available.

7. *Prilled Urea* does not damage concrete, lawns, shrubs, or metal. Prilled urea does not behave like common road salt. It will attract moisture and stay "mushy" longer than salted areas. It takes longer than salt to penetrate ice and works best at breaking up ice with solar action. Prilled urea has little effect after dark or at temperatures below 24^0 F. For best results, use urea to break up ice and then shovel. Urea should not be used in proximity to streams or lakes. Ammonia produced by degrading urea is toxic to fish and other aquatic life. Limit use to applications that will not affect streams or lakes.
8. Many airports use *Ethylene Glycol*, or a solution of ethylene glycol and urea, for ice control on runways and airplanes. While effective to 0^0 F. and non-damaging, it is more expensive than urea and local ordinances may prohibit its discharge into sewers.

It is important to reduce the use or the amount of deicing chemicals during the first 2 years of concrete curing. It is emphasized that properly designed, air-entrained and cured concrete is required in order to have a durable concrete structural system.

Ice build-up can be controlled by using hot sand. Do not apply deicing chemicals containing chloride directly to concrete unless extremely icy conditions exist. Small amounts of salt (3-5% of weight) added to sand can be very effective at increasing traction and preventing skid problems. Apply the sand/salt mixture to ice only as needed.

Protect drain systems against runoff-related sand accumulating during ice-control operations. Use temporary burlap or straw filters to prevent drain clogging and possible damage to drain systems.

Here is a series of recommended deicing measures in order of decreasing preference:

1. Clean, plow, and scrape off ice and snow; do not use deicing agents.
2. Use sand to increase traction; when washing down the floor, protect the drainage system.
3. De-ice with urea. See if CMA or other acetate products are available economically in your area.
4. Use a mixture of sand and calcium or sodium chloride, but protect the drainage system.

18.2.2.3 Mechanical Systems.

All mechanical equipment should be inspected regularly and serviced as required. Mechanical systems include the drainage system, ventilation equipment, elevators and shafts, and fire-fighting equipment.

Drain basins, inlet grates, leaders, downspouts, heat tape, and all support brackets should be inspected for leaks, damage, or distress. Sediment basins should be cleaned as required to prevent clogging and water ponding. Floor sleeves should be examined and sealed against leaking also. Inspect all electrical connections and make repairs to assure a safe heat-tape system. All deficiencies noted should be recorded and appropriate action programmed.

Where water is ponding, such as near corners or at other areas of floor surface, consider installing supplemental floor drains. A small drain and leader to the floor below can alleviate hazardous ice build-up and reduce chloride ion infiltration into the concrete. The minimum recommendation would be to broom or sponge mop the water to existing floor drains. Ponding water, as it evaporates, leaves behind a high concentration of salt, which can migrate into the concrete and contribute to corrosion of the reinforcement and progressive concrete deterioration.

Inspect heating, ventilation fans, air-conditioning equipment ductwork, and the necessary support systems. Service manuals provided for this equipment by the manufacturer should be checked for appropriate maintenance action. All servicing required should be performed promptly and to the specifications provided by the equipment manufacturer. Replacement belts and pulleys for fans should be kept in stock. Replacement of worn or damaged parts should be completed periodically to reduce the chances of breakdown. All questions regarding servicing should be directed to the equipment manufacturer or supplier.

The elevators, shafts, and associated hardware should be inspected and serviced in accordance with the elevator manufacturer's recommendations. A maintenance agreement with a reputable elevator service company or the manufacturer is the most effective method for servicing the elevators to reduce breakdowns. Water leaking into the elevator shaft should be corrected as soon as it is discovered. Use of an auxiliary pump system may be required if water build-up becomes excessive.

Standpipe and sprinkler systems should be periodically charged and activated to check for proper operation. Coordinate the standpipe system check with the fire department and your washdown of the floors. Portable fire extinguishes should be checked for satisfactory charge. Broken extinguishers, damaged fire hoses, and cabinets should be repaired or replaced.

Before the onset of cold weather, the parking facility must be winterized. Water risers, fire protection systems, standpipes, landscaping sprinklers, and hosebib systems must be flushed and completely drained to prevent ice build-up and bursting of pipes. Drain lines and other underground piping should be flushed and checked for blockage.

Heating systems should be started and tested. Often overlooked in winterization procedures are the parking equipment heating units that must be checked for proper operation. In the spring, after danger of freezing, these procedures must be reversed and plumbing systems restored to full operation. Heating systems must be shut down.

18.2.2.4 Electrical System.

The effective operation of any parking facility requires adequate lighting to insure that users can move securely and easily within the facility--motorists as well as pedestrians. If the existing lighting system becomes functionally obsolete, it should be replaced with a new system. New systems, such as high-pressure sodium vapor and metal halide, can be substantially more energy efficient than older fluorescent systems. Replacement of fluorescent light fixtures should be considered since they are inefficient in cold weather. Capital expenditure, maintenance, and energy savings must be evaluated for "cost effectiveness."

An annual detailed inspection of all fixtures and equipment is required. Inspect pedestrian "EXIT" and emergency light fixtures more frequently. Those fixtures not working properly should be repaired or replaced; damaged lenses should be replaced; timers and photo cells should be periodically checked and calibrated.

Studies by manufacturers have shown that the energy consumed by some lamps increases rapidly towards the end of lamp service life. Scheduled relamping before burnout may reduce energy costs. Review service life expectancy versus power consumption with your local lamp supplier. Also, see Chapter 9.

Electrical conduit exposed to leaking water or rusting should be cleaned and repaired. Damaged conduit that has pulled loose from its mounts or has exposed conductors should be maintained in proper condition. Damaged or rusted electrical panels should be cleaned and repainted or replaced.

If the parking facility has an emergency generator, periodic checks of the system should be made per the manufacturer's recommendations to assure reliance of the generator system.

18.2.2.5 Parking-Control Equipment.

All parking equipment should be examined, and a preventive maintenance program established to reduce breakdowns. It is prudent to maintain an inventory of critical components so that the maintenance crew can quickly repair the equipment. Periodic servicing of the parking equipment is essential for smooth facility operation. A service agreement should be established with the parking equipment supplier so that the supplier is on call to provide assistance in the event of breakdown.

Equipment added to the facility after the original installation must be compatible with the existing equipment. Copies of operation and service manuals for all parking equipment should be kept nearby for easy reference. A log of maintenance and service calls should be established for each piece of equipment.

18.2.2.6 Security.

As evidenced by interest and attendance at conventions of various parking groups, security is one of the biggest problems in the industry today. Security is an ongoing process that good design alone will not achieve. Careful selection of equipment, training, and management by security professionals are equally important.

Two types of security measures, "passive security" and "active security," are employed to maximize security in a parking facility. Passive security does not require human response. These security measures are a physical part of the facility, such as lighting and glass walled stairtowers. The common thread among all passive features is visibility--the ability to see and be seen while in a parking facility. Lighting is universally considered to be the most important security feature in the facility. Staining concrete has also proved to be a cost-effective method of increasing brightness. Applying a white stain to ceilings, beam soffits, and walls can improve brightness; however, staining seems to encourage graffiti, which can sometimes tend to hurt the perception of security. The additional general maintenance and upkeep are also important in maintaining security.

Active security measures invoke an active human response. The active systems, such as those listed below, where applicable, should be tested frequently to insure proper operation:

a. Television surveillance camera
b. Audio-monitoring devices
c. Telephone in elevator cabs and cashier's booth
d. Panic hardware on doors
e. Security monitoring
f. Alarms
g. Other special features

Maintain security policing of the facility, such as a scheduled drive through by trained security personnel, to deter undesirable behavior within the facility. The importance of security monitoring cannot be overstressed; it is essential to maintain security systems in proper working order at all times. Periodic inspection of all equipment and observation by in-house personnel is required. When deficiencies in security monitoring are found, take corrective action immediately. Chapter 6 addresses Security in more detail.

18.2.2.7 Graphics and Striping.

Proper graphics are essential to the smooth operation of the parking facility; they must be kept clean and visible. Graphics combining words or symbols with arrows are most effective for traffic- and pedestrian-movement control. Keep all entrance, exit, traffic directional, and display signs clean and legible. Examine paint or facing material for graphics annually for deterioration and repainted or repaired as required. Also replace lights in illuminated signs.

Floor-level and stair-elevator-tower designations directing patrons to their parking locations should be kept legible and visible from all entrances and exits. Locate stair and elevator-tower level designations on both sides of tower doors.

Inspect floor striping each spring after cleaning and repaint as required. In older facilities, consider restriping to accommodate smaller cars. Be careful to maintain proper illumination levels if relocating designated pedestrian walkways. The restriping plan should not remove the walkway from underneath a light, creating a tripping hazard. Restripe after resealing the floor. Chapter 10 addresses Signs in more detail.

18.2.2.8 Inspection.

Annual inspections are the best way to assure that minor conditions requiring repair are contained and corrected before they cause major problems. Inspect each spring to determine if salt and wear exposure has caused concrete deterioration. Qualified restoration engineers should do inspection and concrete testing.

A sample inspection checklist is included in Appendix 18-3. This checklist, appropriately modified, may be used by in-house maintenance staff or the restoration specialist to document existing conditions. A similar checklist can also be prepared for the operational and aesthetic elements discussed in this chapter.

The results of the initial inspection can be summarized as shown by the sample forms included in Appendix 18-4. The initial inspection results, once documented, form the database for later annual reviews and inspections.

18.2.2.9 Safety Checks.

It is important to minimize potentially unsafe conditions in a facility. Certain operational and structural maintenance elements can impact safety. Also, some features that enhance security tend to enhance safety.

Structural system maintenance will reduce tripping hazards and potential injury to facility users from loose overhead concrete. Concrete spalls can develop on ceilings as well as on bumper walls, precast panels, and concrete facades. Proper maintenance of the pedestrian guardrails and inspection of vehicular barriers will minimize unsafe conditions.

Ice and snow control will tend to reduce slipping and skidding hazards for pedestrians and vehicles. Proper selection and application of surface sealer is important to reduce glazing, which tends to make surfaces slippery. Repainting the face and edge of concrete curbs annually is essential to maintaining high visibility and reduces tripping hazards. Other safety considerations include maintaining proper illumination levels within the facility, lighting "EXIT" signs, emergency lights, fire-safety equipment, and active security systems. In addition, in enclosed or underground structures carbon monoxide detectors and other ventilation systems should be checked daily for proper operation.

18.2.3. Aesthetic Maintenance

In addition to operational and structural maintenance needs within the parking facility, aesthetic features also require regular maintenance. The most obvious features of the parking facility associated with aesthetics are landscaping, painting and facility appearance in general. A parking facility deserves maintenance similar to other buildings (Table 18-4).

Table 18-4 Aesthetic Maintenance Schedule

Item	Description	Annual	As Required
1.0	Landscaping	Inspect	
1.1	Mow Grass		Perform
1.2	Prune Shrubs		Perform
1.3	Tend Flowerbeds		Perform
2.0	Painting	Inspect	
2.1	Clean and Paint		Perform
3.0	General Appearance	Inspect	
3.1	Take Corrective Action		Perform

Adapted from "Parking Garage Maintenance Manual, First Edition," Parking Consultants' Council, National Parking Association, 1982.

18.2.3.1 Landscaping.

Landscaping features around the parking facility enhance its appearance. Flower beds, shrubbery, and grass plots should be well tended. Clean and cultivate planters frequently. Landscape judiciously so as not to provide hiding places and reduce security.

18.2.3.2 Painting.

Paint exposed structural elements, fascia panels, stair- and elevator-tower interiors, step landings, pedestrian handrails, vehicular guardrails, and miscellaneous metals periodically. Where painting is required, do it as soon as time and budget constraints allow.

Inspect painted surfaces annually to determine their condition. Clean and touch up small rust spots each year. Repaint as required by the elements, type of paint, and exposure conditions. Most painted surfaces need repainting every three to seven years.

Repaint concrete curb faces and edges semiannually to reduce potential for tripping by maintaining high visibility. Paint concrete surfaces with the following paint types, typically:

1. Water-based Portland cement paints
2. Water-based polymer latex paints
3. Single- or two-component polymer paints
4. Oil-based paints

Refer to ACI 515 for general guidelines selecting paints for a particular use. Water-based Portland cement paints exhibit properties similar to those of concrete. Primary uses are filling in and leveling minor imperfections in concrete surfaces. The disadvantages of Portland cement-based paints are that they cannot be applied over existing paints, have a limited color selection, painted surfaces tend to show stains and dirt, and are hard to clean.

Water-based polymer latex paints are available for interior and exterior use. Latex paints form a breathable layer and can resist blistering when applied to concrete with high or varying moisture content. Latex paints must be applied to a moistened surface and may require a primer coat of a low-viscosity-penetrant paint before application to some concrete surfaces.

Polymer paints are available in single- or two-component forms. Both form a smooth, dense, high-gloss finish that is highly resistant to humidity, stains, or dirt. Polymer paints are available in a wide range of colors. Single-component polymer paints offer flexibility and extensibility; when applied sufficiently thick, single-component polymer paints can bridge minor cracks. Two-component polymer paints form a high-gloss surface highly resistant to chemical attack and easy to clean. Since polymer paints form a moisture barrier, do not apply to moist surfaces or to a concrete substrate with high or varying moisture content.

Oil-based paints are those that contain derivatives of fatty acids or drying oils. These paints are not resistant to the natural alkalinity of concrete. Oil-based paints should always be applied with a primer coat. The primer coat will reduce the paint's susceptibility to a reaction with the alkalinity of the concrete, but will not eliminate it.

Use water-based polymer latex paints in most parking facility concrete painting applications. They will provide a durable, breathable surface protection for general use on concrete and masonry walls. Contact the manufacturer and follow its recommendations for surface preparation, storage of paint, and application.

Metal surfaces are typically painted with the following paints:

1. Enamel paints
2. Zinc-rich paints

Enamel paints are general-purpose interior/exterior paints used for protection against weather. Enamel paints are readily applied to primed, previously painted, or galvanized-metal surfaces. Surface preparation includes the removal of dirt, oil, grease, and other surface contaminants. Rust and paint not tightly bonded should be removed and the area spot primed. Apply primers applied per manufacturers' recommendations. Do not apply enamel paints to damp or wet surfaces. Do apply enamel paint when the air, product, and surface temperatures are at least 50°F. Take care not to apply the paint late in the day when dew and condensation are likely or when rain is possible.

Zinc-rich paints can be used as a one-coat maintenance coating or as a permanent primer. Zinc-rich paints can be used in areas with varying temperature conditions and high humidity. Zinc-rich paint when applied to a surface forms a coating that self-heals and resumes protection when damaged.

As with enamel paints, apply when the air, paint, and surface temperatures are at least 50^0F. Take care not to apply the paint late in the day when dew and condensation are likely or when rain is possible.

18.2.3.3 General Appearance.

Glass in stairtowers is provided for security as well as aesthetics. Sweep windows and wash floors of the stair- and elevator towers, cashiers' booth and lobbies regularly. Repair or replace damaged window glass or deteriorated glazing as needed. Check roof systems for leaks periodically.

Occupied and heated spaces beneath the parking floor, such as the office spaces, public areas, cashiers' booths, restrooms, and mechanical/electrical equipment rooms, may require special attention. If floor-slab cracking or leaking overhead occurs, then vehicular deck coatings may be required to protect against water-related damage.

Keep walkways leading to and from stairtower entries clean and presentable. Trash receptacles placed at convenient locations around the facility help insure proper trash disposal.

Rust stains are usually indicators of other problems, such as concrete cracking or paint or sealant failure. Determine and correct the cause of rust staining. Refer to the *Concrete Construction* magazine publication, "Removing Stains from Concrete."

18.2.4 Checklists

Checklists are important to record completion of required maintenance. To perform maintenance tasks in a timely manner, develop checklists for the daily, weekly, monthly, semi-annual and annual task frequencies recommended by the maintenance program. The checklist of parking structure maintenance tasks and recommended frequencies included in Appendix 18-2 can provide a good start to identify group tasks, and preparing checklists for your facility. Also, refer to the sample checklists included as Forms F-1 through F-4. Review and make appropriate changes to the checklists annually. Add or delete checklists as dictated by operational changes.

FORM F-1

MAINTENANCE MANUAL AND PROGRAM **Inspector____**
DAILY OPERATIONAL CHECKLIST **Date________**
PARKING STRUCTURE NAME
Owner
City, State

CLEANING
- Pick up trash
- Sweep elevator tower
- Sweep stair tower
- Sweep office and collection booth
- Wash away parking areas required to remove odors
- Remove graffiti

SNOW PLOW REMOVAL AND ICE CONTROL
- Remove snow
- Apply sand or deicer

DRAINAGE
- Clean off floor drain grates - all levels
- Squeegee ponded water to nearest drain - all levels

INSPECTION
- Check for trip hazards and other safety concerns

NOTES AND CORRECTIVE ACTION NEEDED:________________

____

FORM F-2

MAINTENANCE MANUAL AND PROGRAM **Inspector____**
MONTHLY OPERATIONAL CHECKLIST **Date ________**
PARKING STRUCTURE NAME
Owner
City, State

MECHANICAL EQUIPMENT

ELEVATORS

- Normal operation of elevators
- Clean door tracks at each level and in cab
- Maintenance performed per service contract

HVAC SYSTEM

- Normal operation of entire system
- Change air filters
- Normal operation of fans

FIRE PROTECTION EQUIPMENT

- Check standpipes for operation
- Check charge on portable fire extinguishers
- Normal operation of smoke and heat detectors

NOTES AND CORRECTIVE ACTION NEEDED:________________

____

FORM F-3

MAINTENANCE MANUAL AND PROGRAM **Inspector_____**
SEMI-ANNUAL OPERATIONAL CHECKLIST **Date _________**
PARKING STRUCTURE NAME
Owner
City, State

ELECTRICAL SYSTEM

- Control and power panels for proper operation
- Timers and photocells for proper operation
- Ground fault circuit interrupters for operation

MECHANICAL EQUIPMENT

FIRE PROTECTION EQUIPMENT

- Test sprinklers for proper operation

GRAPHICS AND FLOOR STRIPING

- Clean signs
  - Directional signs
  - Entrance/exit signs
  - Tier/level designations
- Examine paint or facing material for deterioration
- Floor striping and graphics

NOTES AND CORRECTIVE ACTION NEEDED:____________________

____

FORM F-4

MAINTENANCE MANUAL AND PROGRAM **Inspector_____**
ANNUAL OPERATIONAL CHECKLIST **Date ________**
PARKING STRUCTURE NAME
Owner
City, State

ELECTRICAL SYSTEM

- Distribution panels
- Electrical conduit

CLEANING

- Prune trees

WINTERIZATION

- Washdown
- Flush
  - Standpipes
  - Sprinklers
  - Hosebibs
  - Drains
  - Piping
- Check for blockages

OVERALL

- General review of all operational components

NOTES AND CORRECTIVE ACTION NEEDED:__________________

____

18.3 COST OF MAINTENANCE

Many factors influence maintenance costs for a parking facility. The total cost to maintain the facility is related to the three categories of structure, operational and aesthetic maintenance outlined in the previous section. Develop maintenance costs for each category separately to effectively plan and budget for comprehensive maintenance.

The purpose of this section is to help identify maintenance costs that should be included by facility owners to effectively budget for maintenance. The types of items that need to be included are:

- Cost of periodic repairs and/or corrective actions necessary to maintain serviceability and facility operations. This category includes daily or routine maintenance.
- The replacement cost for structural and operational elements at the end of their estimated service lives.
- Cost of preventive maintenance actions required to extend the facility service life.

Most owners recognize and budget for periodic repairs and/or corrective measures for operational elements, often referred to as routine maintenance. However, many owners do not budget funds to replace structural or operational elements at the end of their service lives. Replacement cost is often viewed as a capital expenditure that may or may not be authorized when needed. It is difficult to assess the cost of preventive actions and is often missed by many owners.

Usually, facility engineers and maintenance supervisors tend to have a strong mechanical/electrical systems background that enable them to more easily understand, plan, and adequately budget for the operational elements of the maintenance program. On the other hand, review by a restoration specialist is required to identify the need and budget appropriately for the structure maintenance cost.

How much does it cost to maintain a parking facility? The results of a 1990 survey of parking facility owners are shown in Table 18-5. Also refer to Table 2-6 in Chapter 2, Section 2.3.2 for a more recent survey result completed in 1999. The tables show the breakdown of the annual operating cost for the various expense categories, including structural and routine maintenance.

The maintenance expenses shown in Table 18-5 include the structural, operational and aesthetic maintenance elements identified in this chapter. The percentage of the total operating cost spent on maintenance appears very low. The trend to spend so little on maintenance is yet another confirmation that most owners continue to budget inadequately for maintenance. Owners usually do not account for the preventive and replacement maintenance costs. In the author's opinion, the actual maintenance cost for a new facility is about twice that shown by the survey. For an older or restored facility the cost is expected to be even higher.

Table 18-5 Operating Costs of Parking Facilities

Expense Category	Annual Operating Cost Per Space		Percent
	1990	1993 (1)	
Cashiering/management	$162	$172	52.6
Utilities	45	47	14.5
Maintenance	42	44	13.5
Miscellaneous	60	63	19.4
TOTAL	$307	$326	100.0

(1) Equal to 1990 survey figures inflated by increase in consumer price index (CPI) from 1990-92. Source of CPI - Dept. of Labor, Bureau of Labor Statistics. Does not include property, parking, or sales taxes; debt service; and depreciation.

Courtesy: WALKER Parking Consultants/Engineers, Inc., Kalamazoo, Michigan

Tables 18-6 and 18-7 are included as examples for computing anticipated annual maintenance cost for new and existing facilities. In addition to assisting in budgeting for the facility's maintenance program, the exercise is also useful in comparing the life cycle cost of different structure types during design, as well as comparing repair scheme costs during restoration. All the applicable structural, operational, and aesthetic elements of a maintenance program should be included in estimating the total maintenance cost. Include the costs for periodic repairs, replacement costs, and preventive actions. The following sections further address maintenance costs.

18.3.1 Structural System Maintenance Cost

The structure maintenance cost usually represents the largest portion of the total maintenance budget. Facility owners tend to grossly underestimate the structure maintenance cost and budget inadequately for timely corrective actions that must be performed to cost-effectively extend the facility service life. Also, the adverse impact of ineffective structure maintenance is deferred. Therefore, it becomes difficult for most owners to recognize long term benefits of timely

Table 18-6 Annual Maintenance Cost (New Facility)

		Construction Cast-in-place		Age 0	Cars 1000	SF 320,000
Item Description	Quantity	Unit Price	Total Cost	Time	$/car/Yr	$/SF/Yr
Preventive Maintenance						
Sealants Floor Slab	10,000	3.00		10	3	0.01
Architectural Sealants	2,600	3.50	9,000	12	1	0.00
Expansion Joints	96	80.00	8,000	10	1	0.00
Penetrating Sealer	256,000	0.50	128,000	5	26	0.08
Traffic Topping	-	2.25	-	15	0	0.00
Supplemental Drains & Piping	-	1800.00	-	25	0	0.00
Miscellaneous	-		-			
Subtotal			**175,000**		**$31.00**	**$0.09**
Replacement Maintenance						
Replace Drainage System	320,000	0.65	208,000	25	8	0.03
Replace Lighting System	320,000	1.75	560,000	25	22	0.07
Replace Parking Revenue Control	320,000	0.32	102,000	6	17	0.05
Replace Signage	1	30,000	30,000	25	1	0.00
Replace Elevators	2	120,000	240,000	25	10	0.03
Miscellaneous			-			
Subtotal			**1,140,000**		**$58.00**	**$0.18**
Routine Maintenance						
Maintain Joint Sealants	1	1,500	2,000	1	2	0.01
Maintain Traffic Topping			-	1	0	0.00
Interim Slab Patching			-	1	0	0.00
Interim Beam & Column Patching			-	1	0	0.00
Stairtower Maintenance	1	2,000	2,000	1	2	0.01
Maintain Drainage System	1	1,000	1,000	1	1	0.00
Maintain Lighting	1	6,000	6,000	1	6	0.02
Maintain Parking/Revenue Control	1	2,000	2,000	1	2	0.01
Annual Inspections	1	5,000	5,000	3	2	0.01
Maintain Elevators	12	500	6,000	1	6	0.02
Miscellaneous	1	2,000	2,000	1	2	0.01
Sweeping/Cleaning	12	1,000	12,000	1	12	0.04
Power Wash Floors	4	2,000	8,000	1	8	0.03
Painting	1	10,000	10,000	1	10	0.03
Subtotal			**56,000**		**$53.00**	**$0.19**
Average Annual Maintenance Cost					**$142.00**	**$0.46**

Table 18-7 Annual Maintenance Cost (20 Year Old Facility)

		Construction Cast-in-place		Age 20	Cars 1000	SF 320,000
Item Description	Quantity	Unit Price	Total Cost	Time	$/car/Yr	$/SF/Yr
Preventive Maintenance						
Sealants Floor Slab	10,000	3.00	30,000	10	3	0.01
Architectural Sealants	2,600	3.50	9,000	12	1	0.00
Expansion Joints	96	80.00	8,000	10	1	0.00
Penetrating Sealer	-	0.50	-	5	0	0.00
Traffic Topping	256,000	2.25	576,000	15	38	0.12
Supplemental Drains & Piping	10	1800.00	18,000	25	1	0.00
Miscellaneous	1	50,000	50,000	10	5	0.02
Subtotal					**$49.00**	**$0.15**
Replacement Maintenance						
Replace Drainage System	320,000	0.65	208,000	25	8	0.03
Replace Lighting System	320,000	1.75	560,000	25	22	0.07
Replace Parking Revenue Control	320,000	0.32	102,000	6	17	0.05
Replace Signage	1	30,000	30,000	25	1	0.00
Replace Elevators	2	120,000	240,000	25	10	0.03
Miscellaneous						
Subtotal					**$58.00**	**$0.18**
Routine Maintenance						
Maintain Joint Sealants	1	1,500	2,000	1	2	0.01
Maintain Traffic Topping	1	2,000	2,000	1	2	0.01
Interim Slab Patching	1	3,000	3,000	1	3	0.01
Interim Beam & Column Patching	1	2,000	2,000	1	2	0.01
Stairtower Maintenance	1	2,000	2,000	1	2	0.01
Maintain Drainage System	1	1,000	1,000	1	1	0.00
Maintain Lighting	1	6,000	6,000	1	6	0.02
Maintain Parking/Revenue Control	1	2,000	2,000	1	2	0.01
Annual Inspections	1	7,000	7,000	1	7	0.02
Maintain Elevators	12	1,000	12,000	1	12	0.04
Miscellaneous	1	4,000	4,000	1	4	0.01
Sweeping/Cleaning	12	1,000	12,000	1	12	0.04
Power Wash Floors	4	2,000	8,000	1	8	0.03
Painting	1	10,000	10,000	1	10	0.03
Subtotal					**$73.00**	**$0.25**
Average Annual Maintenance Cost					**$180.00**	**$0.58**

corrective and preventive maintenance actions. Considering the potential liability associated with neglecting to properly maintain the facility, the cost of structure maintenance is relatively small.

The age and geographic location of a parking facility will impact maintenance costs. Older facilities require more maintenance than new ones. The cost of maintaining the structure will also increase as the structure ages. A structure located in a moderate climate is likely to require less maintenance in comparison to a structure that is located in a severe climate.

The parking facility structural system will influence maintenance costs. However, it is important to realize that the true cost during the structure life comprises two components: the initial cost to construct the facility and the maintenance cost. Structural systems that initially cost less may eventually become more expensive, considering the higher cost of maintaining the structure over its entire service life. A conventionally reinforced structural system is more likely to incur higher maintenance costs than a cast-in-place post-tensioned one. Precast prestressed structures may require more frequent maintenance and higher costs. For a restored structure, the following is a list of some of the important factors that can impact the cost of future maintenance:

- Type of corrosion protection of the existing structure.
- Type of surface waterproofing system installed.
- Level of chloride contamination and the extent of concrete removals specified during construction.
- Existing structural system, design deficiencies and adverse conditions related to drainage, water leakage, joint deterioration and concrete quality.

When comparing repair alternatives for restoring an existing parking facility, it is important to recognize and consider the maintenance cost associated with each of the repair schemes selected. A repair that is initially less costly may be burdened with a higher maintenance cost. Life cycle cost comparison of repair alternatives should always include the anticipated maintenance cost of each repair scheme to make the analysis more complete and accurate.

Periodic structural maintenance includes items such as patching concrete spalls and delaminations in floor slabs, beams, columns, walls, etc. In many instances there are maintenance costs associated with the facade elements. Other periodic repairs may include repair of traffic topping membranes, routing and sealing of joints and cracks, and expansion/construction joint repairs. The cost of these repairs can vary significantly from one structure to another. The factors that will impact the maintenance cost are the value the owner places on the maintenance of the facility, the climate, the age of the structure and other factors discussed previously.

A review by a restoration specialist is usually necessary to identify the preventive maintenance needs of a facility. In addition to the annual or other periodic inspections, material testing and examinations may also be necessary to determine and recommend these maintenance measures. One example of this is the chloride monitoring testing that is necessary to monitor the effectiveness of sealers and coatings. The chloride testing also helps to determine the frequency and extent of sealer reapplication. The results of the periodic inspections may also indicate the need for other materials examinations and laboratory testing. Refer to Chapter 19, Table 19-3, for other commonly used tests and their application. It is important to include these expenses in the maintenance budget.

18.3.2 Operational Maintenance Cost

Operational maintenance includes tasks that are sometimes referred to as routine or daily maintenance. The desired degree of cleanliness, as well as the frequency of certain cleaning tasks, will impact daily management cost. Daily maintenance includes sweeping and washing floors, washing walls, removing graffiti, snow removal, replacing light bulbs and ballasts, repairing parking access revenue control equipment, cleaning restrooms, cleaning floor drains, and line restriping. Owners who value more cleanliness in their parking facilities will undoubtedly experience higher maintenance costs.

In addition to daily maintenance, operational maintenance costs should include replacement costs for items such as lighting, drains and drain pipes, parking revenue control equipment, signage, security systems, etc. Include replacement costs in the maintenance budget so funds will be readily available when needed. Budget for costs of service contracts to service elevators, electrical, mechanical and revenue control equipment. Also, refer to the checklist in Appendix 18-2 for additional operational maintenance items that should be included.

APPENDIX 18-1

CHLORIDE MONITORING CHART

Depth of sample		Floor	Year						
CL – 1	0" – 1								
	1" – 2"								
	2" – 3"								
CL – 2	0" – 1"								
	1" – 2"								
	2" – 3"								
CL – 3	0" – 1"								
	1" – 2"								
	2" – 3"								
CL – 4	0" – 1"								
	1" – 2"								
	2" – 3"								
CL – 5	0" – 1"								
	1" – 2"								
	2" – 3"								
CL – 6	0" – 1"								
	1" – 2"								
	2" – 3"								
CL – 7	0" – 1"								
	1" – 2"								
	2" – 3"								
CL – 8	0" – 1"								
	1" – 2"								
	2" – 3"								
CL – 9	0" – 1"								
	1" – 2"								
	2" – 3"								
CL – 10	0" – 1								
	1" – 2"								
	2" – 3"								

APPENDIX 18-2

PARKING MAINTENANCE TASKS AND RECOMMENDED FREQUENCIES

	DAILY	WEEKLY	SEMIMONTHLY	MONTHLY	QUARTERLY	SEMIMONTHLY	ANNUALLY
CLEANING:							
- Sweep localized areas.	D	M					
- Sweep all areas/curbs.		D	M				
- Empty trash cans.	D	M					
- Clean restroom floors/fixtures.	D	M					
- Clean restroom walls.			D	M			
- Clean cashier booths (floors/windows)	D	M					
- Clean elevator floors.	D	M					
- Clean elevator walls/windows)			D		M		
- Clean stairway windows.		D		M			
- Clean stairway windows.					D		M
- Clean lobby/office floors.	D	M					
- Clean lobby/office windows.		D		M			
- Wash parking-area floors.				D		M	
- Clean parking-control equipment		D	M				
DOORS AND HARDWARE:							
- Check hinges/latches.	D	M					
- Check mechanized doors.	D	M					
- Check panic hardware on security doors	D	M					
- Lubricate mechanized doors				D	M		
ELECTRICAL SYSTEM:							
- Check light fixtures.		D		M			
- Relamp fixtures.*							
- Inspect special units.*							
- Check distribution panels.						D	M
ELEVATORS:							
- Inspect for proper operation.		D	M				
- Check indicators and other lights.		D	M				
- Perform preventive maintenance.**							
HVAC SYSTEM:							
- Inspect for proper operation.				D	M		
- Check ventilation in enclosed/ underground areas.		D	M				
- Perform preventive maintenance.*							
LANDSCAPING:							
- Remove trash.	D		M				
- Mow, trim and weed.		D	M				
PAINTING:							
- Look for rust on doors/door frames.							
- Look for rust on handrails/guardrails.						D	M
- Look for rust on exposed pipes/pipe. guards/conduit						D	M
- Look for rust on other metal surfaces					D	M	
- Inspect striping.						D	M
- Check signs.						D	M
- Check walls.				D	M		
- Inspect curbs.						D	M
				D		M	

	DAILY	WEEKLY	SEMIMONTHLY	MONTHLY	QUARTERLY	SEMIMONTHLY	ANNUALLY
- Touch up paint.						D	M
- Repaint.*							
PARKING CONTROL EQUIPMENT:							
- Inspect for proper operation.	D	M					
- Perform preventive maintenance.***							
PLUMBING SYSTEM:							
- Inspect sanitary facilities.	D	M					
- Inspect irrigation.			D	M			
- Check floor drains.	D		M				
- Check the sump pump.		D		M			
- Test the fire protection system.				D	M		
- Check drain - water system (for winter)							M
ROOFING/WATERPROOFING:							
- Check roof for leaks.				D		M	
- Check joint sealant in floors.				D		M	
- Inspect expansion joints.				D		M	
- Inspect windows/doors/walls.				D		M	
- Inspect the floor membrane						D	M
- Check for deterioration.							
SAFETY:							
- Check carbon-monoxide monitor (s).	D	M					
- Check handrails/guardrails.				D	M		
- Check exit lights.		D		M			
- Check emergency lights.		D		M			
- Eliminate tripping hazards.		D		M			
SECURITY SYSTEM:							
- Check closed - circuit television.	D	M					
- Check audio surveillance.	D	M					
- Test panic buttons.	D	M					
- Test stair - door alarms.	D	M					
GRAPHICS:							
- Check sign placement.	D	M					
- Check sign cleanliness.				D	M		
- Check sign visibility.	D	M					
- Check sign legibility.				D			M
- Check sign illumination.	D	M					
SNOW/ICE CONTROL:							
- Check for icy spots (in season).	DM						
- Remove snow and ice (as required).	DM						
STRUCTURAL SYSTEM:							
- Check floor-surface deterioration.						D	M
- Check for water leakage.						D	M
- Inspect concrete for cracks.							
- Inspect structural steel for rust.						D	M
- Make repairs. (see a consultant).							
- Replace floor coating. (see a consultant)							

D - Desirable M - Minimum

Adopted from "Parking Garage Maintenance Manual, First Edition," Parking Consultants Council, National Parking association, 1982

APPENDIX 18-3

ANNUAL STRUCTURAL CHECKLISTS

FORM F-5

ANNUAL STRUCTURAL CHECKLIST **Inspector______**
PARKING STRUCTURE NAME **Date_________**
MAINTENANCE MANUAL AND PROGRAM
Owner
City, State

FLOORS

_______ When was the last floor sealer application? (Typically applied every 3-5 years)

_______ Are there rips, tears, debonded areas or signs of embrittlement in the traffic topping?

_______ Are there cracks in the floor slab? If yes, where are they located and how wide are they?

_______ Are there signs of leaking?

_______ Any spalls or delaminations? If yes, how big and where are they located?

_______ Has chloride ion content testing been performed this year?

BEAMS AND COLUMNS

_______ Are there cracks? If yes, are they vertical or horizontal and how wide?

_______ Are there any signs of leaking?

STAIR/ELEVATOR TOWERS

_______ Are there any signs of a leaking roof?

_______ Are there any cracks in the exterior brick?

_______ Are there any cracks in the mortar joints?

NOTES AND CORRECTIVE ACTION NEEDED:________________

____

JOINTS

_______ Are there any signs of leaking, loss of elasticity or separation from adjacent surfaces?

Expansion joints
Control joints
Construction joints
Tee-to-tee joints

ARCHITECTURAL SEALANTS

_____ Are there any signs of leaking, loss of elasticity or separation from adjacent surfaces?

Between windows and doors
In block masonry
Exterior sealants
Concrete walks, drives and curb landings

EXPOSED STEEL

_______ Is there any exposed steel? If yes, where is it located and is it rusted?

MASONRY

_______ Are there any cracks in the brick?
_______ Are there any cracks in the mortar?
_______ Are there any brick spalls? If yes, where are they located and how big are they?

NOTES AND CORRECTIVE ACTION NEEDED:________________

____

BEARING PADS

__________ Are bearing pads squashed, bulging, or out of place? If yes, where?

AFTER ANSWERING THE ABOVE QUESTIONS, PLEASE CONSULT A QUALIFIED ENGINEER TO DISCUSS YOUR ANSWERS.

NOTES AND CORRECTIVE ACTION NEEDED:________________

____

____

APPENDIX 18-4

SAMPLE ANNUAL CONDITION SURVEY SUMMARY

FORM 1

Structure Name______________	Inspection Date________________________
Location__________________	Inspector____________________________
	Next Scheduled Inspection Date_________

1. STRUCTURAL REPAIRS	
Structural Element	Typical Deterioration Observed and Location
Floors/Ceilings	
Beams/Joists	
Columns	
Walls	

REQUIRED REPAIR	REPAIR PRIORITY*
Floor Surface Preparation	
Floor Repair	
Ceiling Repair	
Beam and Joist Repair	
Column Repair	
Wall Repair	
Precast Tee Beam Repair	
Expansion Joint Repair	
Expansion Joint Replacement	
Crack and Joint Repair	
Concrete Surface Repair	
Concrete Overlay	
Overlay Control Joint System	
Protective Sealer	
Traffic Topping	
Floor Drainage System	
P/T System Repair	
Brick/Masonry Repair	
Structural Steel	

* Priority Classification 1 = Immediate action required 3 = Repair within 3-5 years
2 = Repair within 1-3 years 4 = Repair after 5 years

NOTES: ____

____

FORM 2

Structure Name__________________ Location________________________	Inspection Date_________ Inspector______________ Next Scheduled Inspection Date_____

2. MAINTENANCE/REPLACEMENT			
Action Required	Frequency Required	Date last Performed	Date next Scheduled
A. Structural			
Floor/Beam/Column/ Wall Patches			
Joint Repair			
Joint Replacement			
Crack Repair			
Expansion Joint Repair			
Expansion Joint Replacements			
B. Operational			
1. Lighting			
Replace Light Bulbs Replace/Repair Exposed Conduit Replace Timers and Photocells			
2. Snow Removal			
Cleaning Sweep Floors Wash Down Floors Clean Expansion Joint Glands Paint./Stain Landscaping			

NOTES: ____
____

FORM 3

	Inspection Date______________
Structure Name___________	Inspector__________________
Location________________	Next Scheduled Inspection Date_______

3. PREVENTIVE MAINTENANCE			
Action Required	Frequency Required	Date last Performed	Date next Scheduled
Chloride Ion Tests			
Sealer Application			
Traffic Topping Application/ Repair			

TEST LOCATIONS			
Location Number	Location	Level	
			Cl = Chloride
			C = Compressive
			P = Petrographic
			S = Shear Bond

NOTES: ____

____

NEXT INSPECTION DATE: ____________________________

Chapter 19

REPAIR INVESTIGATION

Sam Bhuyan

19.1 INTRODUCTION

Although concrete is a relatively durable construction material, preventive maintenance and necessary corrective actions are required to extend the useful life of parking structures. Parking facilities experience harsh exposure conditions that can contribute to accelerated concrete deterioration and adversely impact the life expectancy of the structure. Quite often, owners and operators have to repair deteriorated structures after only 15 - 20 years of service. See Figure 19-1 (a) and (b). It is common for repair costs of structures to exceed $10.00 per square foot. In addition, the repairs disrupt the facility's operations and cause inconveniences for users, which result in a loss of revenue.

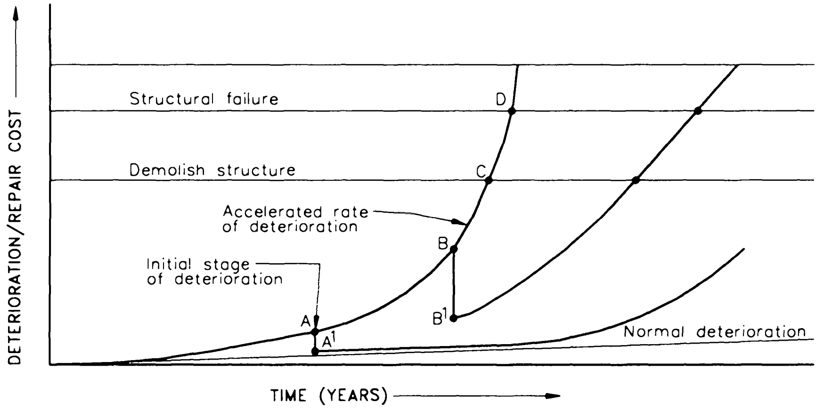
The impact of deterioration on repair costs and service life of parking structures is shown by the curves in Figure 19-2. Most structures deteriorate normally over time. This normal rate of deterioration is shown by the line labeled "Normal deterioration" close to the horizontal axis in the figure. Structural elements of buildings that are enclosed, protected, and maintained in a controlled environment tend to experience normal deterioration as represented by this line with a gentle slope. In comparison, the deterioration rate experienced by parking facilities is shown by the curve connecting the points A through D. This curve indicates that initially, during the early stage of their service life, parking structures also deteriorate at a normal rate. However, after they have been in service for a period of time, they tend to deteriorate at an accelerated rate.

There are several mechanisms that contribute to this accelerated deterioration and reduce the service life of the structure. In northern regions, corrosion of embedded reinforcement due to chloride contamination by road salt is a primary contributor to accelerated deterioration. Another commonly

A. P. Chrest et al., *Parking Structures*

(a)

(b)
Figure 19-1(a): Facility in need of repairs. *(b):* Facility after repairs.



NOTES:
1. Points A – D represent stages of accelerated deterioration in parking structures.
2. Structures repaired at point A cost less overall and last longer than structures repaired at point B. (Compare curve at A1 to curve at B1.)

Figure 19-2: Parking structure deterioration curve.

observed concrete deterioration is due to the lack of, or inadequate, air-entrainment in concrete. In this instance, freezing and thawing can contribute to progressive and rapid concrete deterioration. Some structures in southern regions also are exposed to an equally harsh environment. Concrete structures located in coastal regions are susceptible to corrosion-induced deterioration. Airborne chlorides and marine waterspray can be just as damaging as road salts.

The durability of structures is also adversely affected by a lack of corrosion-protection systems. Today, an owner can use a combination of state-of-the-art corrosion protection systems, such as concrete sealers, membrane coatings, epoxy-coated reinforcement, admixtures to reduce concrete permeability, corrosion-inhibiting admixtures, and cathodic protection to extend the life of a structure effectively. See Chapter 15 for a discussion of durability requirements for new parking structures.

Other deterioration mechanisms such as cracking, leaching, carbonation, and abrasion can also adversely affect structures in severe as well as moderate climates. In addition, inadequate design details, poor drainage conditions, poor quality concrete, and joint deterioration can have a significant impact on the structure's service life.

Appropriate repairs must be performed to address existing deterioration due to service exposure and inherent structure deficiencies. The repair methods and materials selected must be durable and capable of extending the service life of the structure cost effectively.

In Figure 19-2, the vertical lines AA^1 and BB^1 represent such repairs performed to maintain serviceability and extend the service life of the structure. Also, note the following:

1. Repairs performed at an early stage of distress cost less than repairs that are delayed. The length of line AA^1 is shorter than that of line BB^1. The increased repair cost is due to more deterioration in the structure at later stages.
2. Structures that are in an advanced stage of deterioration (between points C and D on the curve) cannot be repaired cost effectively. For such structures the best strategy is to perform Band-Aid repairs that will buy time to fund a new facility or make other arrangements for the lost parking spaces.
3. It costs more to repair and the benefits realized are reduced with increased deterioration. The service life (benefit realized) of the repaired structure represented by the curve beyond point A^1 is much longer than the service life represented by the curve beyond point B^1. The deterioration rate experienced by the structure beyond point A^1 is slower than the deterioration rate beyond point B^1.
4. Periodic and timely repairs can add significant service life to the structure. Routine repairs performed at an initial stage of deterioration such as at Point A are often referred to as *maintenance*. These less costly maintenance efforts defer major repairs and greatly extend the service life of the structure.

19.2 APPROACH TO RESTORING A PARKING STRUCTURE

19.2.1 Repair Investigation

A thorough condition appraisal of the structure is essential to develop a comprehensive restoration program to properly restore the structure. Repair investigation focuses on documenting the symptoms and establishing the cause(s) for the noted or observed concrete deterioration. Once the investigation is complete, repair schemes and methods are selected to address the root cause for the accelerated concrete deterioration. Due consideration is also given to minimizing the impact of adverse conditions that will affect the service life of the restored structure.

This chapter covers the essential elements necessary to conduct a repair investigation of concrete parking structures. The following elements are included:

- Commonly noted deterioration mechanisms that adversely affect the service life of concrete parking structures.
- Visual examination and documentation of symptoms of concrete deterioration.
- Field testing, non-destructive testing and laboratory examination of field samples.
- Data evaluation to address the impact of concrete deterioration on safety, structural integrity and service life of the structure.

19.2.2 Repair Implementation

To correct problems and restore a parking structure, owners must develop comprehensive programs for evaluating existing conditions, making repairs, and setting up maintenance procedures that extend the life of the facility. A comprehensive and cost-effective restoration program is built around an accurate evaluation of the condition of the structure. A parking structure restoration program will generally focus on addressing the following key technical issues:

1. Repairing deteriorated concrete floor-slab and other structural elements to restore structural integrity.
2. Providing durable wearing surfaces that will effectively waterproof the floor slab and reduce further deterioration.
3. Performing repairs to underlying structural members for continued safe use of the facility.

The primary objective of the repairs is to cost-effectively realize additional service life for the structure. How much longer the structure will last depends on the existing condition of the structure and the repair approach that is selected. The repairs can be short term (3 to 5 years) or long term; i.e., intended to last over 20 years. The long-term repairs usually cost more than the short-term repairs. The more permanent repairs also take longer to implement and have a greater impact on the patrons and lost parking spaces during construction. Therefore, it is common to phase major restoration work over several years to reduce the adverse impact of the repairs on the facility operation.

Implementing the repairs will require selecting a contractor who specializes in parking facility restoration. Also, budget more time for the engineer to perform field observation during construction. Compliance to specifications with respect to concrete removals, surface preparation, material placement, and unexpected field conditions all demand immediate response to maintain project schedules and budget. A full-time project representative is often required to assist in construction administration, management, and observation.

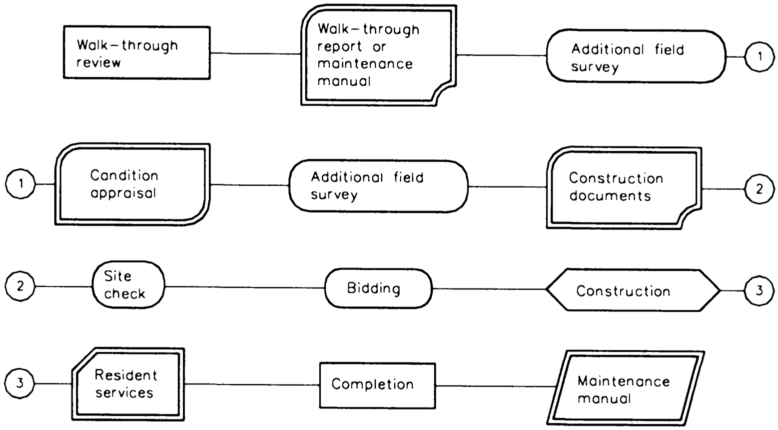


Figure 19-3: Systematic project delivery process.

After a structure is restored, it still needs to be maintained. Restoring a structure does not eliminate all the adverse conditions that contributed to the premature deterioration of the facility in the first place. Some of the built-in deficiencies can be corrected and many other conditions improved. However, the structure will require more maintenance in comparison to a newly constructed facility. The repairs will lower the deterioration rate of the restored structure, but it will continue to deteriorate at a faster rate than a new facility and will cost more to maintain.

A systematic approach is essential to realize a successful project. A flow diagram representing this approach to deliver a restoration project is shown in Figure 19-3. Each step of the approach must be followed in proper sequence. For instance, never attempt to repair a structure without the benefit of a good set of construction documents that has been developed based on the results of a thorough condition appraisal. Similarly, never attempt to develop a maintenance program without the benefit of walk-through review by a restoration specialist.

Always budget and plan for resident services during construction. A structure is never built exactly as shown in the design documents or the "as-built" documents. It is not unusual to find many surprises and unexpected conditions that will require change in repair schemes and details. If these field changes are not addressed in a timely manner, they will often contribute to cost overruns and delays.

Repair approach, methods and selection of materials commonly used to restore parking structures are covered in Chapter 20.

19.2.3 Types of Restoration Services

An owner should have a clear understanding of what his needs are in order to obtain appropriate services. Table 19-1 summarizes some of the reasons for an owner to request restoration services.

19.2.3.1 Walk-Throughs.

The purpose of a walk-through review of the structure is to provide a general overview of the structure's condition or to report any significant additional change in the condition of the structure. The work should be performed by an experienced restoration engineer or trained in-house personnel.
Observations are generally limited to visually obvious items, such as spalling, cracking, rust staining, cold joints, leaking, leaching, poor formwork, debris in the concrete, and honeycombing. The Appendix for Chapter 18 contains a sample inspection checklist that may be used for walk-through reviews.

19.2.3.2 Condition Appraisal.

A condition appraisal is required to assess the facility condition. The time and effort required to perform the condition appraisal can vary considerably from one structure to another. The nature and the extent of the work required to perform the condition appraisal needs to be evaluated by a restoration specialist. The specialist should perform a preliminary walk-through review of the structure to properly assess the scope of the work required to evaluate the structure. The scope of the condition appraisal should also include upgrading of other operational and aesthetic elements such as:

- ADA Compliance
- Electrical System including the lighting levels
- Mechanical systems, related to floor drainage, air quality, fire protection and elevators
- Parking control equipment
- Signs
- Functional review to improve traffic pattern and restriping for increased efficiency
- Appearance related to painting, staining and landscaping

Table 19-1. Restoration Services

Owner's Need	Type of Service	Scope of Work
Do I have a problem?	Walk-through review	State problems, if any. Recommend further work, if any.
Just how bad is my problem?	Field survey and condition appraisal	Identify problems, causes and effects; recommend repairs.
How much should I budget for repair and/or maintenance?	Field survey and condition appraisal or maintenance program	Give repair cost budget estimate. May also provide life cycle cost analysis of various repair alternatives and may provide structural analysis.
I want to repair my deck.	Field survey and construction documents	Develop plans and specifications, final quantities, and cost estimates for bidding.
How will I know the repairs will be done correctly?	Project resident	Record of actual quantities of work done. Daily records of work progress. Guard against deviations from plans and specifications.

With respect to the structure, the following factors can affect the level of effort required to conduct an appropriate assessment:

- Age, location and size of the structure
- The structural system
- Existing condition of the structure
- Extent of materials testing and examination required

Older structures generally show more distress and deterioration than a newer facility. See Figure 19-2. Also, structures that are exposed to more severe weather conditions are likely to be more deteriorated. It takes more time and effort to complete the field survey, document the results and evaluate the data collected from a more deteriorated structure. The size of the structure will obviously have a similar impact on the time and effort required.

Some structural systems, such as one-way slab and beam, and flat slab systems with relatively large flat exposed soffit areas, require less time to complete the field survey. Precast double-tee systems, pan-joist systems, and waffle slabs, where the view of the soffit is interrupted by the closely spaced floor-slab elements, require more time to complete a review of the floor-slab underside. The materials testing and examination required vary considerably depending on the nature and the extent of deterioration and the type of structural system.

In addition to the technical issues related to the repairs, it is also important to develop a management plan to implement the repair program. The management plan helps to address the following key questions:

- Do I have a problem?
- How bad is the problem?
- Can I fix it?
- What will it cost?
- How do I fund the project?
- Can I survive the construction?

Management plans become extremely important when dealing with multiple parking structures. The repairs for the individual structures and the entire group of structures must be planned and programmed to address repair priorities, budget constraints, level of occupancy, revenue loss and impact on the facility operations. This repair planning and programming can extend over a period of three to ten years.

The following four classifications of the condition appraisal are presented to more appropriately match the services provided to meet the Owner's specific needs:

Level I - The Level I condition appraisal provides a general professional opinion of the condition of the parking structure. The opinion is based upon a visual examination of the structure. This process will identify the existence and nature of visible problems with the structure including scaling conditions; cracks in the slab, columns, and beams; rust staining; spalling; etc. All components of the structure are examined, including stairtowers, elevators, exits and entrances, rooms, and exterior facades. Subsurface problems are not identified in this level other than on the most limited representative basis, based on visual evidence of cracking, etc. Chain dragging of selected areas will provide a representative view of sub-surface problems that have yet to manifest themselves on the surface.

The purpose for this level of appraisal is to provide a record of the structure's "health," including evaluation of the existing maintenance program or recommendations for developing such a program. It also provides a baseline from which to gauge the structure's deterioration rate. This level of appraisal will not provide enough information on which to base or budget a repair program.

Level II - The Level II condition appraisal provides an in-depth "health report" on the condition of the parking structure. It identifies the existence and extent of problems in the structure. In addition to the visual examination described in Level I, selected areas are tested to obtain representative repair quantities. Selective chain dragging and limited chloride ion testing combined with the visual examination provide enough information to determine a range of restoration alternatives and order of magnitude repair costs.

This level of condition appraisal allows monitoring of the structure's rate of deterioration. It recommends preventive measures for potentially serious problems that are obvious. It also provides a basis for preparing preliminary estimate of the range of repair costs.

Level III - The Level III condition appraisal can provide an in-depth analysis of the structure's condition. Comprehensive testing including chloride ion, petrographic and chain dragging, combined with the visual examination described in Level II provides a complete cataloging of the problems, their nature, effect on the structure and accurate quantity estimates. Repair program alternatives are evaluated, prioritized, and a restoration program recommended to meet available funds and operational constraints.

The information gathered and evaluated in a Level III condition appraisal provides the owner with the necessary budget data and justification to begin immediate repair, planning, and budgeting of funds for construction. The construction document stage can begin without need for further field evaluation of the structure.

Parking Asset Repair Planning and Programming (PARPP) – The report serves as a management tool to budget for the repairs, maintenance and protection of the structure(s) continuously over several years. The focus of the report is to project future repair and maintenance costs based on a Level I or Level II condition appraisal. These preliminary cost projections include repair recommendations based on applicable repair alternatives, life cycle costs analysis and impact of continued deterioration over a plan period.

The PARPP report serves as a management plan for Owners with multiple parking structures or a very large parking structure. The repair planning and programming is spread over several years to meet budget constraints, minimum level of occupancy, revenue loss and adverse impact on the facility operations. The repair and maintenance needs for the individual, as well as the entire group of structures, are prioritized and sequenced to optimize the overall capital expenditure.

The scope of work for each Level condition appraisal identified is also presented in Table 19-2.

19.2.3.3 Construction Documents.

Construction documents implement condition appraisal findings, which require preparation of plans and specifications. Construction documents should not be based only on a facility walk-through. Services that may be included are as follows:

- Attend pre-construction meeting.
- Review shop drawings and material sample submittals.
- Evaluate materials test results submitted by Testing Agency.
- Review contractor's payment requests and/or verify completed quantities.

Table 19-2. Condition Appraisal: Level of Services

Tasks	Level I	Level II	Level III	PARPP
Field Investigation				
1. Visual survey				
a. Identify Distress	Yes	Yes	Yes	Yes
b. Document Locations	No	Some	Yes	Yes
c. Document quantities	No	Some	Yes	Yes
2. Nondestructive testing				
a. Delamination (chain drag)	Some	Limited	Yes	Some
b. Concrete cover measurements	No	Limited	Yes	No
c. Half-cell potential testing	No	No	Yes/no	No
3. Material testing				
a. Chloride ion content	Some	Limited	Yes	Limited/no
b. Compressive strength	No	No	Yes	Limited/no
c. Microscopic examination	No	No	Yes	Limited/no
d. Shear bond	No	No	Yes	Limited/no
e. Air content	No	No	Yes/no	Limited/no
f. Excavations (test wells)	No	Limited/no	Yes/no	Limited/no
g. Others (as required)	No	No	Yes/no	Limited/no
Report				
1. Results of visual survey				
a. Identify conditions (distress)	Yes	Yes	Yes	Yes
b. Describe problems				
1) Cause	Some	Some	Yes	Some
2) Effect	Some	Some	Yes	Some
3) Impact on structure	Some	Some	Yes	Some
2. Provide recommendations				
a. Immediate repairs	Yes	Yes	Yes	Yes
b. Further investigation required	Yes	Yes	Yes/no	Yes
c. Alternative repair schemes	No	No	Yes	Some
d. Repair priorities	No	Some	Yes	Yes
e. Specific actions	No	No	Yes	No
3. Construction cost estimates				
a. Range of estimated cost	No	Yes	No	No
b. For budgeting/planning	No	No	Yes	Yes
c. For alternative repair schemes	No	No	Yes	As required
4. Life cycle cost analysis	No	No	Yes	As required
5. Structural capacity analysis	No	No	As required	As required
6. Repair planning & programming	No	No	Limited	Yes

- Make periodic site visits to observe work progress. When required, provide full-time resident services.
- Prepare and issue change orders.
- Review or prepare record drawings.
- Make final punch list visits towards project completion.

- Resolution of problems or conflicts due to latent conditions or failure of contractor to perform in accordance with contract documents.
- Provide overall administration of the contract as owner's representative to maintain operation of the facility, required occupancy, pedestrian and vehicular traffic control and noise/dust control during facility restoration.

19.2.3.4 Resident Services.
Field observation of repair/restoration work by the project resident and contract administration supplements the more traditional periodic observations at appropriate intervals during construction.

19.2.3.5 Maintenance Programs.
Maintenance program development is generally based on a brief walk-through inspection that allows the restoration engineer an opportunity to get a feel for the facility and its existing or potential problems. In addition, chloride samples are sometimes taken and original construction documents reviewed. The maintenance inspection is intended only to qualify the conditions requiring maintenance and provide general procedures and guidelines to extend the structure's service life.

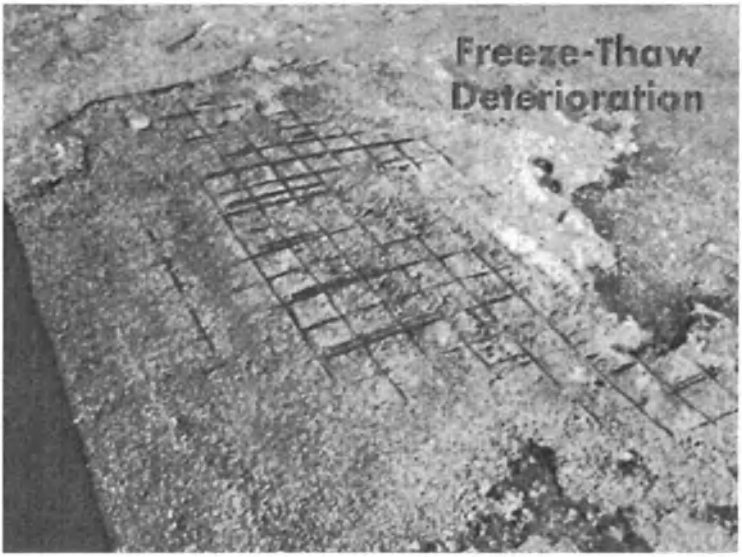
19.3 CONCRETE DETERIORATION

This section will present the most common forms of distress observed in parking facilities. Referring back to the Figure 19-2, concrete deterioration generally signals the onset of accelerated deterioration. Symptoms of concrete deterioration generally fall into one of the following major categories - spalling, cracking, deterioration, scaling, rust staining and abrasion. The deterioration mechanisms that are primarily responsible for this accelerated deterioration of parking structures are as follows:

- Corrosion
- Freezing and thawing
- Leaching
- Others

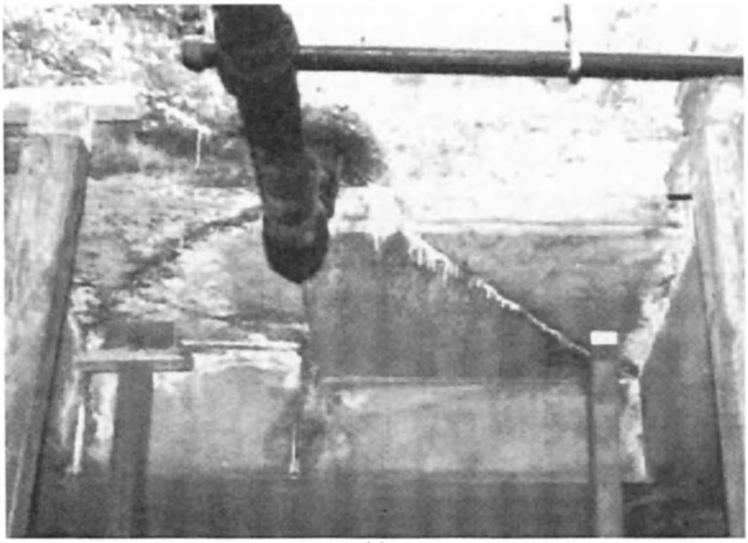
Corrosion induced deterioration is the most dominant and aggressive form of deterioration of parking structures located in the northern climatic region. Freezing and thawing can also cause very rapid deterioration of concrete structures that are not adequately air entrained. Leaching over an extended time will eventually cause concrete to weaken and promote corrosion of embedded steel reinforcement. Other less aggressive and uncommon mechanisms include carbonation and alkali-aggregate reactions. See Figures 19-4 (a) through (d).

(a)

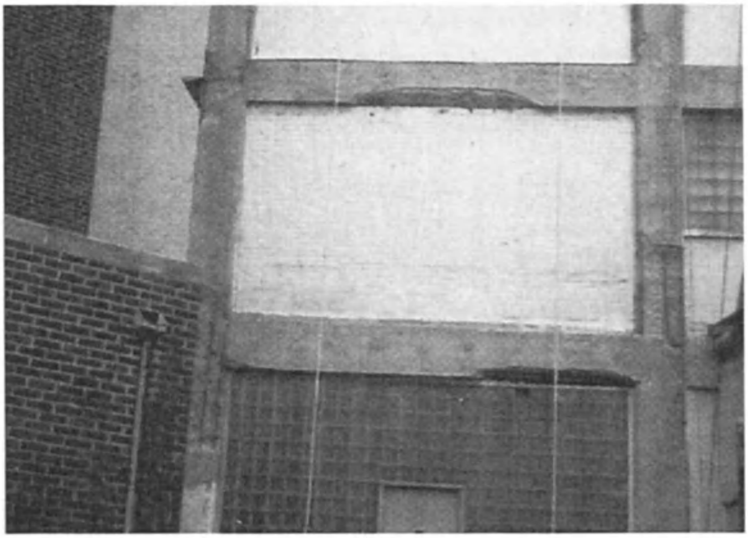


(b)

Figure 19-4(a): Premature deterioration of parking structure. *(b):* Freeze-thaw damage accelerated by poor drainage.



(c)



(d)

Figure 19-4: (c) Leaching at floor-slab cracks. *(d)* Concrete deterioration due to carbonation of concrete in exterior building frame.

There are several factors that can impact the onset of accelerated concrete deterioration and the rate of the concrete deterioration in parking structures. Adverse conditions that contribute to the deterioration mechanisms can be grouped under design deficiencies, substandard materials, construction deficiencies and lack of effective maintenance. A parking structure has to be properly planned, designed, built and maintained to realize a reasonable service life for the facility. Refer to ACI 362 "Guide for the Design of Durable Parking Structures" and Chapter 12 for criteria on design and construction parking structures. Maintenance is discussed in Chapter 18. Following is a list of adverse conditions that will contribute to performance problems and premature deterioration of parking structures:

- Selection of a less durable structural system
- Poor detailing in construction documents
- Inadequate corrosion protection
- Poor drainage
- Shallow concrete cover
- Poor concrete quality and other construction deficiencies
- Cracking and joint deterioration
- Ineffective maintenance

19.3.1 Corrosion-Induced Deterioration

Spalling and delamination of concrete due to corrosion of embedded reinforcement are common forms of distress in structures located in northern climates or in other areas subjected to salt environment. The use of road salt during winter months often results in chloride contamination of floor-slabs and acceleration of reinforcement corrosion in the presence of oxygen and moisture. See Figure 19-5. Many relatively older structures in mild climates are also susceptible to corrosion-induced deterioration to a lesser degree. The spalls in reinforced-concrete surfaces are usually dish-shaped cavities one inch to several inches deep with varying surface areas. Floor-slab spalling can be quite extensive, sometimes covering several hundred square feet. See Figure 19-6 (a). Corrosion-induced deterioration can also occur in structures having extremely porous concrete that is susceptible to carbonation. See Figure 19-7.

Before open spalls or "potholes" can occur on the floor surface, a horizontal fracture called a *delamination* will usually develop below the concrete surface. Fractures begin at the level of the corroding reinforcement or other embedded metal and migrate to the surface. These floor-slab delaminations can be detected by tapping the floor surface with a hammer or by a chain-drag survey. Freeze-thaw cycles, traffic action, and additional corrosion tend to further accelerate the rate of spall development.

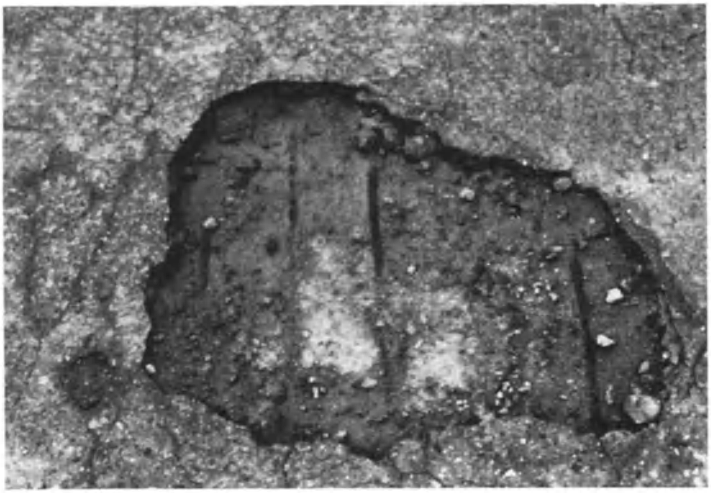


Figure 19-5: Concrete spall.

Figure 19-6: (a) Extensive concrete deterioration can adversely affect load carrying capacity of structural members.

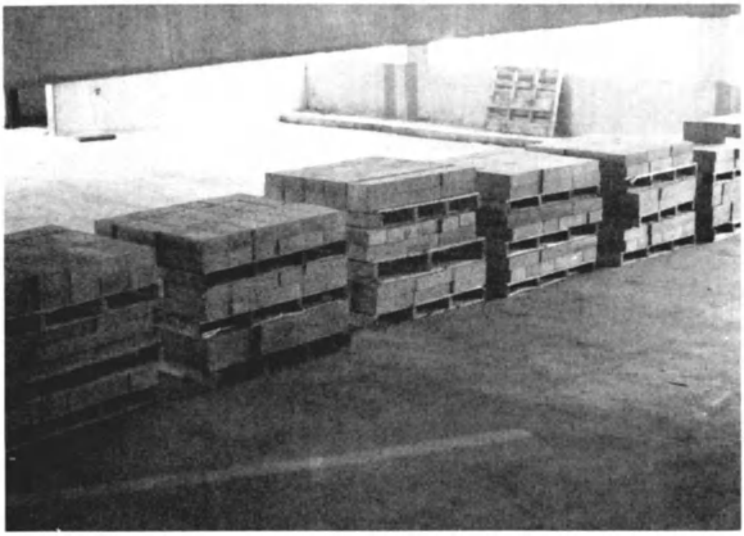


Figure 19-6 (b) Load testing of slab to determine impact of deterioration on structural members.

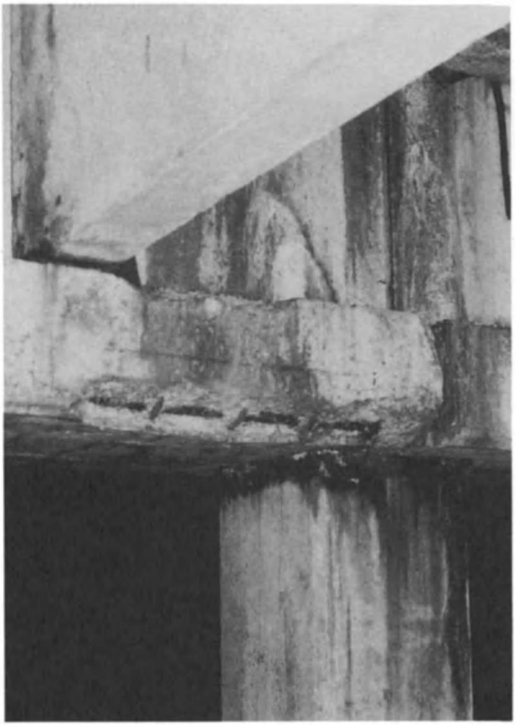


Figure 19-7: Corrosion of embedded reinforcement due to leaching and carbonation of poor quality concrete.

19.3.1.1 Chloride Contamination.

Concrete is not an impervious material. Excess water, not required for hydration, eventually dries, leaving behind an interconnected network of capillary pores. Concrete capillary pores have a relatively larger diameter, ranging from 15 - 1000 Å (Angstroms). See Figure 19-8. The unit of measurement for the capillary pore diameter is an Angstrom. One Angstrom is equal to 10 millionths of a millimeter. In comparison, the chloride ion diameter is less than 2 Å. Therefore, chloride ions can eventually penetrate into the concrete. Once the chloride ion reaches the level of the reinforcement, the concrete is contaminated enough for chloride induced concrete deterioration to begin. The contamination process is accelerated by salt accumulation on surfaces, shallow concrete cover, and wetting and drying.

The amount of chloride content in concrete that will contribute to corrosion of the embedded steel reinforcement is referred to as the *corrosion threshold.* The National Cooperative Research Program Report #57 defines the corrosion threshold as the minimum quantity of chloride required to initiate the corrosion of embedded steel in the presence of moisture and oxygen. See Figure 19-9. The chloride content is reported in various units:

- percentage chloride ion by weight of concrete
- ppm chloride ion by weight of concrete
- percentage chloride ion by weight of cement
- lb chloride ion per cubic yard

The chloride ion content is reported as acid-soluble or water-soluble based on the analytical test procedure utilized to obtain the results. The acid-soluble test method measures the chloride soluble in nitric acid and will report more chlorides than will the water-soluble test method. The test procedure recommended by the ACI Building Code (ACI 318) for determination of water-soluble chloride is ASTM C1218.

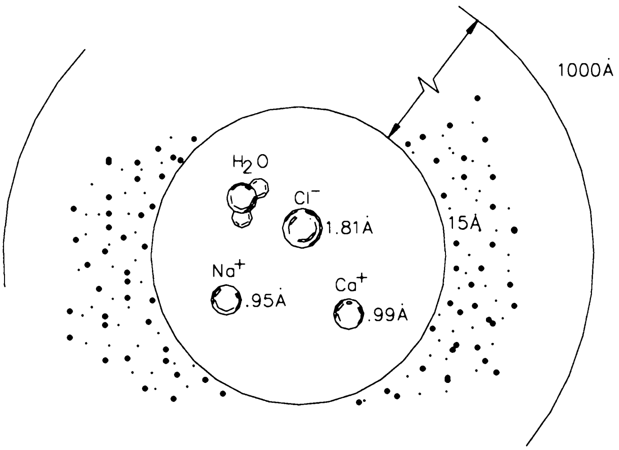
Chlorides in concrete occur in the water-soluble form or may be chemically combined with other ingredients. The water-soluble chlorides initiate corrosion, while combined chlorides are believed to have little effect on corrosion. When considering the probability of corrosion, it is more appropriate to consider only the water-soluble chloride ion content of the concrete since the acid-soluble chloride test results include chlorides that are chemically combined.

The ACI Building Code (ACI 318) reports chloride ion contents as percentage chloride ion by weight of cement. Research done by the Federal Highway Administration indicates that the corrosion threshold is 0.20% acid-soluble chloride ion by weight of cement. ACI 318 limits the maximum permissible water-soluble chloride ion content for mild steel reinforcement to 0.15% by weight of cement, which is 75% of acid-soluble chloride ion content.

For prestressed-concrete structures, the ACI 318 chloride ion content limit has been established at 0.06% by weight of cement. This is primarily to reflect the severe effects of corrosion and resulting loss of cross sectional area on highly stressed steel reinforcement.

ELEMENT	ATOMIC NO.	ATOMIC RADIUS	IONIC RADIUS
Cl^-	17	0.99Å	1.18Å
Ca^+	20	1.97Å	0.99Å
Na^+	11	1.86Å	0.95Å

Capillary pores in hardened concrete estimated to measure: 15A – 1.000A



Magnified one million times
Schematic representation only

Figure 19-8: Concrete porosity will eventually allow chloride ions to migrate to level of embedded reinforcement.

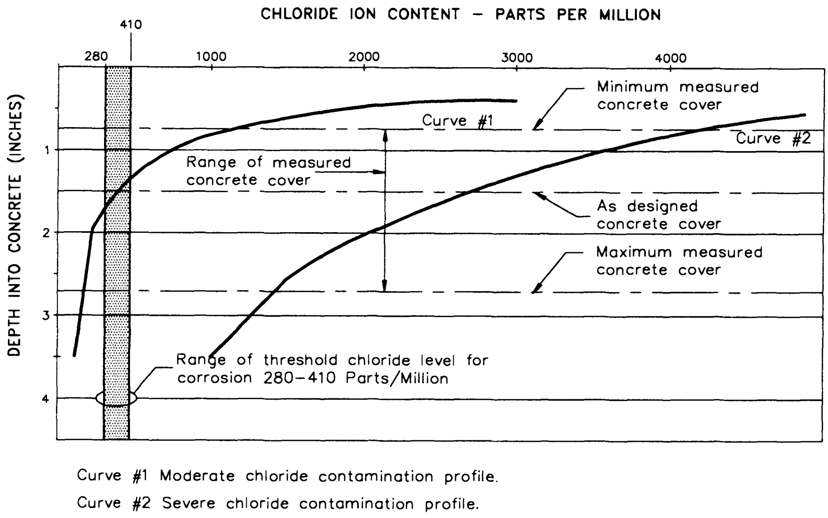


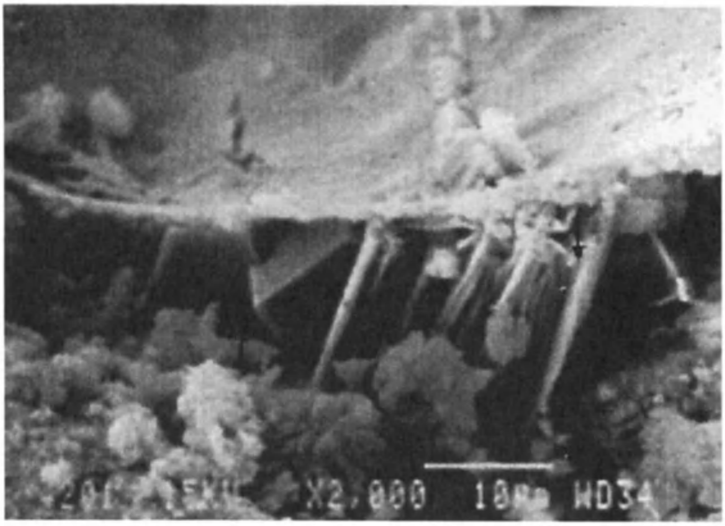
Figure 19-9: Chloride ion profile.

How long will it take to contaminate the concrete in a parking structure? The three most basic factors that control the "time-to-corrosion" are: concrete permeability, water-to-cement-ratio, and the concrete cover to the embedded steel reinforcement. As previously mentioned, other factors include design practices (deficiencies), "as built" conditions, effectiveness of the corrosion protection system, and maintenance. The use of special additives to reduce concrete permeability in construction of new parking facilities was not customary prior to the mid 1980s. Instead, finishing and curing practices were primarily relied upon to provide less permeable concrete. More recently, pozzolans, such as silica fume admixtures, have been used in repair materials and construction of new facilities to reduce concrete permeability. See Figure 19-10 (a) and (b).

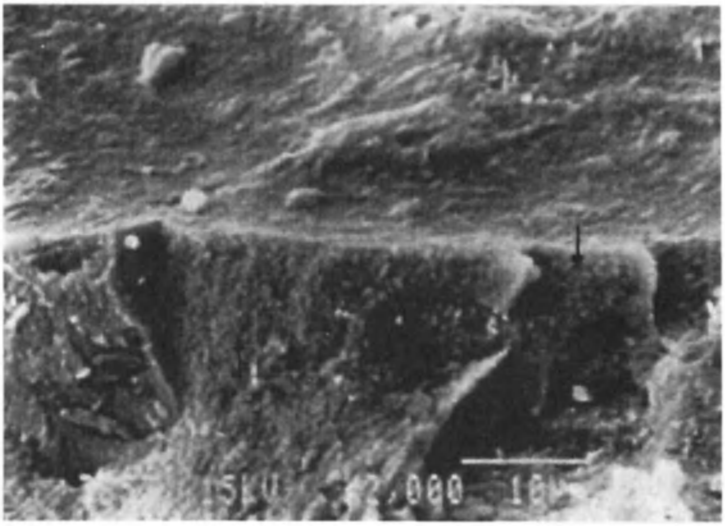
The water-to-cement ratio of the concrete currently specified for use in parking facilities by the ACI Building Code and that recommended in the ACI 362 report on design of parking facilities is 0.40 to 0.45. Structures designed prior to the 1977 ACI Building Code utilized a water-to-cement ratio of 0.53 or greater in accordance with the specified limits. Therefore, many older facilities are now susceptible to chloride-induced concrete deterioration. The minimum concrete cover specified by the ACI Building Code is 1-1/2 inch to 2 inches, based on reinforcement size.

The minimum concrete cover specified by the ACI 362 Committee parking structure design guide is 2 inches. The cover may be reduced to 1-1/2 inch for epoxy-coated reinforcement and concrete with a corrosion inhibitor. For most older facilities built in accordance with the Building Codes prior to 1977, the minimum specified concrete cover is 3/4 inch. Again, older facilities are very susceptible to chloride contamination due to the potential for shallow concrete cover over embedded reinforcement. See Figure 19-11.

The type and extent of cracking will affect the "time-to-corrosion" of the embedded reinforcement in structural members. The cracks and joints in concrete provide avenues for moisture and chloride ion penetration. See Figure 19-12 (a) through (e). Crack control measures such as reducing the bar size and/or limiting the reinforcement stress in negative moment regions will reduce flexural crack widths and the potential for corrosion of the embedded reinforcement. Many older structures were designed without these effective crack control measures. Surface cracks in slabs can be reduced by following proper finishing and curing procedures during construction. As-built conditions and the extent of surface cracking can vary considerably from structure to structure.



(a)



(b)

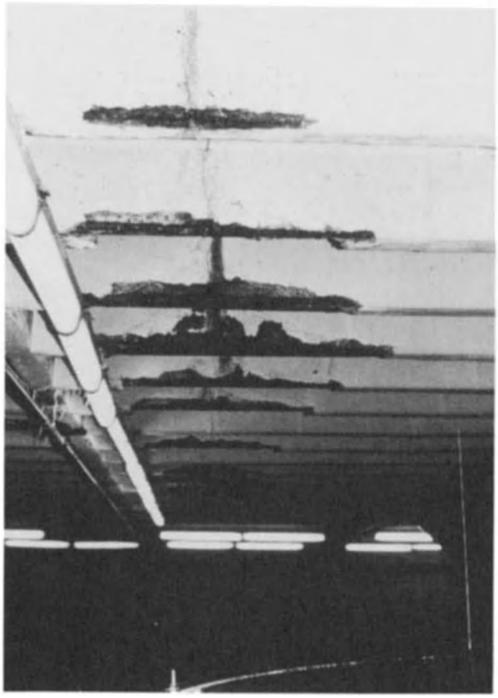
Figure 19-10: (a) Concrete is relatively porous as viewed under an electron microscope. *(b)* Concrete porosity reduced by silica fume additive.

Figure 19-11: Shallow concrete cover will reduce "time-to-corrosion" of embedded reinforcement.

(a)

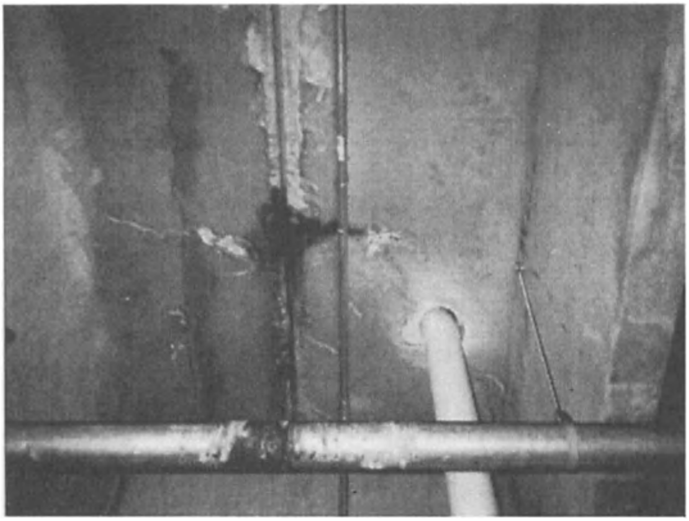
Figure 19-12: (a) Underside of slab deterioration due to water leakage through slab crack.

(b)



(c)

Figure 19-12: (b) Metal deck corrosion due to slab cracking. *(c)* Water leakage at construction joint.



(d)

(e)

Figure 19-12(d): Hollow core slab joint leakage. *(e):* Damage to double tee flange and underlying connectors due to water leakage.

The floor-slab and other horizontal members of a parking facility are most susceptible to chloride contamination. Road salt tracked into the facility or directly applied on the surface during the winter accumulates on the surface and accelerates the penetration of the chloride ions into the concrete. Ponding only makes the situation worse and tends to further accelerate concrete contamination. See Figure 19-13.

Vertical members of the parking facility such as columns and walls are also susceptible to chloride contamination, but to a lesser degree than the floor-slabs. The contamination of vertical members tends to be more localized and limited to the areas where saltwater can leak through the floor-slab system. Therefore, leaking cracks and joints in the floor-slab system can cause conditions that will lead to chloride contamination of the concrete in the underlying structural members. The bases of columns and bumper walls also become contaminated by salt spray from moving vehicles. See Figure 19-14 (a) through (d).

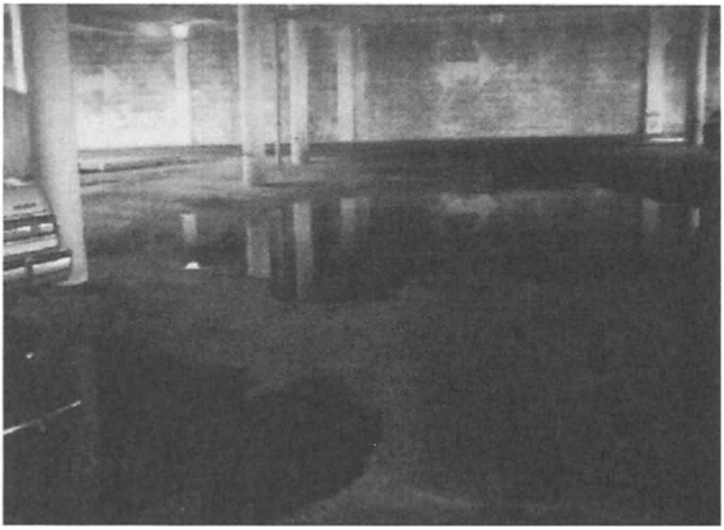
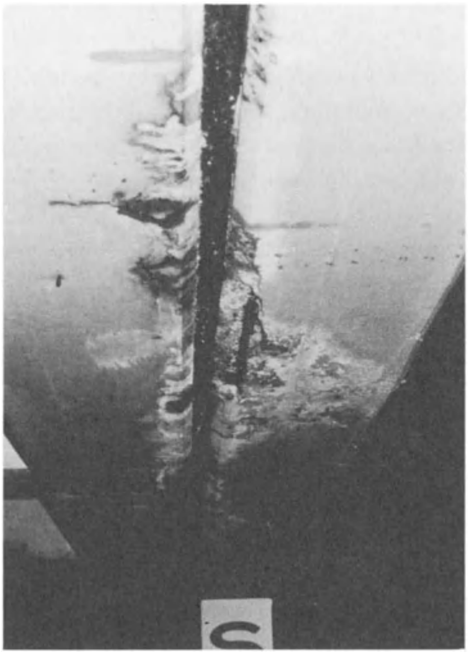
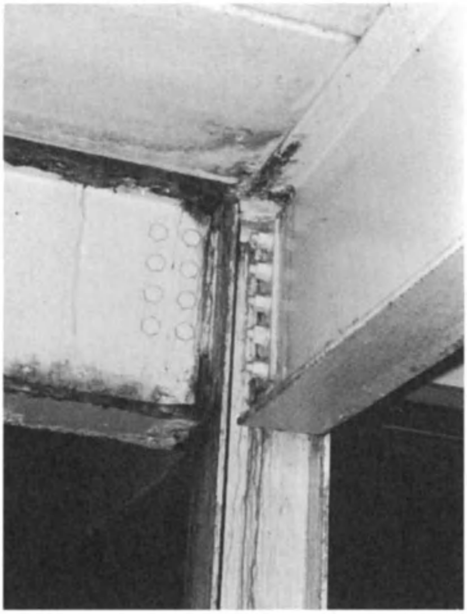


Figure 19-13: Ponding will accelerate chloride contamination and contribute to corrosion of embedded reinforcements.

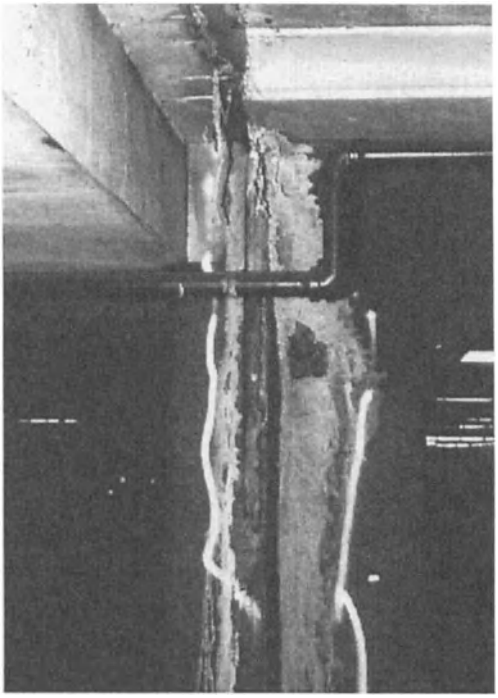


(a)



(b)

Figure 19-14: (a) Concrete deterioration due to water leakage at expansion-joint. *(b)* Corrosion of underlying structural steel beam and column.



(c)

(d)

Figure 19-14: (c) Damage to concrete columns at expansion-joint.
(d: Deterioration at the base of concrete column.

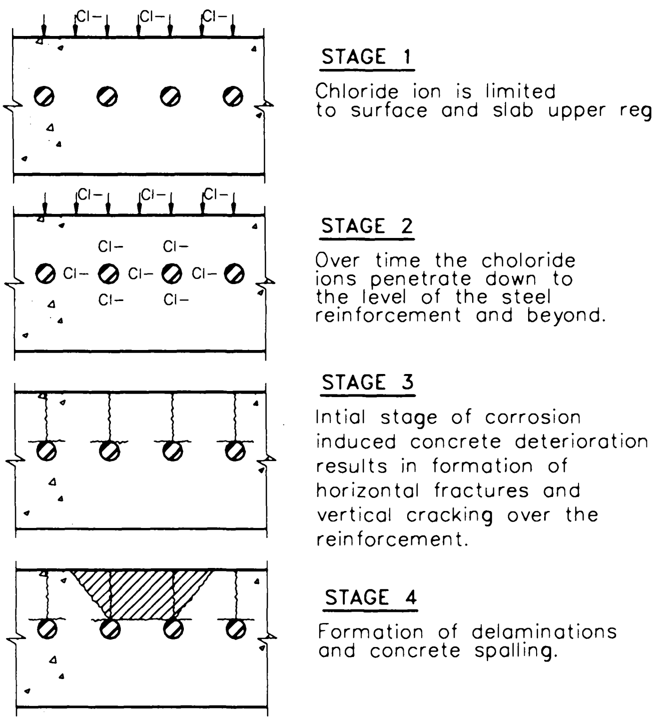


Figure 19-15: Stages of concrete contamination.

The answer to the question at the top of page 21 regarding the rate of chloride contamination is that it can vary considerably. The complete life cycle of a parking structure can be represented by the four stages of chloride contamination shown in Figure 19-15. Often, the adverse affects of chloride contamination are not apparent until the final stage of the deterioration process (Stage 4). By then it is too late to implement preventive measures, and costly repairs are needed to extend the service life of the structure. Also, Stages 1 and 2 of the process cannot be determined by a mere visual review. Chloride monitoring at periodic intervals is necessary to determine the progressive contamination of the structure. This monitoring assists in implementing appropriate and timely preventive maintenance measures. Maintenance performed when the structure is in Stage 1 or 2 provides the best return on the investment of the repair efforts and funds. Refer to Figure 19-2.

19.3.1.2 Corrosion Mechanism.

Corrosion of metal in concrete is an electrochemical process that contributes to progressive concrete deterioration. The impact of chloride contamination and corrosion can be explained by understanding the protective,

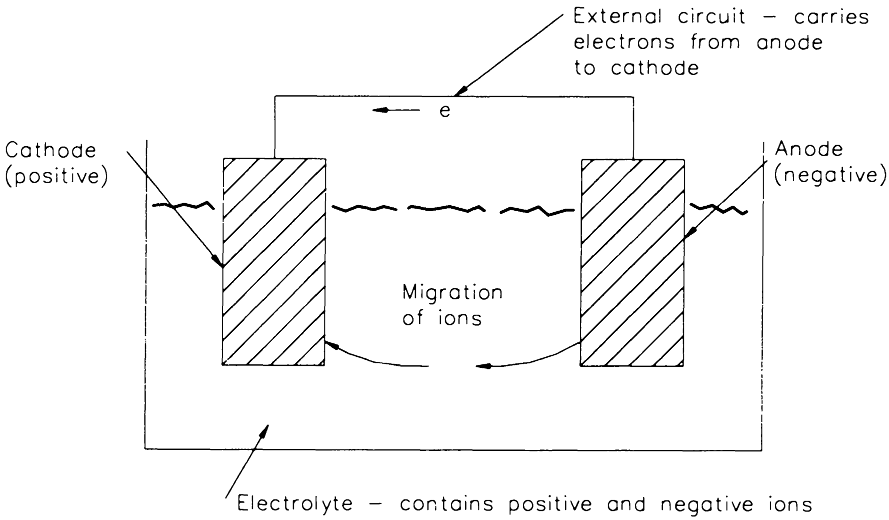


Figure 19-16: Schematic diagram of basic corrosion cell.

as well as the corrosive, mechanism of reinforcement in concrete. The ability of metal to form a protective film greatly reduces the rate at which it corrodes. This protective film is generally an oxide and plays an important role in the corrosion resistance of metals, such as aluminum, chromium, stainless steel, lead, and other relatively noble metals. The oxide film on the steel reinforcement embedded in the concrete is relatively stable in a caustic (alkaline) environment with a high pH level.

Concrete is a product of the cement hydration process. When water is added to cement it reacts to form a gel that is the binder in the concrete matrix. Another primary reaction-product of the cement hydration process is calcium hydroxide [$Ca(OH)_2$]. The presence of calcium hydroxide in the concrete results in an environment within the concrete that is at a high pH of 12 to 13. This highly alkaline environment provides a passive environment that naturally protects the steel embedded in the concrete. However, if the pH of the concrete falls below 11.5, the protective oxide film on the surface of the steel becomes unstable, which can then lead to corrosion of the embedded reinforcement.

The electrochemical reactions of the corrosion process involve the transfer of electrons and migration of ions. The essential elements of a basic corrosion cell are illustrated in Figure 19-16.

The anode is the point where corrosion occurs by migration of ions into the electrolyte. The cathode is the point where electrons are consumed and no corrosion occurs. The electrolyte is usually an aqueous solution containing ions capable of conducting current. The return circuit is a metallic path through which electrons move from the anode to the cathode, which usually consists of the metallic reinforcement itself.

The voltage difference between the anode and the cathode needed to drive the corrosion current can exist due to the presence of dissimilar metals in the concrete that are electrically connected. It can also exist in a continuous metallic element, such as an embedded reinforcement, due to the difference of the environment between two areas on the same element. The difference of the environment along concrete reinforcement can be attributed to variations in chloride ion concentrations, variations in surface condition, extent of consolidation, availability of oxygen, pH of concrete, or moisture. See Figure 19-17. This corrosion cell is also referred to as the "micro-cell".

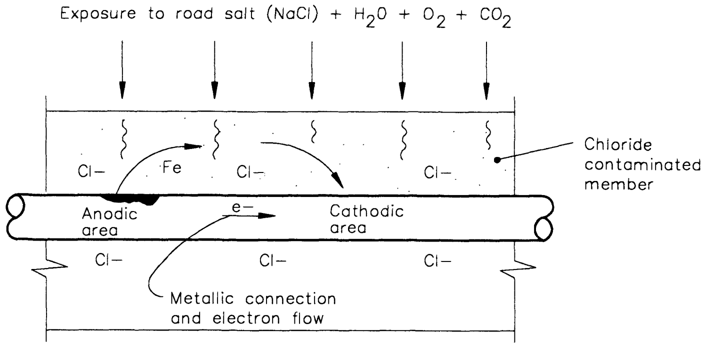


Figure 19-17: Development of corrosion cell along embedded reinforcement (micro-cell).

In a chloride-contaminated slab, the potential difference that will sustain the corrosion process can be attributed to the difference in chloride ion concentrations along the reinforcement, as well as the amount of chloride ions reaching the top and lower reinforcement mats of the slab. The upper layer of reinforcement in the more chloride-contaminated concrete will be anodic to the bottom layer and results in development of a strong corrosion cell referred to as a "macro-cell." This macro-cell will result in the corrosion of the upper layer of reinforcement when the mats are electrically connected. See Figure 19-18. Generally, a macro-cell corrosion will contribute to a more rapid deterioration of the structure than a micro-cell corrosion. A single reinforcement electrically isolated, but embedded in chloride-contaminated concrete, is likely to corrode at a relatively slower rate than a top reinforcement also connected to the lower mat of reinforcement in uncontaminated concrete. Reinforced concrete structures tend to deteriorate due to micro- as well as macro-cell corrosion.

Another example of accelerated corrosion is a reinforcing bar exposed to both concrete and water, as at a spalled area of the floor-slab. The part of the

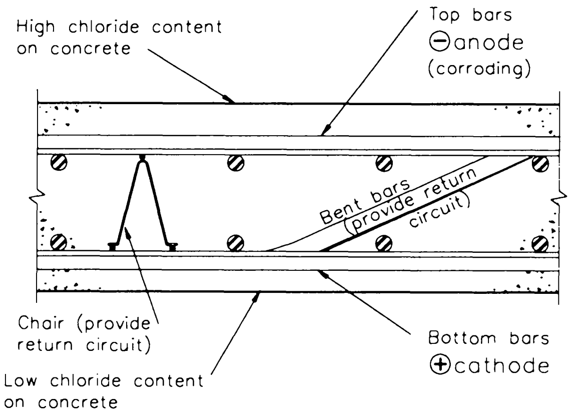


Figure 19-18: Development of corrosion cell between top and bottom layers of slab reinforcement (macro-cell).

bar in the water is likely to corrode due to the different electrolytes to which it is exposed. The reinforcement in the water will be anodic to the reinforcement in the concrete. The rate at which corrosion occurs is also affected by the relative areas of the anode and the cathode. If the anodic area is small, relative to the area of the cathode, the anode (the upper mat of reinforcement in a slab) will tend to corrode rapidly. This is because the corrosion current is concentrated in a smaller area.

Corrosion byproducts (rust) occupy a volume at least 2.5 times that of the parent metal. This expansion causes high tensile stresses which crack (delaminate) the surrounding concrete. Concrete cracking can occur when section loss of the corroding metal is 5% or less. Cracks first appear vertically over, and parallel to, the corroding reinforcement. These cracks permit more moisture, oxygen, and chloride ions to the level of the reinforcement, causing accelerated corrosion and concrete delamination. Refer to Figure 19-15.

The corrosion-induced cracks running along the length of the reinforcement are potentially more damaging than transverse cracks running perpendicular to the reinforcement. If the concrete has low permeability and/or high resistivity, relatively fine hairline transverse cracks (0.007 in. wide) are unlikely to contribute to accelerated corrosion of embedded reinforcement. However, wide transverse and through-slab cracks can contribute to localized corrosion of embedded reinforcement at the crack.

19.3.1.3 Corrosion-Induced Distress.

Exposure to road salt or chloride contamination leads to corrosion-induced distress in concrete structural elements. As previously mentioned, the floor-slab system (the horizontal riding surface) is much more susceptible to chloride contamination than the vertical framing members, such as beams and columns. Therefore, concrete deterioration generally starts in structural members of the floor system. Deterioration of vertical members is usually limited to isolated areas adjacent to joints and cracks in the floor-slab system that leak.

Many different types of floor-slab systems have been used in the construction of parking structures. Some of the more commonly encountered systems are:

- Cast-in-place conventionally reinforced concrete
- Cast-in-place post-tensioned concrete
- Precast prestressed concrete
- Precast hollow core units with concrete topping
- Composite structures (structural steel and concrete)

Each of the structural systems tends to exhibit a pattern of deterioration that can be associated with the ability of the structural system to effectively resist corrosion-induced deterioration. For instance, conventionally reinforced structures are relatively more flexible and have a greater tendency to crack. Also, there is significant concentration of reinforcement over a large portion of the slab surface area. This concentration of reinforcement generally contributes to more extensive floor-slab deterioration. Cracking and water leakage contributes to deterioration of underside of slab and underlying structural members. See Figure 19-19(a) through (c).

Figure 19-19(a): Concrete deterioration due to water leakage through slab crack.

(b)

(c)

Figure 19-19 (b): Extensive floor-slab deterioration in heavily reinforced column-column strip region of a flat slab floor system.
(c): Floor-slab cracking in a composite floor-slab system.

The impact of concrete deterioration due to corrosion of embedded reinforcement is as follows:

- Serviceability and operational problems. Shallow concrete floor spalls can be a trip hazard for the facility users. Periodic maintenance is required to protect users from overhead spalls on underside of the floor-slab system. Localized failures, such as slab punch-through, are possible.
- Loss of reinforcement cross sectional area can adversely affect the load carrying capacity of slabs, beams, columns and other structural members.
- Reinforcement debonds from the concrete in delaminated areas, which can also result in reduced load carrying capacity due to loss of anchorage. This loss can also lead to redistribution of the stresses within the structure.
- Loss of concrete cross section can be critical and adversely affect load carrying capacity.

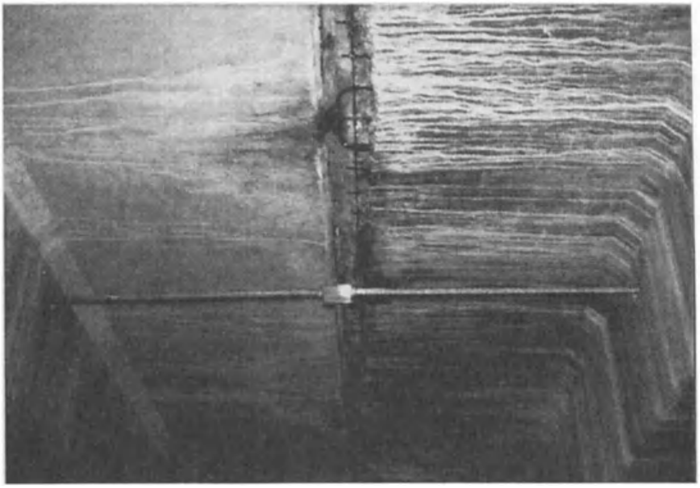
Post-tensioned structures tend to limit the extent of flexural and through-slab cracking and generally perform better than conventionally reinforced structures in an aggressive environment. However, there are some vulnerable locations of the post-tensioning system that need to be well protected to assure long-term performance of prestressed concrete structures. Post-tensioned concrete structures are not immune to corrosion induced deterioration. The impact of unbonded slab tendon failure is more extensive and affects several bays between anchorages. Corrosion of post-tensioned systems and the impact on the structure is further discussed in this chapter.

Precast prestressed structures are susceptible to joint leakage and subsequent corrosion damage of the embedded welded wire fabric in the upper portion of the floor system and the underlying structural steel connections. Water leakage can also contribute to corrosion of the embedded reinforcement in the floor-slab members, beams and columns. See Figure 19-20 (a) and (b).

Double tee precast members are most commonly used in the floor-slab system for parking structures. The precast double tees are pretopped or field topped. Corrosion of the welded wire fabric and embedded steel connectors in the concrete topping or in the flanges of pretopped tees can potentially contribute to widespread flange deterioration.

Most parking facilities built prior to 1977 generally did not have an effective corrosion-protection system, such as surface sealer, epoxy-coated reinforcement, or corrosion inhibitor, with the exception that some structure floor slabs were sealed with boiled linseed oil. Concrete surface treatment with boiled linseed oil is now considered relatively ineffective in screening chloride ions.

(a)



(b)

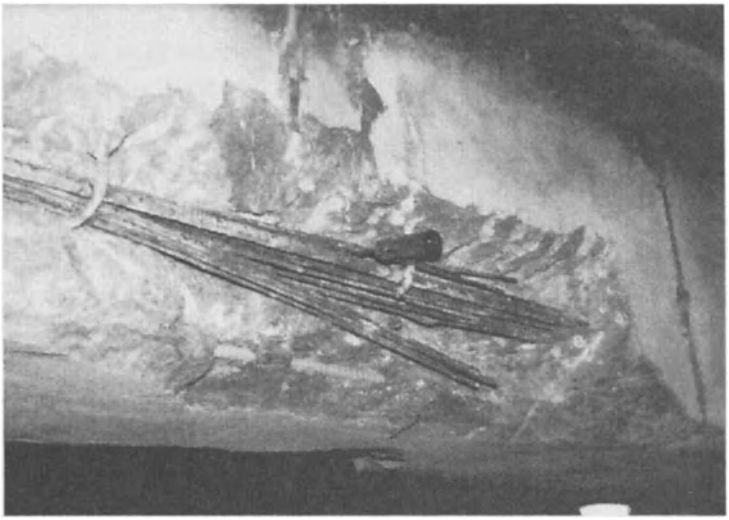
Figure 19-20: (a) Double tee joint deterioration due to corrosion of embedded steel flange connector. *(b)* Deterioration on underside of double tee flange.

A more detailed discussion of corrosion is provided in the American Concrete Institute's (ACI) committee reports, entitled "Guide to Durable Concrete", ACI 201.2R, and "Corrosion of Metals in Concrete", ACI 222R and other referenced publications. The subject matter discussed in this section is also intended to provide an overview of the corrosion process and familiarize the reader with the impact of this distress mechanism on structural members.

19.3.1.4 Corrosion of Prestressing Tendons.

Many older prestressed structures are now starting to show evidence of corrosion related distress. The corrosion of prestressing tendons appears to be more evident in cast-in-place post-tensioned structures. See Figure 19-21 (a) through (c).

(a)



(b)

Figure 19-21: (a) Corrosion of intermediate anchor and unbonded button-head wire tendon. *(b)* Corrosion of bonded button-head beam tendon.

Figure 19-21(c) *Corrosion of unbonded strand at end anchorage.*

In the author's opinion, precast parking structures are just as vulnerable to corrosion-induced deterioration as post-tensioned parking structures. Some of the adverse conditions that can contribute to the accelerated deterioration of parking facilities are listed in Section 19.3. In addition, specific conditions that can affect prestressed structures are:

- The type of corrosion protection system of the tendon in the structure.
- Water leakage through random cracks, construction joints, control joints and expansion-joints.
- Water leakage into the tendons through end anchorages.
- Shallow concrete cover to tendons at high-points of the tendon profile.
- Corrosion of mild steel reinforcement and open spalls that can expose the tendon directly to traffic abrasion and wear.
- Chloride contamination of the slab to the level of the tendon.
- Damage to protective sheathing during construction.

A discussion of corrosion-induced damage of unbonded single strand tendons is provided in the ACI/ASCE Committee 423 Report entitled "Corrosion and Repair of Unbonded Single Strand Tendons," (ACI 423.4R). The report includes the evolution of the types and components of the unbonded tendons, performance characteristics and methods to repair, replace or supplement tendons. This report will supplement and add to the information included on prestressing tendons in this chapter.

19.3.1.4.1 Corrosion Mechanism.

Prestressing tendons are made of high strength steel, and the corrosion mechanism of prestressing steel is similar to that presented for mild steel reinforcement. Chloride ions will cause accelerated corrosion of prestressing steel. In addition, the tendons are susceptible to "stress-corrosion cracking", which results in micro-cracking and loss of ductility. The stress-corrosion cracking is accelerated in presence of certain other ions such as nitrate and bisulfide ions. Do not confuse nitrate with nitrites such as calcium nitrite, a corrosion inhibitor often used for corrosion protection of embedded reinforcement. Stress corrosion related failures are uncommon. Failure related to "hydrogen embrittlement" is also very uncommon. Hydrogen embrittlement failure is caused by the tendon coming in contact with hydrogen ions. Hydrogen ions are formed by applying external electrical currents to the structure. In some instances the application of external currents to the structure is intentional, such as in the cathodic protection of mild steel reinforcement. The most common cause of tendon failure is accelerated corrosion in the presence of chloride ions, which is sometimes referred to as "pitting corrosion." The prestressing steel will corrode when it is exposed to the atmosphere. Therefore, the tendon always needs to be permanently protected by a special coating and/or wrapping, particularly during shipping, handling and storage.

19.3.1.4.2 Corrosion Protection.

Cross-sectional loss of prestressing tendons due to corrosion will have a significant impact on the load-carrying capacity and integrity of the structure. Prestressing wires or strands require protection from corrosion prior to, during, and after construction of the structure. The best protection for the strand is concrete with a high pH. In precast concrete members the tendons are encased, and the concrete provides the corrosion protection of the tendon.

Since the 1950s, several different types of encasements for unbonded tendons have been developed for cast-in-place post-tensioned construction. The encasement prevents the tendon from bonding to the surrounding concrete. In addition, the encasement also provides corrosion protection for the tendon under service conditions. See Chapter 12 for further discussion and description of bonded and unbonded post-tensioning systems. In an aggressive environment, the corrosion protection provided by the encasement is an important factor that will influence the service life of the structure. Refer to Figure 19-22 for a summary of the evolution of strand corrosion protection systems.

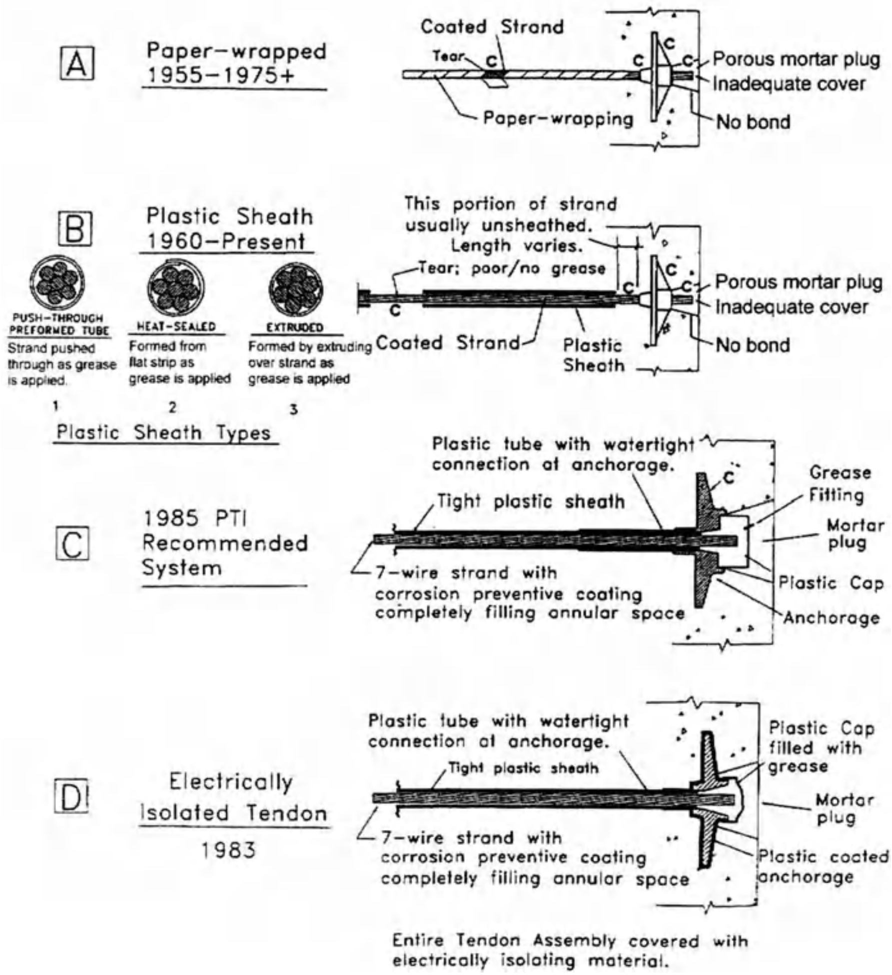


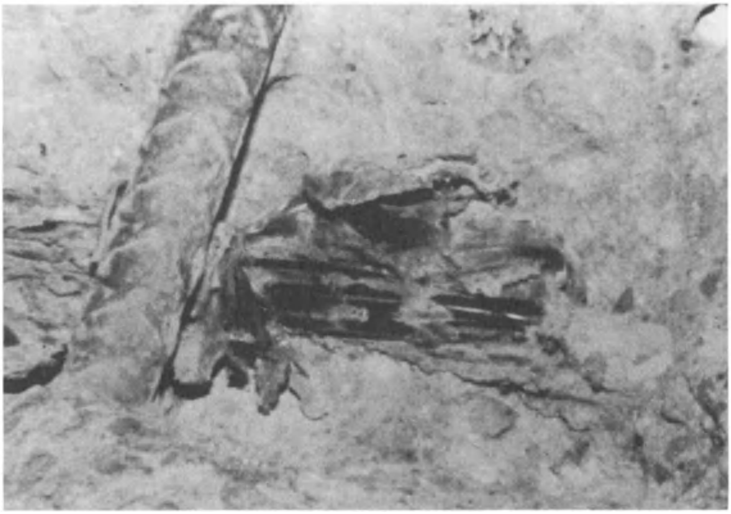
Figure 19-22: Evolution of unbonded tendon corrosion protection systems. From: Paper entitled "Unbonded Tendons-Evolution and Performance," by Morris Schupack, Concrete International Journal, American Concrete Institute, December 1994.

The tendon corrosion protection systems that have been used in the construction of parking structures are as follows:

1. **Greased and Paper-Wrapped Tendons**. The grease and paper-wrapped tendons were used in parking structures built in the late 1960s and the early 1970s. Both strands as well as button-head wire elements were paper-wrapped. At times, a mastic was substituted for the grease. See Figure 19-23 (a) and (b). The paper wrapping provided very minimal protection against moisture and chloride ion intrusion. The paper is easily damaged

during concrete placements. Intermediate anchorage hardware is usually left unprotected. The tendon end sections close to anchorages are also left unprotected. Structures built with prestressing tendons protected by this system are exceeding 20 years old and have the greatest potential for problems.

(a)



(b)

Figure 19-23: (a) Greased and paper-wrapped strand. (b) Grease and paper-wrapped wire tendon.

2. **Plastic Sheathing with Grease.** Plastic sheathing with grease was primarily used in structures built since the early 1970s. There are two sheathing types: the heat-sealed and the extruded type. The heat push-through and sealed plastic sheathings were developed first and the extruded type was introduced later. The push-through heat sealed plastic sheathings are a loose-fit, and the extruded type is a tight-fit. The push-through and the heat sealed sheathing leave a much larger void around the tendon and provide an avenue for moisture to enter into sheathing. See Figure 19-24. It is much more difficult for the moisture to get into the tightly wrapped extruded sheathing. Structures built with this tendon protection system are vulnerable to corrosion in sections that are left unprotected by sheathing. The tendon section close to anchorages is usually left unprotected. Also, the end and intermediate anchorage hardware are left unprotected. See Figure 19-25.
3. **Encapsulated Tendons.** Based on the recommendations of the 1985 Post Tensioning Institute (PTI) guide specifications, totally encapsulated systems were developed for corrosion protection of the prestressing tendons. In this system the tendons, as well as the anchorages, are completely sealed for water tightness.

Figure 19-24: Strand with grease and push-through sheathing.

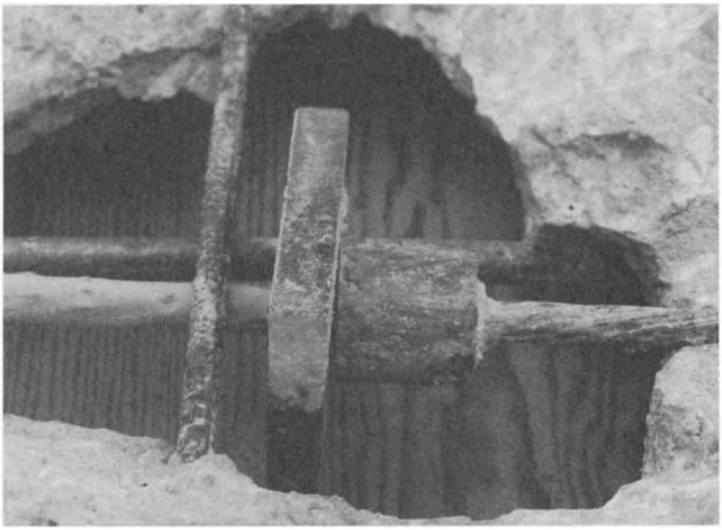


Figure 19-25: Unprotected strand and intermediate anchor at construction joint.

Sheet Metal Duct with Grout. The sheet metal duct with grout is used for bonded tendons. See Figure 19-26. The grout provides corrosion protection of the tendons.

Figure 19-26: Grouted beam tendon encased by sheet metal duct.

Most parking facilities tend to have unbonded tendons for post-tensioning of slabs and beams. The use of bonded tendons in older facilities is primarily limited to post-tensioning of beams and girders. Occasionally one might come across a parking structure with a bonded post-tensioning system in the slab. The grouted tendons are susceptible to moisture infiltration into the system if voids are left in the duct during tendon grouting. Also, the metal duct sheathing is just as susceptible to corrosion in chloride contaminated concrete as any other metal. Modern bonded systems use plastic ducts.

Corrosion of post-tensioning tendons results in formation of cracks directly over the tendon, delamination, and/or spalls. Spalling can occur on the slab surface or underside. See Figure 19-27 (a) and (b).

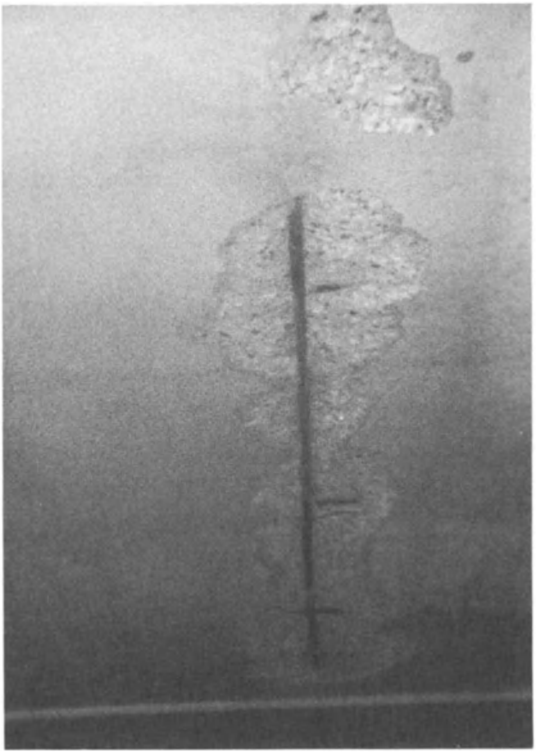
Release of the post-tensioning force due to tendon failure sometimes causes the tendon to break through the surface of the slab, as shown in Figure 19-28.

The probability of this type of tendon break-through increases if there are areas of shallow concrete cover over the tendon. The tendon break-through can occur on the top or the bottom surface of the slab. There is generally no correlation between the tendon failure location and the location where the tendons break through the surface. This type of tendon break-through generally occurs with strand post-tensioning systems. Other areas where one can look for evidence of tendon breakages are slab and beam tendon end anchorages.

Corrosion of the prestressing tendon can occur at many points along the tendon profile. See Figure 19-29.

The most vulnerable points of the post-tensioning system are at construction joints and random cracks. Water leakage through random slab cracks and construction joints can easily corrode and damage tendons. The intermediate tendon anchorages are susceptible to corrosion damage. Structures without an encapsulated tendon protection system are extremely vulnerable to tendon corrosion at leaking construction joints. A large majority of tendon corrosion problems currently encountered in older parking facilities can be attributed primarily to tendon corrosion at construction joints. Some couplers tend to be very large, which can sometimes result in reduced concrete cover over the anchorage, resulting in surface deterioration that can eventually cause tendon corrosion. See Figure 19-30 (a) through (c).

(a)



(b)

Figure 19-27: (a) Tendon corrosion and spall on slab surface. *(b)* Spalling and cracking on underside of slab due to tendon corrosion.

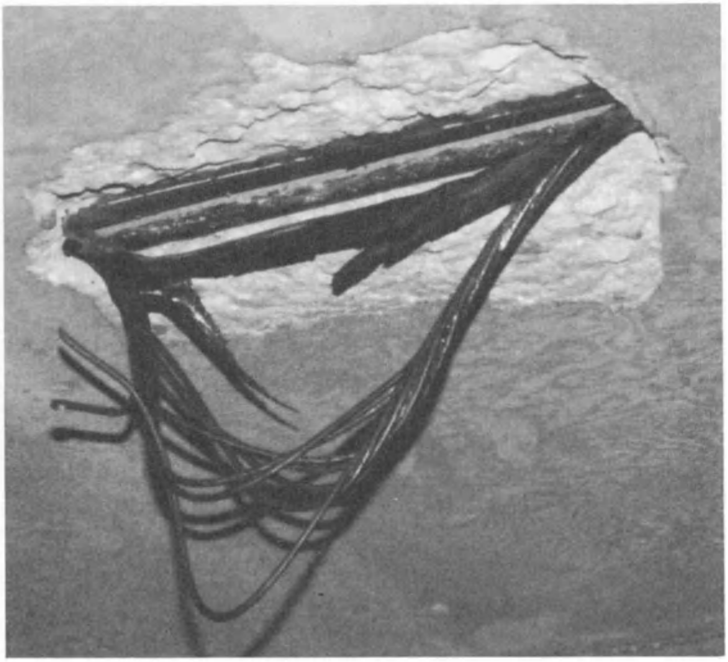
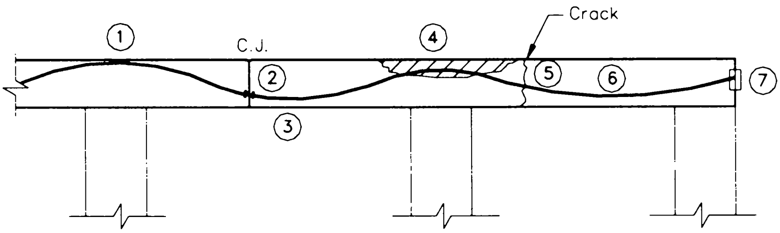
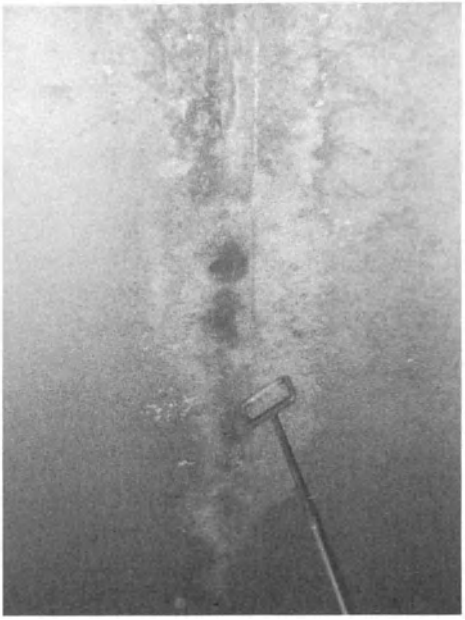


Figure 19-28: Tendon breakthrough on slab underside in area with shallow concrete cover (<3/4").

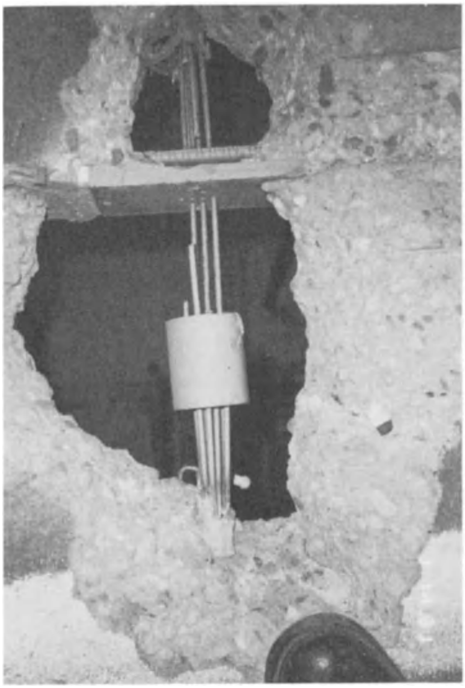


1. Shallow cover over tendon at tendon profile high point.
2. Tendon corrosion due to water leakage at construction joints.
3. Moisture can collect at low points of the tendon profile due to damaged sheathing at high point.
4. Tendon exposed at concrete spalls caused by corrosion of embedded mild steel reinforcement.
5. Tendon corrosion at random through-slab cracks.
6. Moisture can enter the tendon from end achorage and collect at low point of the tendon profile.
7. End anchorage corrosion.

Figure 19-29: Tendon corrosion locations.



(a)



(b)

Figure 19-30: (a) Leaking, leaching, and rust staining due to corrosion at construction joint. *(b)* Failure of button-head tendon at construction joint.

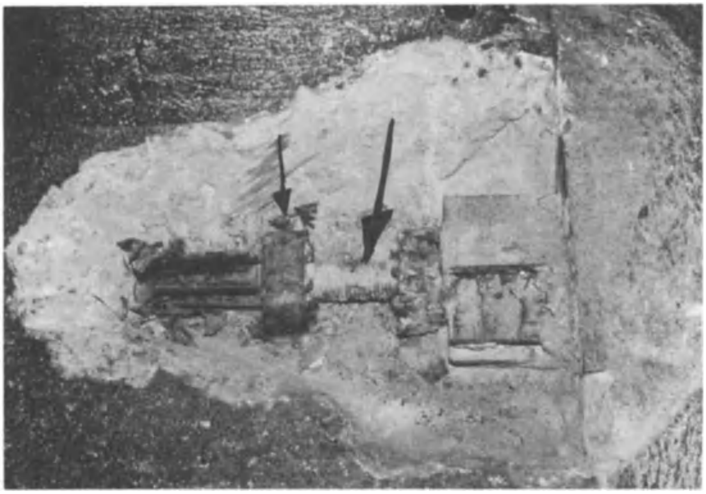


Figure 19-30 (c): Corrosion of intermediate anchor and tendon at construction joint.

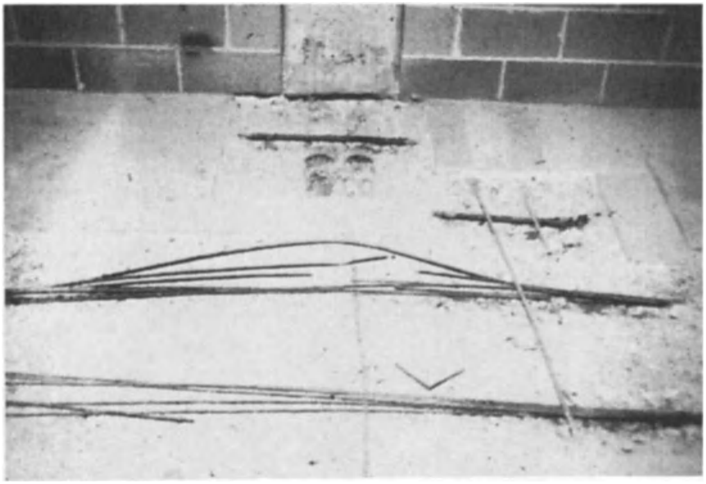
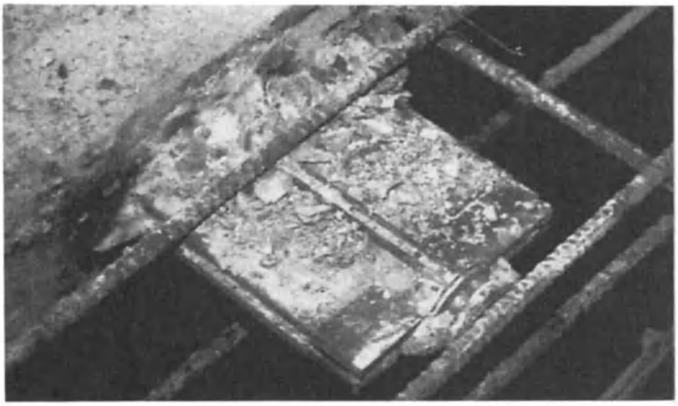


Figure 19-31: Damaged tendons at high point over beam.

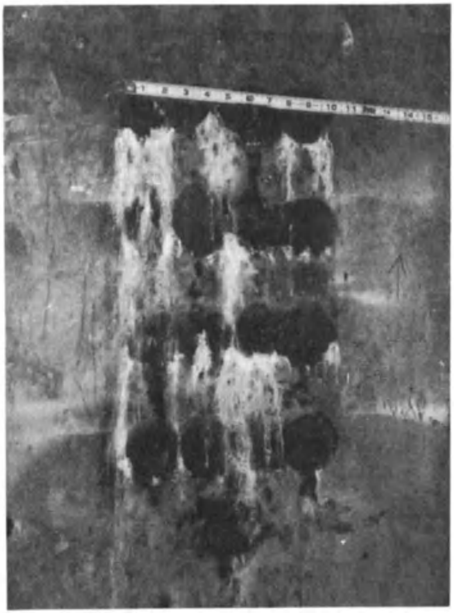
If the sheathing is damaged, moisture can enter the sheathing and migrate to any location along the tendon profile and cause tendon damage in other areas. This situation can also occur due to sheathing damage over high points of the tendon profile. Sometimes tendons over beams are exposed and subjected to traffic abrasion and wear. See Figure 19-31.

Damaged tendon sheathing provides an avenue for moisture to run down and collect at the tendon low points located at mid-spans. Tendons with plastic sheathing provide better protection than paper-wrapped tendons. Grease stains on ceilings sometimes indicate moisture intrusion into the tendon sheathing.

The end anchorages need to be protected from corrosion. Poorly grouted tendon pockets or poor quality grout can trap moisture that will tend to accelerate the corrosion of the tendon and/or anchorage hardware. The grout should be capable of preventing water entering into the tendon through the end anchorage. Moisture will enter and collect at the tendon profile low points. End anchorages at expansion joints and unsealed pour strips are particularly susceptible to water leakage. Leaching and/or rust staining at slab or beam grout pockets is an indication of potential problems. See Figure 19-32 (a) and (b).

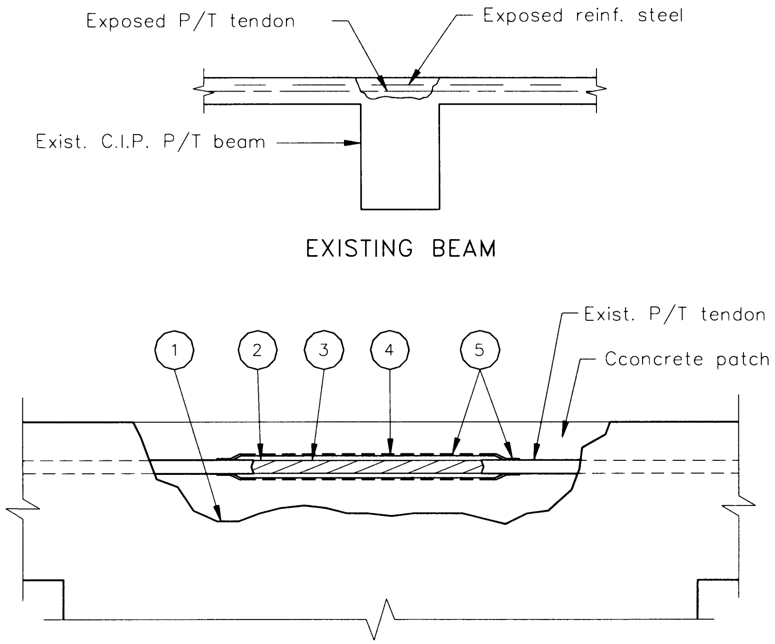


(a)



(b)

Figure 19-32: (a) End anchor for button-head tendon at pour strip. *(b)* Grease stain and leaching at end anchorage grout plug.



Notes:

1. Remove concrete back to light grey steel
2. Remove paper wrap & sandblast rusted cable to light grey steel
3. Grease tendon
4. Cover P/T tendon with plastic sheathing
5. Cover P/T tendon with waterproof tape & seal ends to paper wrap

Figure 19-33: Tendon must be protected prior to patching floor spalls.

Tendon failure can sometimes be accelerated by routine patching of open spalls to maintain serviceability. These temporary patches are generally acceptable for normal mild steel reinforcement, but can be very damaging for prestressing tendons. Open spalls should not be patched without restoring the continuity of the tendon sheathing to isolate the tendon from accelerated electrochemical corrosion (see Section 20.4.2). A detail to protect the tendon and to reduce the potential for accelerated corrosion of the tendon in floor-slab patches with prestressing tendons is shown in Figures 19-33 and 19-34.

Figure 19-34: Protection of tendon to reduce potential for accelerated corrosion.

19.3.2 Freeze-Thaw-Induced Deterioration

Concrete floor surfaces of parking facilities are susceptible to freeze-thaw deterioration, especially if the concrete is not adequately air-entrained and critically saturated due to ponding or poor drainage. The most common form of surface deterioration is scaling. Scaling is characterized by the progressive deterioration of the concrete surface through paste (sand/cement) failure. It results from the disruptive forces generated in the paste when the concrete is saturated and freezes. Scaling is common in those regions subject to freeze-thaw cycling.

Scaling begins with a slight surface flaking or internal horizontal delamination close to the surface, which becomes deeper with continuing exposure. Initially, only the surface texture and a small amount of paste are eroded. Surface flaking and scaling creates depressions that can retain water and contribute to progressively deeper and more extensive deterioration. Eventually, however, coarse aggregate is exposed, and larger surface areas are affected. See Figure 19-35.

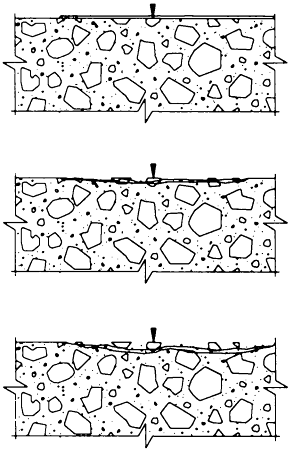


Figure 19-35: Concrete surface scaling mechanism. Source "Parking Garage Maintenance Manual," Parking Consultants Council, National Parking Association.

Scaling can significantly impair the serviceability of concrete intended as driving or walking surfaces. Flat portions of floor-slabs, gutter lines, areas near drains, and ponded areas are more susceptible to scaling due to greater potential for saturation of the surface and the presence of de-icing chemicals See Figure 19-36 (a) through (d).

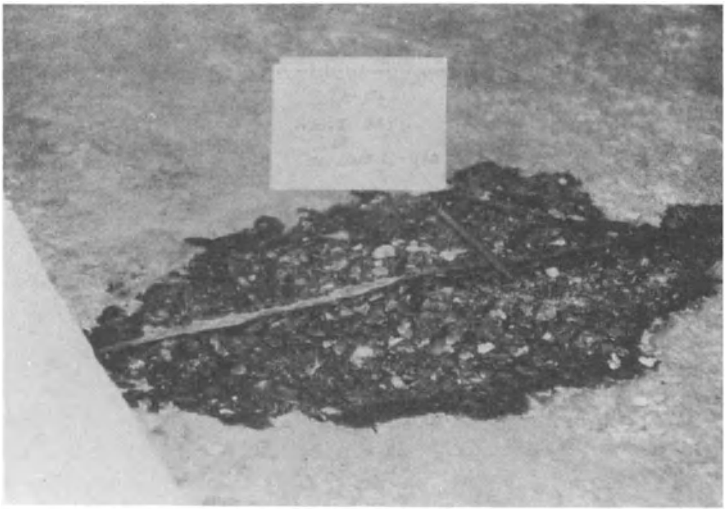
Also, exposed surfaces, such as the upper-most floors, are subjected to more freeze-thaw cycling and therefore are more susceptible to scaling. A concrete mixture with a proper entrained air-void system is required to protect concrete against freeze-thaw deterioration. See Figures 19-36.

Air-entrained concrete is generally produced by using an air-entraining admixture during mixing. Unlike entrapped air, the entrained air voids in air-entrained concrete are microscopic in size and uniformly distributed to accommodate the expansive forces generated by frozen moisture in saturated concrete.

(a)

(b)

Figure 19-36: (a) Scaling adjacent to drain can contribute to ponding and progressive concrete deterioration. *(b)* Surface scaling.



(c)

(d)

Figure 19-36: (c) Undermining of control joint due to concrete deterioration adjacent to sealant. *(d)* Scaling on underside of slab at leaking construction joint.

19.3.2.1 Deterioration Mechanism.

Concrete is naturally porous. Excess water not required for hydration (hardening), but needed for workability during mixing, placement, consolidation, and finishing eventually dries, leaving behind a continuous network of pores and capillaries. This network gives concrete its porosity. Porosity, or "permeability," is generally high for concrete mixes with a high water/cement ratio and low for mixes with a low water/cement ratio. High porosity allows the concrete to absorb significant free water during exposure to rain or snow. If concrete cannot dry and becomes saturated during a freeze cycle, ice accumulates in the pore structure.

The destructive mechanism is not ice accumulation itself, but water pressure generated during ice development. Water migration through the pore network exerts significant pressures during freezing. It has been substantiated that water pressure causes the paste failure.

19.3.2.2 Influencing Factors.

There are a number of factors that influence the nature and extent of scaling on concrete surfaces. The following discussion is not intended to convey any particular order of importance for the factors reviewed, which are divided into two categories.

- The first category defines and describes those factors related to the service environment. Factors associated with the environment are number and intensity of freeze-thaw cycles, presence of deicer chemicals, and degree of saturation.
- The second category of influencing factors is that associated with the particular concrete and its design features. Material properties that greatly influence the susceptibility of concrete to scaling and freeze-thaw deterioration are air-entrainment, strength, water/cement ratio, and the mix design.

As previously discussed, freezing is the principal cause of scaling. If there were no freeze-thaw cycles, scaling could not occur. It has been established that the number of freeze-thaw cycles directly influences the deterioration rate. For similar concretes subjected to equivalent degrees of saturation, concrete exposed to the higher number of freeze-thaw cycles will disintegrate earlier and more severely than concrete subjected to fewer freeze-thaw cycles.

In addition to the number of cycles, the rate or cycle intensity is also significant. Rapid freeze-thaw cycling can cause concrete deterioration due to the redistribution of the pressures in the concrete matrix. Concrete surfaces exposed to direct sunlight during winter periods are subject to more frequent and rapid cycling than concrete exposed to ambient temperatures, but shaded from direct sunlight.

The impact which deicer chemicals (salt) have on scaling is both mechanical and chemical. High concentrations of salt depress the pore-water freezing point and increase the osmotic pressures that cause paste failure. Also, high salt concentrations can set up a counter system of pressures caused by the alkaline/acid relationships between the concrete and pore water, respectively.

As previously discussed, excess water is required within the pore network during freezing to induce disruptive pressures. Concrete that is relatively dry and subject to freeze-thaw cycling experiences minimal disruption. Continually moist concrete will disintegrate rapidly during freeze-thaw cycling because the water cannot escape without generating disruptive pressures.

Air-entrainment has been used successfully during the past several decades to protect concrete against scaling. Air-entrainment consists of a uniform dispersion of small bubbles in the paste matrix. These bubbles compete with the pore network for water during freezing and thus relieve the destructive pressures. Research has shown that the bubbles must have a particular size and spacing to be effective at protecting concrete. See Figure 19-37.

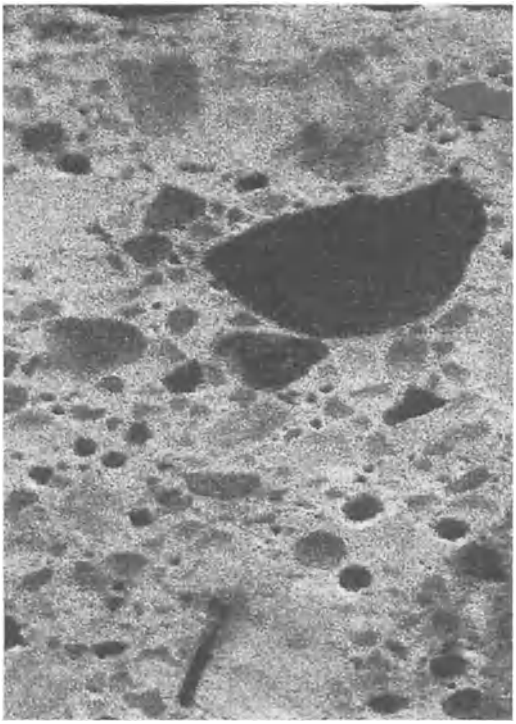


Figure 19-37: Magnified concrete section showing distribution of air entrained bubbles within the concrete. Note lack of air bubbles at top (surface) of the concrete.

In addition to air-entrainment, the development of minimum strength prior to the first frost exposure is needed to insure adequate resistance against freeze-thaw damage. Concrete strength must be at least 3500 psi prior to exposure to the freezing cycle if it is to remain durable in service. Properly air-entrained concrete that has not gained sufficient strength before freezing will be subject to premature freeze-thaw deterioration.

The water/cement ratio directly influences concrete porosity (permeability). Highly permeable concretes are more susceptible to rapid saturation than are those of lower permeability. Concrete has a certain tolerance for moisture. Moisture diffusion within a relatively dry matrix can influence the concentrations of water and can minimize saturation, thus preventing premature deterioration.

Design of the concrete mix, especially the cement factor, water-to-cement ratio, and use of the maximum-size coarse-aggregate fraction can also enhance long-term durability. The mix design should be tested prior to concrete placement in order to insure that the air system specified is achieved during construction. It is common to find differences between the specified and measured air-entrainment in the plastic concrete and in the air content of the finished hardened slab.

Concrete design details and concepts also influence susceptibility to scaling. Concrete floor surfaces subject to frequent freezing and deicer chemical application can be designed to drain rapidly, reducing critical saturation potential. Parking-facility floor-slabs with a minimum of 1½ - 2% grade will drain rapidly and will be inherently less susceptible to scaling due to the limited potential for saturation.

The above discussion is intended to provide an overview of the scaling process and familiarize the reader with those conditions that affect this distress mechanism and its influence on structural members. A more detailed discussion is provided in the American Concrete Institute's (ACI) committee report, entitled "Guide to Durable Concrete," ACI 201.2R. Also, refer to "Design and Control of Concrete Mixtures," Thirteenth Edition, Portland Cement Association for a more complete review of air-entrainment and entrained concrete.

19.3.3 Concrete Cracking

Concrete is strong in compression, but relatively weak in tension. Therefore, concrete cracking is caused by development of tensile stress in concrete members. Concrete cracking can occur in plastic as well as in hardened concrete. See Figure 19-38 (a) through (f). Plastic concrete cracking can be attributed to improper concrete placement, consolidation, and/or plastic shrinkage of the concrete. Cracking in hardened concrete is usually due to the internal stresses induced by the normal response of structural members to applied loads, temperature changes, support settlement, or drying shrinkage. In some instances, cracking in slabs, beams, columns, walls, and load bearing areas can be attributed to restraint and to concrete volume change. Cracking can occur in concrete structural members due to design or construction deficiencies. See Figure 19-39 (a) and (b) and Figure 19-40 (a) and (b). Cracking is also an indication of concealed problems in the concrete floors or supporting members, such as the initial stages of corrosion of embedded reinforcement. Concrete cracking due to corrosion is discussed in Section 19.3.1. Localized loss of prestressing forces due to prestressing strand or tendon deterioration, or embedded anchorage failure, can also result in cracking. Concrete cracks occur when the concrete member is subjected to tensile stresses and reinforcement is provided to transfer stress across the cracks. Properly designed, sized, and positioned reinforcement helps to distribute and control crack widths. For floor-slabs exposed to de-icing chemicals, ACI 224R suggests limiting crack widths on the tension face of members to 0.007 inches. Cracking can be detrimental when it will permit water leakage or contribute to concrete deterioration. These cracks should be repaired and sealed to reduce the adverse effects of cracking on the long-term durability of the structure.

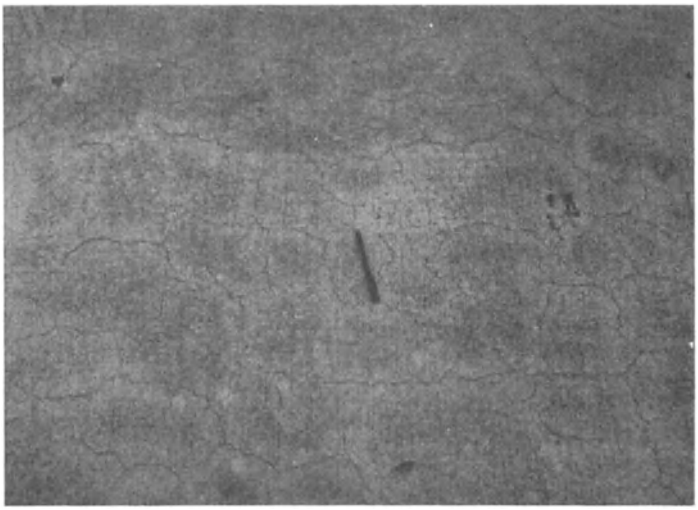
Concrete cracking can be reduced by proper selection of structural systems at the time of design. Conventional reinforced concrete floors are highly susceptible to cracking due to shrinkage, thermal, and flexural stresses. Precast pre-tensioned or cast-in-place post-tensioned concrete floor systems are much less susceptible to cracking. Other crack control measures related to design and construction issues are discussed in ACI 224R.

Proper design and installation of control and expansion joint systems will also limit concrete cracking. Floor-slab joints allow for shrinkage and temperature related volume changes that limit the tensile stresses in concrete. When volume change of concrete is restrained, random concrete cracking can occur. See Figure 19-38 (a) through (f). The restraint to volume change is provided by various parts of the structure, such as shear walls, stairtowers, and rigid columns. The likelihood of crack formation from volume change is increased by the presence of geometrical discontinuities, construction discontinuities (joints), and tension already existing from applied loads. Concrete spalling and cracking can occur due to inadequate design details that can result in "binding" of expansion-joints and slip-bearing joints. All floor-slab joints should be sealed to reduce leakage and potential deterioration of underlying beams, columns and connections.

The above discussion is intended to provide an overview of concrete cracking and the conditions that impact upon this distress mechanism and its influence on structural members. A more detailed discussion is provided in the American Concrete Institute's (ACI) committee reports, entitled "Control of

Cracking in Concrete Structures", ACI 224.1R. Also, refer to "Guide for Making a Condition Survey of Concrete in Service," ACI 201.1R for definitions and samples of various types of concrete cracking.

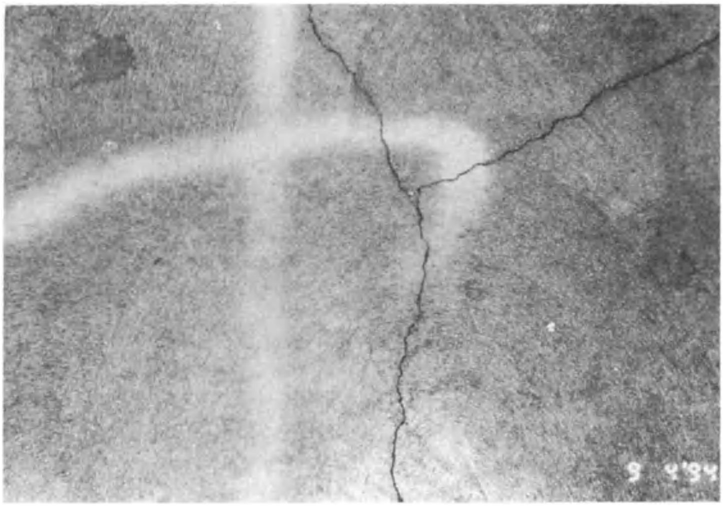
(a)



(b)

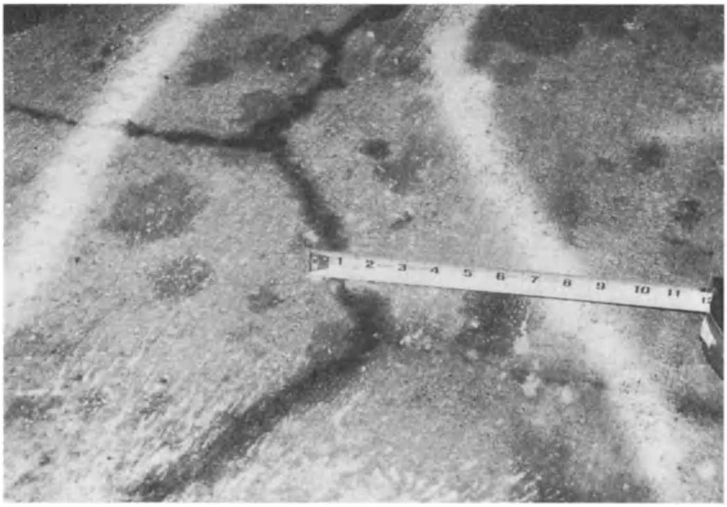
Figure 19-38: (a) Surface pattern cracking. *(b)* Flexural cracks in slab over beam edge.

(c)



(d)

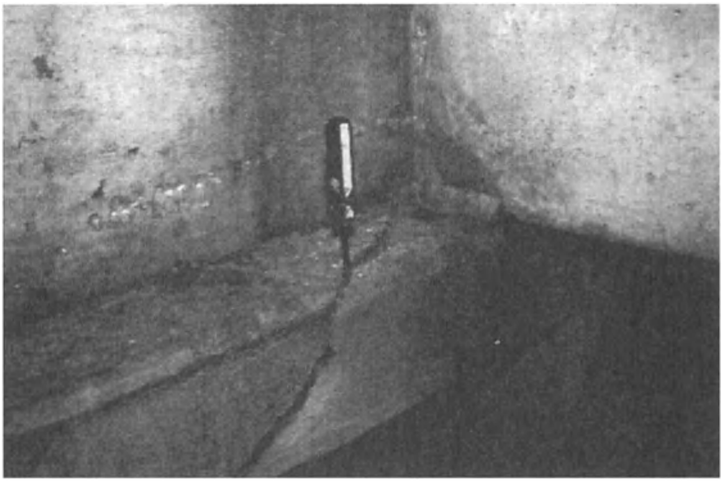
Figure 19-38: (c) Flexural cracking around column. *(d)* Random floor-slab crack.



(e)

(f)

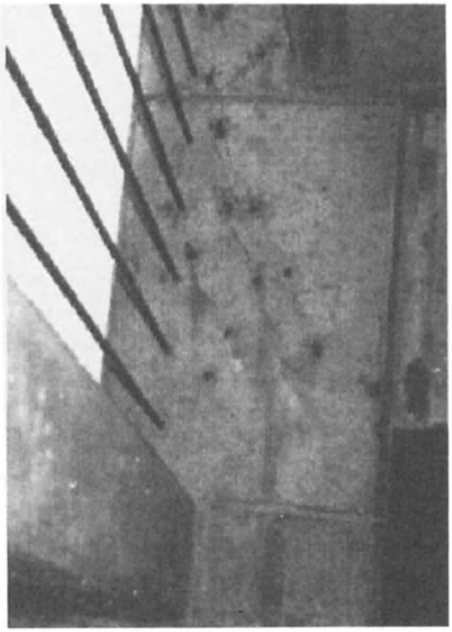
Figure 19-38: (e) Crack in concrete topping over double tee precast joints. *(f)* Reflective crack in concrete topping over double tee precast joints.



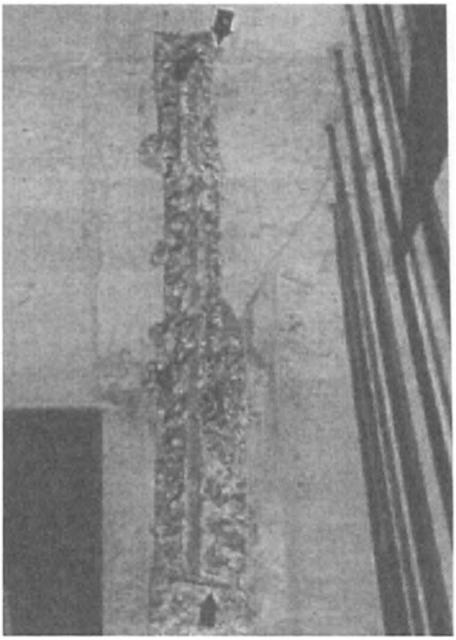
(a)

(b)

Figure 19-39: (a) Failure of double tee bearing ledge. *(b)* Distress in structural members and adjoining elements due to volume change movement and settlement.



(a)



(b)

Figure 19-40: (a) Crack in beam/column connection. *(b)* Beam/column connection cracking is due to missing column ties over the entire depth of the connection.

19.3.4 Joint Distress and Leakage

Construction joints are installed at preselected locations to limit the size of concrete placements. After the concrete hardens, these joints are tooled and filled with a flexible sealant to prevent leakage. Control joints provide for concrete volume change movements by creating a series of weakened planes for cracking at predetermined points in the plastic concrete and then filled with a flexible sealant to prevent water leakage. Joints must be properly designed, installed and maintained to reduce premature deterioration of underlying structural elements.

Flexible joint sealant material installed in joints in the structure will deteriorate due to exposure to ultraviolet rays, abrasion, and age. Joints on supported floor-slabs must be maintained by sealing against water leakage and intrusion of debris. To maintain the effectiveness of floor-slab joints, most sealant material needs to be removed and replaced at 8- to 10-year intervals.

Often, joint sealant deterioration is not the only cause for failed and leaking construction and control joint systems. A joint sealant for a particular application should be selected based on the required degree of flexibility, hardness, bond, strength, or durability. Deterioration of the concrete joint edge also affects joint system performance. Edge deterioration due to wheel or snowplow impact is a typical observation. Freeze-thaw related distress from entrapped moisture between a failed sealant material and the adjacent concrete can contribute to edge deterioration. Overfilled sealant material is typically ripped from joints or cracks by vehicular traffic. Inappropriate application of the flexible sealant material, either in too deep a groove or too wide and shallow a joint, can result in premature joint failures.

Expansion joints provide a practical limit on structure dimensions to accommodate movements associated with temperature changes, concrete creep, and long-term concrete shrinkage. Expansion joint openings are also sealed with a flexible material. The expansion joint system's effectiveness to seal the opening varies considerably. Some systems that are properly designed, installed, and maintained can be effective; however, design and installation failures in expansion joint systems are often due to a lack of cleaning of dirt and debris and the potential corrosion of exposed metal components. Also, expansion joints are susceptible to vandalism.

Premolded flexible urethane expansion-joints are quite often specified for parking structures. When properly designed and installed, these joints can be effective; however, improper design considerations, such as undersized sealant width, lack of provisions for shear transfer across the joint, positioning of joints in or adjacent to turn aisles, and excessive vehicular and snowplow abuse usually result in premolded joint failure. Failures can also be attributed to improper preparation of the concrete joint edge and variations in thickness of the installed joint sealant.

Metal-edged expansion joint systems with flexible glands are capable of withstanding greater abuse than premolded joint systems. It is preferable to specify a metal-edged system on exposed levels of a structure. However, these systems are susceptible to dirt and debris accumulation and require periodic cleaning. The metal-edged joint systems are more costly to install and repair. See Chapter 12 for more information about expansion joints.

Leakage through a failed and unmaintained joint system in a parking facility can create concerns for corrosion-induced and freeze-thaw related distress on interior levels. Serious concerns for patron safety, damage to vehicles, and general aesthetics are also raised by failed joint systems.

19.3.5 Leaching

Leaching is caused by frequent water leakage through cracks. Water leaking through a crack carries along part of the hydrated lime and other water-soluble products and deposits them as a white film, a stain, or in extreme cases, stalactites on the ceiling below. See Figure 19-41. Continued leakage will weaken the concrete over a period of years, and the deterioration rate is affected by the concrete quality. Leaching is generally more noticeable in cracks along gutterlines and areas that are susceptible to ponding. Water that leaks through cracks can leave deposits that will damage automobile paints.

Figure 19-41: Leaching and formation of stalactite on underside of slab.

19.4 CONDITION APPRAISAL

19.4.1 General

Parking structure restoration and maintenance programs begin with a thorough facility appraisal. The condition appraisal assists in locating existing distress, qualifying materials, and quantifying the extent of deterioration. Therefore, the condition appraisal provides a foundation for selecting repair materials, repair methods, and evaluating specific repair alternatives to restore the facility. This section contains details which can assist practicing professionals to develop a restoration program that enables owners to evaluate proposed programs. Again, proper condition appraisal is necessary to assure success in restoring a structure.

An appraisal requires an in depth review of existing conditions by observing individual elements and performing selective material and nondestructive testing. Evaluation of laboratory and field survey data collected requires review by both a materials specialist and a structural engineer. The primary objectives of the condition appraisal are to:

1. Define and describe conditions which exist within the facility, focusing mainly on the deterioration of floor-slabs and supporting structural elements.
2. Identify cause(s) of the observed deterioration. (Detailed survey must often be supported by materials and nondestructive testing to identify causes of deterioration.)
3. Describe the extent of the observed deterioration.
4. Evaluate the impact of the observed deterioration on the serviceability, durability, and structural integrity of the facility.
5. Develop repair alternatives for the facility. Repair alternatives should include discussion of only those feasible repairs that can effectively extend the useful life of the facility.
6. Recommend repairs for the facility based on technical interpretation of data and establish repair priorities to stage construction over several years.
7. Identify items which can adversely affect safety:
    a. Accelerated deterioration of structural members.
    b. Code items, such as barrier heights, barrier wall lateral-load-carrying capacity, and mechanical/electrical systems.
    c. Structural distress of *as-built* members due to material quality, design deficiencies, or construction practices.

Evaluation of structural distress requires a more extensive testing program to verify results of the analytical work performed to determine the cause(s) of the problem. In some cases, full-scale load testing of the structural element is required to verify results of field, laboratory, and analytical work.

The following ACI Committee reports are recommended as additional reference material:

1. ACI 201.1R, "Guide for Making a Condition Survey of Concrete in Service."
2. ACI 437R, "Strength Evaluation of Existing Concrete Building" ACI 437R.
3. ACI 364.1R, "Guide for Evaluation of Concrete Structures Prior to Rehabilitation."
4. ACI 423.4R, "Corrosion and Repair of Unbonded Single Strand Tendons."

19.4.2 Field Survey

Prior to preparing a comprehensive condition appraisal of a structure, it is essential to perform an accurate and complete field survey. Three key words characterize the field survey: locate, qualify, and quantify. Deterioration found in the survey is recorded on field survey plan sheets which may become part of the condition appraisal report. Materials testing also constitutes an essential part of the survey.

The field survey consists of six phases: preparation, initial walk-through, visual examination documentation, photographic recording, materials testing, and preliminary evaluation. Each of these phases will be discussed in detail. Emphasis placed upon any one phase is a function of the condition of the structure being surveyed. Usually structures in a more advanced state of deterioration require more effort than structures showing minimal deterioration.

19.4.3 Preparation for Field Survey

Effective preparation is essential to insure efficient use of field survey time and systematic accumulation of relevant information. Readiness for the survey consists of reviewing documents, preparing field survey sheets, and obtaining appropriate equipment.

19.4.3.1 Document Review.

The first step in preparing for the field survey is to attempt to obtain and review plans and specifications used in construction of the structure. It is also helpful to review other available construction records, such as shop drawing submittals, mix-design data, testing and inspection reports, and any maintenance or restoration work that may have been performed. This review is necessary to:

- Become aware of problems characteristic of the type of construction.

- Identify potential problem areas that may require more extensive investigation and preliminary selections of test methods and locations.
- Reduce start-up orientation period (time in the field getting your bearings, etc.)
- Obtain details on materials (e.g., type of steel, prestressing system, concrete, and admixtures) and cover requirements.
- Determine type, size, and orientation of embedded reinforcing. For prestressed structure, review types of tendon corrosion protection and system specified.
- Determine strength of concrete and steel.
- Determine design loads for supported tiers and roof.
- Examine drainage characteristics and locate gutterlines and drains.
- Locate stairtowers, elevators, and other features.

Prepare a checklist of items to be covered during the survey, including quantity and types of testing to be performed. Also review ACI 201.1R, "Guide for Making a Condition Survey of Concrete in Service," which contains a checklist for making a condition survey of structures. Contact the appropriate testing agencies to establish requirements and lead time required to perform the evaluation of samples collected during the field survey. Contact a testing laboratory or coring company to take cores at the job site and arrange for shipment of the cores back to the office. For prestressed structures, contact contractor to assist in exploratory excavation of tendons and anchorages. For prestressed structures, locate cores carefully so as not to cut through tendons.

When construction or previous repair documents are unavailable, try to retrieve information from other sources. Potential sources for obtaining construction records and documents include:

- Municipal building and zoning departments or inspection services departments
- Original architects (or later-generation firms)
- Historical society archives
- Contractor's or fabricator's (or later-generation firms') records
- Physical plant or engineering departments of major corporations, educational, or healthcare institutions

Have as much information as possible on hand when making inquiries. The following will prove useful:

- Building location
- Original name of owner of facility (if different)
- Date of construction

- Name of architect, structural engineer, fabricator, and/or contractor

Any of the above information may provide a clue that could lead to tracking down a set of drawings. Especially with older facilities, even as obscure a clue as a rebar identification tag can prove to be essential information that may result in obtaining a source of drawings.

Always try to supplement paper review with verbal discussions with the owner (or other staff member). From your conversations, try to get a feel for the past history of problems and to obtain information regarding specific problems that are most troublesome to the owner.

Reviewing contract documents and construction records can be invaluable in determining the cause(s) of the problem(s). Results of any analysis performed should accurately predict measurement of crack widths, deflections, relative movement, etc. made during the field survey. Analysis is based on actual existing loads, geometry, and material properties, rather than design values.

When design and construction documents are not available for review, in addition to use of a pachometer (refer to Section 19.4.8), other nondestructive test methods that use X-ray, radar, and infrared thermography are also required to determine reinforcement location and pattern. In most instances, nondestructive test results are visually verified by limited exploratory excavations or test wells. Developing design information by these methods is time consuming. Therefore, the need for and extent of information required should be established based on results of an initial walk-through review of the structure.

19.4.3.2 Field Survey Sheet.

Prior to the field survey determine the scale to be used for the condition survey sheets. Points to consider are: (1) minimize the number of sheets required for a report; (2) keep the scale large enough to accurately record data, typically 1/16 or 3/32 inch scale; (3) choose a sheet size that can be easily handled during the field survey; and (4) where possible, use the same scale that will be used for the contract documents. Typically, photocopies of original design drawings can be utilized for the condition survey. (Architectural plan sheets typically are the "cleanest" drawings available and usually indicate all "landmarks" within the facility.) Otherwise, draft a grid and produce sufficient blank sheets for the survey. A sample field survey blank sheet is illustrated in Figure A-1 in Appendix 19-1.

19.4.3.3 Equipment.

Prepare the appropriate equipment. Decide which members of the field survey team are to bring which pieces of equipment. Avoid field delays by making sure that all equipment is clean, charged, complete, and ready to use.

19.4.4 Initial Walk-through

Conduct an initial walk-through of the structure during the initial stages of the site visit. Items or issues of particular concern can be identified, and the relative condition of the various structural elements determined. Note special conditions and established code requirements. It is advisable to first perform the tasks that require the largest amount of time (chain drag and visual examination) so one can reevaluate the time schedule. Also, it may be advisable to perform reflected ceiling surveys prior to floor-slab surveys in certain types of facilities (thin one-way slabs, pan joist systems or waffle slabs, or slabs with a waterproofing membrane system) where (1) the condition of the ceiling holds the key to gaining a quicker appreciation of the facility conditions, and/or (2) the floor-slab deterioration is extensive, and the ceiling survey may provide the insight required to expedite the floor survey.

19.4.5 Visual Examination and Documentation

During this phase of the survey, distress in members is identified as potential subjects for work items. Perform a visual examination and a general review of the structural and operational elements summarized in Figure A-2 in Appendix 19-1. Also, note all work item locations on the field sheets and any other forms of distress or features in the various structural members that may help in the evaluation of the structure's performance, but not necessarily identified as potential work items. (Refer to Section 19.3 for the cause and significance of typical forms of deterioration.) Also review ACI 201.1R, which contains definitions of terms associated with concrete durability and forms of commonly observed distress.

In most instances, the upper surface of floor-slabs receive the first and greatest attention. Because of the presence of embedded reinforcement near the top surface, there is a greater potential for concrete deterioration. Floor surveys consist of two phases: (1) locate deteriorations, and (2) record them.

The person recording data accurately locates and scales the spalled/deteriorated areas onto field survey sheets using the appropriate coding. The square footage of the patch required to repair the deteriorated area should be estimated as carefully as possible. Refer to Figures A-3 through A-7 in Appendix 19-1 for a field survey legend and illustration of procedures to systematically record survey data. Document the size, location, and depth of scaling and spalling. Use a tape measure if necessary; it is of course better to estimate higher than lower.

Cracks may also be an early indication of corrosion of embedded reinforcement. Refer to ACI 224.1R for determining other causes of cracking. Floor-slab areas with cracks oriented parallel to embedded reinforcement should be examined with a pachometer to locate the proximity of the embedded reinforcement to the crack. Also, record crack patterns (if present), types, widths, and lengths. It is important to note whether the cracks are through-slab. Through-slab cracks should be documented during the visual survey of the underside of the slab.

As suggested in the National Cooperative Highway Research Program Report #57, cracks can be classified with respect to width, orientation, and, where possible, cause. Precise measurement of crack widths is neither feasible nor desirable, though a description in the following terms is useful: Fine(F) less than 0.01 in.; Medium(M) 0.01 - 0.03 in.; Wide(W) greater than 0.03 in.

The crack width may be indicated by the abbreviation F, M, or W beside each crack. If the cracks are described, their orientation is usually classified according to one of the following terms: transverse, longitudinal, diagonal, radial, pattern, or random. Care is required in ascertaining crack widths; cracks usually look wider at the surface because of their broken edges. Consequently, the width (¼ inch below the surface) is often reported. The crack width measurements reported by the petrographer during the microscopic examination of core samples are generally more accurate than those obtained in the field survey. The depth of cracks can be verified by taking core samples. The amount of moisture on the deck has a dramatic effect on the degree of cracking that is visible. Fine cracks are difficult to identify on wet or dry decks. Conversely, if a deck is examined under drying conditions, when moisture is associated with each crack, all the cracks are visible and appear to be wider than they are. The inexperienced observer may produce an exaggerated report.

Active (moving) cracks of any width are much more troublesome than inactive (dormant) cracks because they tend to enlarge and also limit the options when selecting the method of repair. It is often difficult to determine whether or not a crack is active, though a crack that is visible on both the top and bottom surfaces of the deck will tend to be active. In some instances, it may be advisable to use a crack comparator to record crack width accurately. A crack comparator is a small hand-held microscope with a scale on the lens closest to the surface being viewed. Cracks should be recorded simultaneously with floor delaminations, indicating lineal footage and width.

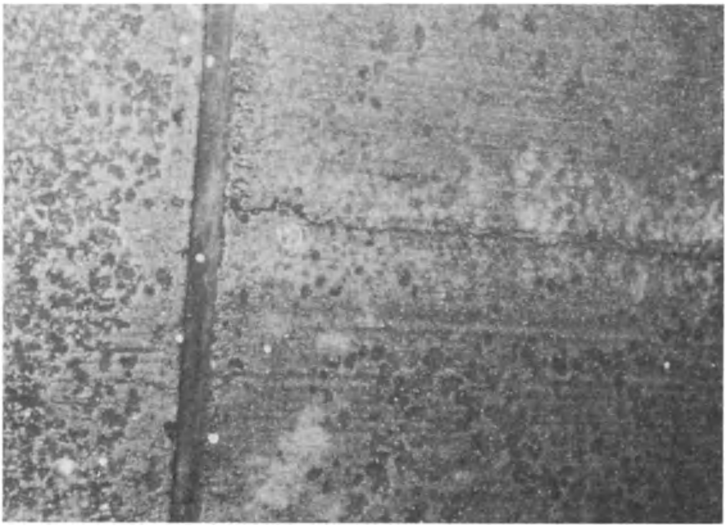
Previously repaired spalls and cracks should also be noted, as well as signs or remnants of previous floor-surface sealer or coating applications. It is critical to determine variations in extent of deterioration for floor areas that are protected compared to those areas that are not. It is also important to note variations in the extent of the floor-slab deterioration. For instance, the lower (first-supported) level tends to have more deterioration than the roof (exposed) level. This can be attributed to natural wash-down off the roof by rain and periodic removal of the accumulated road salt. In contrast, the first (supported) level surface tends to have a relatively greater accumulation of road salt which is tracked in and deposited by vehicles entering the facility from the street.

Freeze-thaw related deterioration, such as scaling and shallow sub-parallel delaminations, should also be noted. Items to consider when quantifying freeze-thaw related deterioration are as follows:

1. Exposure conditions: top levels, entrance areas, and perimeter parking bays typically exhibit greater levels of freeze-thaw deterioration.
2. Drainage: ponded areas, flat turn aisles or end bays, and gutterlines typically exhibit greater levels of freeze-thaw deterioration.
3. Location of construction joints: resistance to freeze-thaw deterioration can change for different concrete placements.
4. Location and condition of drains: ponding will contribute to increased freeze-thaw deterioration.

As described in ACI 201.1, surface scaling may be qualified as follows:

- *Scaling-light:* loss of surface mortar without exposure of coarse aggregate. See Figure 19-42(a).
- *Scaling-medium:* loss of surface mortar up to 5-10 mm in depth and exposure of coarse aggregate. See Figure 19-42(b).



(a)

(b)

Figure 19-42: (a) Light scaling. *(b)* Moderate scaling.

Figure 19-42 (c): Heavy scaling.

Figure 19-43: Surface abrasion and cracking.

- *Scaling-severe:* loss of surface mortar 5-10 mm in depth with some loss of mortar surrounding aggregate particles 10-20 mm in depth, so that aggregate is clearly exposed and stands out from concrete. See Figure 19-42(c).

Scaling should not be confused with abrasion. Abrasion will typically be concentrated in drive and turn aisles, and will generally appear as a more "smooth" and "polished" surface than that which is evident in scaled floor areas. See Figure 19-43. Concrete popouts are also an early indication of freeze-thaw deterioration.

Systematic passes should be made through the structure, concentrating on negative-moment regions, gutterlines, and turns. The slab-on-grade area of the structure should also be inspected for potential problems, such as differential settlement, drainage and scaling concerns, and trip hazards.

The inspection of ceilings is typically the next step in the survey. Beam distress is also recorded in this step. Beam, column, and ceiling delaminations are located by sounding the member with a hammer or tap rod. Longitudinal cracks near beam and column corners are usually reliable indicators of delaminated concrete. Ceilings showing evidence of cracking or salt or water staining should also be sounded. Ceiling deterioration is recorded in the plan view on the reflected ceiling sheets. The next step is to survey the columns to determine the extent of deterioration present on columns, connections, bumper walls and retaining walls. Since beam, column, and bumper wall distress cannot be shown in plan view, the coding system shown in Figure A-3 in Appendix 19-1 is very helpful in documenting deterioration. Refer to Figure A-5 in Appendix 19-1, where a column spall for example, is denoted as "3C" with an arrow drawn to the appropriate face of the column.

Stairtowers are systematically surveyed, followed by electrical and drain system inspection. Finally, a perimeter survey is made to observe conditions not visible from within the structure.

Concerning the recording of information during a survey, it may be practical to separate top-of-slab data and ceiling/column data on different sheets, especially where extensive deterioration of slabs is encountered. Color coding can be helpful when separate sheets are not used.

19.4.6 Photographic Recording

It is extremely helpful to record deterioration forms by means of photographs or video cameras. First, the photos and videotapes serve to further qualify distress found. Second, forms of distress which cannot be explained immediately in the field can be presented to other engineers to obtain their opinions. Remember, film is relatively cheap, and a photo may prevent mistakes or an unnecessary return to the job site.

ASA 200V and 400 are good all-around film speeds when variable lighting conditions are encountered. Color film should always be used. Location of photographs should be recorded on field survey sheets or on separate log sheets with an explanation of the subject being photographed.

19.4.7 Delamination Survey

When the steel begins to corrode and before spalls are visible on the deck surface, horizontal cracks, or delaminations, occur at or above the level of the top reinforcing steel. Delaminations need to be detected because they indicate a high level of corrosion activity and represent areas of unsound concrete that must be removed and repaired. It is not uncommon for more than one delamination to occur on different horizontal planes above the reinforcing steel.

Floor-slab delaminations are located by sounding the surface with a hammer, iron rod, or chain. When the delaminated area is struck, a distinct hollow sound is heard. Further sounding defines the limits of an area, and the boundaries are then marked with spray paint or chalk. See Figures 19-44 and 19-45.

Figure 19-44: Chain drag delamination survey.

Figure 19-45: Chain drag survey results.

Delamination surveys are very effective in detecting potential problems with tendon and anchorage corrosion in prestressed structures. The floor-slab delamination pattern can be very useful in planning the locations of exploratory excavations to evaluate the condition of prestressing tendons. See Figure 19-46.

Just a reminder: many of the older prestressed structures designed in accordance with the ACI Building Code, prior to the 1971 edition, did not require the use of mild steel reinforcement to support the dead load of the slab. The delamination survey results expressed as a percentage of the floor area for these older structures are usually very small in comparison to structures reinforced with mild steel reinforcement. However, any delamination noted is usually attributed to corrosion of prestressing tendons. Even a small percentage of delaminated area (<2%) could potentially signal severe tendon corrosion and significant loss of structural integrity for these structures.

Detection of delaminated areas by remote sensing through the application of thermograph and radar systems has also been developed. These methods are not currently in routine use for delamination survey of parking structures. These methods have been successfully used in bridge deck surveys.

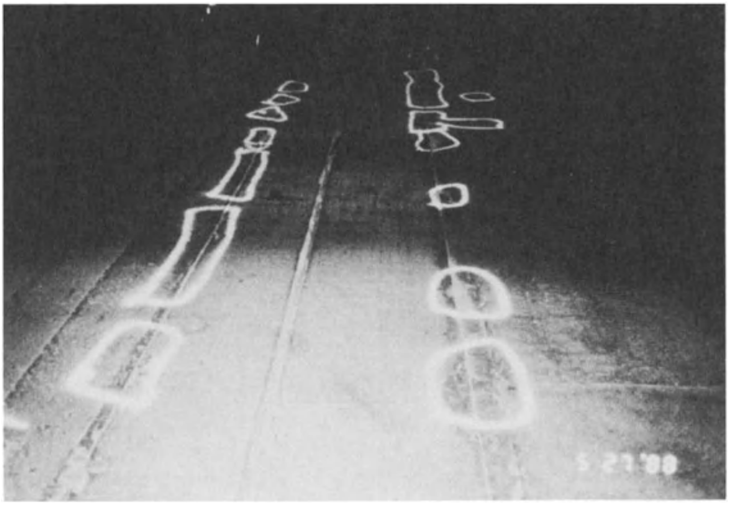


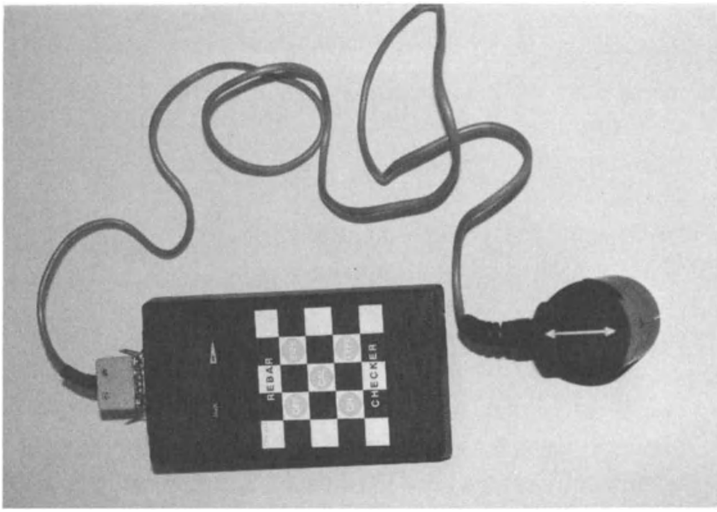
Figure 19-46: Chain drag survey at pour strip with prestressed tendon end anchorages.

19.4.8 Pachometer (Concrete Cover) Survey

The pachometer, also referred to as "covermeter," can measure concrete cover to embedded reinforcement. There are two types of covermeters. The "magnetic reluctance meter" operates on the principle of magnetic reluctance. The "eddy-current" type operates on a principle associated with the electrical conductivity of the embedded reinforcement. See Figure 19-47 (a) and (b).

The magnetic reluctance type covermeter magnetically locates the embedded steel and measures the intensity of the magnetic field produced by the embedded steel, which can then be correlated to a specific depth from the concrete surface, provided the size of the embedded steel is known. It cannot detect the presence of aluminum or PVC conduit. However, it will respond to electric current in its vicinity. One should stay clear of electrical equipment to obtain accurate readings.

(a)



(b)

Figure 19-47: (a) Cover meter based on principle of magnetic reluctance. *(b)* cover meter based on principle of eddy current.

Always review available structural drawings prior to performing the survey. The pachometer will give accurate results if the structural member is lightly reinforced. In heavily reinforced members, the effect of secondary reinforcement does not allow accurate measurement of cover. Also, reinforcing bars that run parallel to the bar to be measured will influence the reading if the distance between the bars is less than two or three times the cover distance. The magnetic reluctance based covermeters cannot be used accurately at temperatures below 40°F, unless the meter is equipped with dry-cell batteries.

When the diameter of the embedded steel is known, the depth of concrete cover can be read from the needle position on the dial of the pachometer. As nearby steel can have an additive influence on needle deflection, the cover reading should be taken at a few locations along a bar. This practice will help to determine the influence of other elements. Large meter readings indicate shallow reinforcement.

Rebar cover measurements should be taken at ten to fifteen random points at each location of supported tier and recorded on field survey sheets. Extra readings may be required over beams on prestressed decks to locate tendons and measure cover. Pachometer readings should also be taken in the area of coring and in the vicinity of test locations.

It is necessary to locate and determine the depth of concrete cover over the reinforcement for the following reasons:

- Establish the chloride ion content of the concrete at the level of the embedded reinforcement.
- Correlate extent of observed deterioration.
- Locate areas with shallow cover that would restrict concrete removal by rotary or scarifying equipment.
- Relate position of reinforcement to concrete removal limits specified in repair details.
- Recommend appropriate floor-slab protection.
- Predict future repairs and level of maintenance.

19.4.9 Materials Testing

In conjunction with the field survey, it is necessary to perform materials and nondestructive testing to supplement the results of visual observations. Testing should be performed by experienced personnel and, where necessary, the results evaluated by a materials consultant. The testing assists in verifying the extent of deterioration and in evaluating the condition of the existing concrete. This information is useful in selecting appropriate repair methods and materials. In some instances, test wells are opened to visually verify the extent of the problem. Some of the commonly used laboratory and nondestructive tests for a condition survey of a concrete parking structure along with their applications are listed in Table 19-3. Where applicable, standard test methods are referenced.

The testing program for a structure is generally established by considering the following items:

Table 19-3. Commonly Used Laboratory and Nondestructive Tests

Tests	Standard Designation	Application
Materials Testing		
1. Chloride ion content	FHWA-RD77 or AASHTO T260 or ASTM C1218	Determining the chloride content of concrete to establish potential for corrosion of reinforcement and extent of chloride ion penetration.
2. Compressive strength	ASTM C42	Obtaining and testing drilled core samples to establish quality of concrete.
3. Petrographic examination	ASTM C856	Microscopic examination of concrete core samples to evaluate quality and durability of concrete.
4. Shear bond strength or pull-out test by applying direct tension	Iowa Direct Shear and ACI 503R, Appendix (Field test)	Determining bond strength of core sample to evaluate integrity of concrete topping, overlays, and patches.
5. Air-void system of the concrete	ASTM C457	Evaluate surface scaling or freeze-thaw resistance of concrete.
6. Physical and metallurgical examination	Scanning microscopic/X-ray analysis/hardness. Tensile strength.	Examination of prestressing tendons to detect corrosion or embrittlement.
Nondestructive Testing		
7. Delamination survey (chain drag)	Chain drag ASTM D4580	Determining extent of concrete deterioration in structural members including floor-slabs (chain drags often used).
8. Pachometer survey	_	Measuring concrete cover over reinforcement and size.
9. Half-cell testing	ASTM C876	Detection of corrosion activity.
10. Pulse velocity	ASTM C597	Locating internal discontinuities, such as voids, cracking, etc.
11. Radar	ASTM D4748	Locating internal discontinuities and measure size and location of reinforcement.

1. The type of structural system involved.
2. The types and forms of deterioration observed, such as corrosion-induced spalling and scaling cracking. The testing should be representative of the type and extent of deterioration noted.
3. The need to qualify previous repairs.
4. Probable repair solutions and repair costs.

Additional information with respect to development of a sampling plan and sample size may be obtained in ASTM C823, "Practice for Examination and Sampling of Hardened Concrete in Construction" and ASTM E122, "Practice for Choice of Sample Size to Estimate the Average Quality of a Lot or Process." Also refer to ACI 364.1R, "Guide to Evaluation of Concrete Structures Prior to Rehabilitation," for practices and methods for assessing the condition and properties of materials in an existing structure.

19.4.9.1 Chloride Ion Content of Concrete.

Concrete powder samples are taken at various locations throughout a facility by means of a rotary hammer, and the pulverized samples are taken in equal increments of depth at each location to establish chloride content as a function of depth. This method aids in determining the corrosion potential of the steel at a certain depth within the concrete. The use of the rotary hammer to obtain concrete powder samples has the advantage of portability, lightweight, speed, and economy. See Figure 19-48. An alternate method is to obtain pulverized concrete samples in laboratory from individual core samples. The use of samples permits the preparation of test samples under controlled conditions and provides better accuracy.

It is generally desirable to sample for chloride content at two or three locations from each level of the structure. Sites should include drive lanes, parking stalls, turns, and speed ramps on all supported levels. In addition, a "baseline" sample from an uncontaminated area should be obtained. Also, determine the minimum depth of the reinforcement in the vicinity of the sample location.

The significance of chloride ion testing is to determine the chloride ion concentration at the level of the reinforcing steel. High chloride ion concentration at the level of reinforcing steel correlates well with the presence of active corrosion. Research by the Federal Highway Administration (FHWA) has established that an acid soluble chloride ion content of 280 to 410 ppm at the reinforcing bars results in accelerated corrosion. This information is valuable for investigation of rehabilitation alternatives. A graph is used to interpret chloride ion test results. Parts per million (ppm) are plotted on the horizontal axis and depth into the concrete is plotted on the vertical axis. A typical plot is shown in Figure 19-49.

Figure 19-48: Obtaining concrete powder sample in field

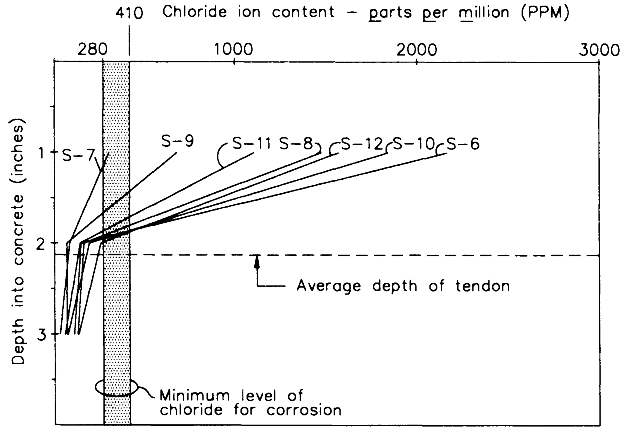


FIG. 3 – CHLORIDE ION CONTENT VS DEPTH INTO CONCRETE

SAMPLE NO.	SAMPLE LOCATION
S-6	Supt. tier 4, west bay, drive lane
S-7	Supt. tier 4, east bay, drive lane
S-8	Supt. tier 4, east bay, parking stall
S-9	Supt. tier 3, west bay, drive lane
S-10	Supt. tier 3, east bay, drive lane
S-11	Supt. tier 2, east bay, parking stall
S-12	Supt. tier 2, east bay, drive lane

Figure 19-49: Chloride ion content vs. depth.

Performance of traffic-bearing membranes or coatings can also be established by chloride ion penetration testing. Samples taken from concrete before membrane application and after several years of service provide insight into system effectiveness. Surface sealers can be evaluated for effectiveness in a like manner. Performance of a floor-slab protection system can be monitored simply by repeating the sampling, analysis, and evaluation of results annually.

19.4.9.2 Coring and Testing.

Drilled concrete cores provide valuable information into the types of deterioration encountered within the structure and to the types of repairs required to return the structure to serviceable condition. Note the location of all cores removed from the structure on the field survey sheets for future reference. Do not core prestressed structures prior to confirming location of tendons by x-ray examination.

Remove core samples from selected locations after performing the visual observations, delaminations survey, and other nondestructive testing. This practice assists in correlating, confirming, or resolving conflicting data obtained during the field survey. The majority of the cores should be taken in areas of deterioration, such as delaminations, scaling, and cracking. See Figures 19-50 (a) and (b) and 19-51 (a) through (c).

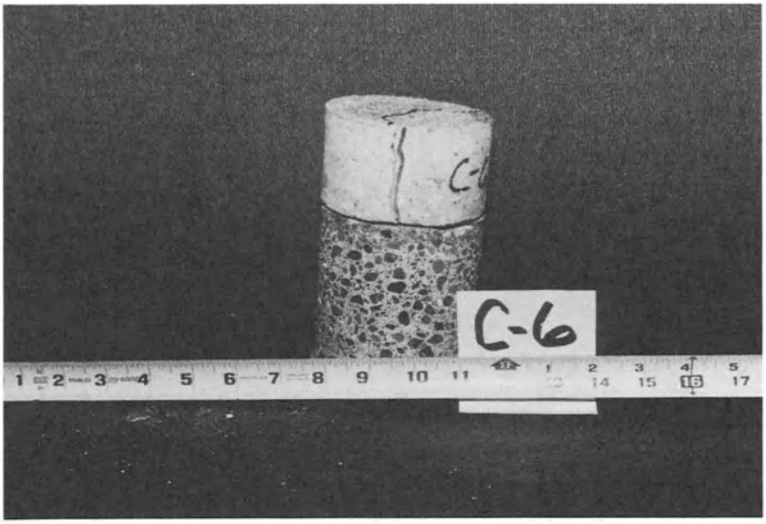
For instance, core through cracks aligned directly over embedded mild steel reinforcement to obtain the depth of concrete cover and the extent of the corrosion of the steel. However, do not attempt to core through prestressing tendons. Always obtain a few core samples from apparently good areas of the structure to establish a "reference" for comparison of the extent of deterioration in other samples. Locations for coring must be marked by the survey team. Use the pachometer to locate reinforcement in the area. Mark the coring location so that the chance of reinforcement damage is minimized, especially when coring near post-tensioning tendons. Cores for testing concrete compressive strength should be specifically sited to avoid reinforcing steel. However, it is desirable sometimes to obtain samples of reinforcing steel in cores selected for petrographic examination. Try to obtain core samples by cutting steel near the ends of the rebar (to compromise only the development of the rebar) or in structurally redundant locations of the facility.

The minimum number of samples obtained depends on the type and size of the facility being examined. Visual examination of cores considered useful can generally be gained from three to four samples for a one-level facility, four to five for two levels, five to six for three levels, etc.

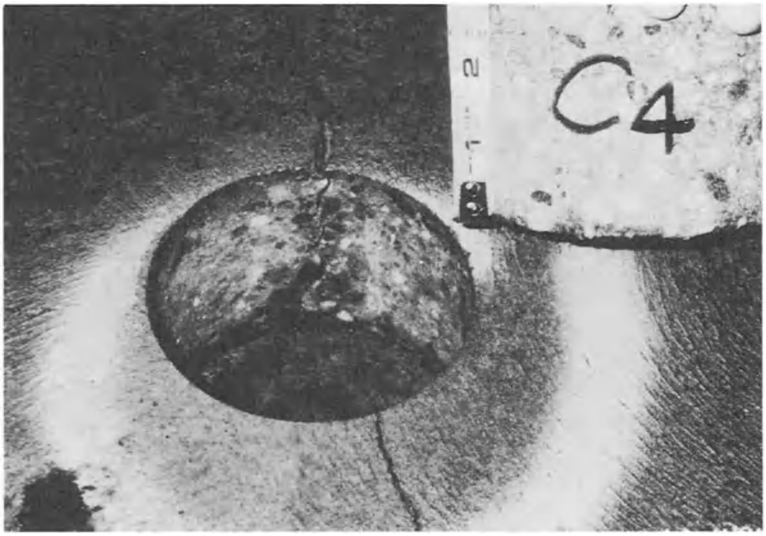
(a)

(b)

Figure 19-50: (a) Coring for concrete sample. *(b)* Concrete core samples obtained from selected locations for laboratory examination and testing.



(a)



(b)

Figure 19-51: (a) Core sample over crack in overlay to determine depth of cracking. *(b)* Core over random crack in concrete topping.

Figure 19-51(c): Core sample over previously patched area with a waterproofing membrane and asphalt wearing surface.

Upon returning to the office, photograph all the cores taken with a scale reference object. At this time select cores for compressive or petrographic examination, and if necessary, bond and/or air content testing depending upon the type of the deterioration observed.

19.4.9.2.1 Concrete Compressive Strength.

Concrete core samples are usually obtained from selected areas of the structure to determine compressive strength. Core samples are obtained and tested in accordance with the Standard Test Method ASTM C42. A minimum of three core samples should be tested initially from a facility to obtain an average concrete compressive strength. Additional cores should be taken when noticeable variations in the extent of concrete deterioration are related to different concrete placements or different levels of the structure.

Compressive strengths quantify the relative quality of concrete in the floor-slab. They provide confirmation of results obtained by visual observation, materials testing, and nondestructive examination. For instance, extensive floor-slab spalling due to corrosion of reinforcement in a structure with adequate concrete cover may be attributed to poor quality concrete. This

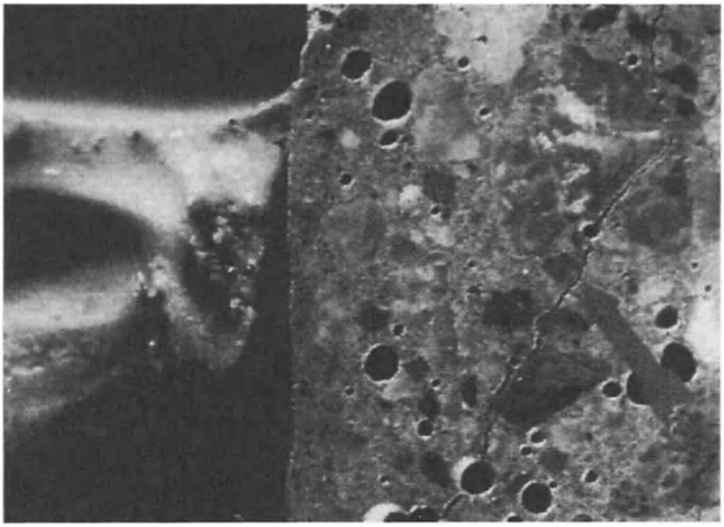


Figure 19-52: Crack at joint edge can undermine effectiveness of joint sealant.

assumption can be confirmed qualitatively by petrographic examination and measured by core compressive strength results. Concrete compressive strength results assist in estimating concrete removal methods and costs. The unit price for concrete removal and preparation is higher for concrete with higher compressive strengths. Also, the selection of concrete removal methods is affected by the concrete compressive strength.

19.4.9.2.2 Petrographic Examination.

Microscopic examination, sometimes in combination with other techniques, is used to examine samples of concrete. Features that can be evaluated include denseness of cement paste, depth of carbonation, occurrence of bleeding, presence of contaminating substances, air content, and other properties. Standard recommended practice is given in ASTM C856.

Perform an examination of core samples both from deteriorated areas, as well as potentially sound areas. Microscopic examination can provide valuable information on the extent of damaged concrete that may require removal, depth and nature of cracks, and presence of other distress that may affect the repairs. See Figure 19-52.

When indicated by petrographic examination and visual observations, determine the characteristics of the entrained air-void system to evaluate the durability of the concrete. Refer to Figure 19-37. The air-void characteristics are determined in accordance with Standard Test Method, ASTM C457. In accordance with ACI 345, air-void characteristics of an adequate system are: (1) calculated spacing factor less than 0.008 inch; (2) a surface area of the air voids greater than about 600 square inches per cubic inch of air void volume; and, (3) a number of air voids per linear inch of traverse significantly greater than the numerical value of the percentage of air in the concrete.

19.4.9.2.3 Shear Bond Test.

Shear bond testing is performed to evaluate the bond strength of concrete overlays, precast topping, and patches to the substrate. The National Cooperative Highway Research Program Report #99 indicates that a value of 200 psi is a desirable bond strength, which has generally been accepted and used as a guide in designing bonding mediums. In areas of questionable bond integrity, microscopic examination of the bond interface should be performed to determine the potential cause(s) of debonding. Debonding of concrete topping can contribute to a reduction in the load-carrying capacity of structural precast double-tee floor systems.

19.4.10 Nondestructive Testing

The delamination and pachometer surveys described earlier in this section are also a form of nondestructive examination. There are several other nondestructive test methods which can be utilized to evaluate the condition of the structure. A detailed review of various nondestructive test methods are presented in ACI 228.2R, "Nondestructive Test Methods for Evaluation of Concrete in Structures." Some of the commonly used nondestructive test methods used in evaluation of concrete in parking structures are briefly described and included in this section.

19.4.10.1 Half-Cell Corrosion Potential Testing.

The half-cell potential method consists of estimating the electrical half-cell potential or reinforcing steel in concrete for the purpose of determining the potential of corrosion activity of the reinforcing steel. The method is limited by the presence of electrical continuity. A concrete surface that has dried to the extent that it is dielectric, and surfaces that are coated with a dielectric material (e.g., epoxy) will not provide an acceptable electrical circuit. The testing apparatus consists of a copper-copper sulfate half-cell, which is effectively a rigid tube or container composed of a dielectric material that is nonreactive with copper or copper sulfate, a porous wooden or plastic plug that remains wet by capillary action, and a copper rod that is immersed within the tube in a saturated solution of copper sulfate. A detailed description of the apparatus and parameters for use of the apparatus are included in ASTM C876. Means and methods for electrical connections to embedded steel, the half-cell and prewetting of the concrete surface are also described in the test method.

Except in very specialized cases, half-cell potential testing should be used to evaluate corrosion potential of floor-slab surfaces only. A spacing of 4 feet has been found satisfactory for evaluation of bridge decks and is appropriate in most instances in conventionally reinforced parking structures. A wider spacing is not recommended.

Record the electrical half-cell potentials to the nearest 0.01V. By convention, a negative (-) sign is used for all readings. Report all half-cell potentials in volts and correct for temperature if the half-cell temperature is outside the range of 72 ±10°F. The temperature coefficient for correction is given in ASTM C876.

According to ASTM C876, the significance of the numerical value of the potentials measured is as shown below. Voltages listed are referenced to the copper-copper sulfate (CSE) half-cell.

- If potentials over an area are less negative than -0.20V CSE, there is a greater than 90% probability that no reinforcing corrosion is occurring at that area at the time of measurement.
- If potentials over an area are in the range of -0.20 to -0.35V CSE, corrosion activity of the reinforcing steel in that area is uncertain.
- If potentials over an area are more negative than -0.35V CSE, there is greater than 90% probability that reinforcing steel corrosion is occurring in that area at the time of measurement.

Results of half-cell potential testing only indicates the probability of corrosion occurring in areas with a potential reading greater than 0.20V. The numerical value of the results is not intended to indicate the relative rate of corrosion. Measurement of corrosion rates requires measuring the corrosion current and the resistance to flow of current.

19.4.10.2 Pulse Velocity Test.

The ultrasonic pulse velocity method consists of measuring the time of travel of an ultrasonic pulse passing through the concrete to be tested. The pulse generator circuit consists of electronic circuitry for producing pulses of voltage, and a transducer for converting these pulses into a form of mechanical energy having vibration frequencies of 15-50 kHz. Contact with the concrete is made through a suitable connection; another transducer is connected to the concrete at a measured distance from the first. The time of travel of the pulses between the two transducers is measured electronically. The apparatus requirements are defined in ASTM C597.

There are three ways of measuring pulse velocity through concrete. The best and most accurate method is by direct transmission through concrete where the transducers are held on opposite faces of the concrete specimen. Only personnel experienced in the use of this equipment should operate and interpret results of testing.

Some applications of pulse velocity testing for use in the evaluation of concrete structures are listed below:

- Establishing the uniformity of concrete.
- Establishing acceptance criteria for concrete; generally, high pulse velocity readings indicate good quality concrete.
- Estimating the strength of concrete through correlation of known strengths of core samples.
- Measuring and detecting cracks.
- Inspecting reinforced concrete members.

19.4.10.3 X-Ray Examination.

X-ray examination can be helpful to identify the location of embedded reinforcement in very thick structural members where a pachometer survey is likely to be ineffective. However, x-ray examination is costly and should only be used if useful data are anticipated. Some of the concerns regarding x-ray examination are as follows:

1. Access to both surfaces of the member is required - one surface for the x-ray source transducer, the opposite surface for the recording film.
2. The x-ray does not distinguish reinforcement placement relative to depth. Images from rebar on the near face of a member may "shadow" an image from rebar deeper in the member.
3. The x-ray signal as it moves through a member is conical; i.e., the range of area the x-ray examines increases with depth of penetration. Careful interpretation of results is required.

X-ray examinations are recommended prior to obtaining core samples from post-tensioned decks to locate post-tensioning tendons. Other potential uses of x-ray examination are to locate end zone reinforcement in a post-tensioned beam or beam-column connections, or to locate end zone stem reinforcement in a precast tee beam.

19.4.10.4 Radar Examination.

Radar examination is especially useful in locating large areas of embedded reinforcement within a floor-slab or structural member. A graphic representation of the reinforcement location is continuously developed during the examination, which can be easily calibrated by coring at predetermined locations to record visually the depth and size of reinforcement.

Welded wire fabric reinforcement can be easily located by radar examination where pachometer examination is generally ineffective. Agencies using radar examination present the opinion that the equipment is capable of detecting voids beneath concrete pavements on grades, determining concrete thickness when only one side is accessible, determining asphalt overlay thickness, and surveying slab delamination.

In radar profiling, echoes from a pulsed electromagnetic wave are received by an antenna. The penetration and resolution of the signal are a function of the frequency of the electromagnetic pulse. A high-frequency signal provides high resolution but has shallow penetration. Lower-frequency signals have greater penetration but poorer resolution. Depending on the thickness of individual layers and the desired penetration, two or possibly three different radar antennas ranging from a few hundred to a thousand or more megahertz may be utilized. The data-recording rate is chosen to yield high resolution continuous profiles over multiple traverses. Field evaluation and preliminary interpretation of data are generally made from a group of parallel profiles.

Radar profiling detects the presence of delaminated conditions and may indicate deterioration caused by cracking. Chemical deterioration of concrete and consequent changes in the dielectric constant may be detected if radar is used in conjunction with other methods, particularly electrical resistivity. Although radar examination is expensive, it proves to be cost effective when large areas of floor-slabs are required to be surveyed for reinforcement placement, particularly when graphic representation of the survey information is desired.

19.4.11 Exploratory Excavation

Exploratory excavations are very useful to verify conditions of the underlying concrete or embedded reinforcements. In some instances, exploratory excavations may simply consist of coring through the slab surface. In other instances, one may need to perform partial or full-depth excavation of the floor-slab to verify conditions. Examples of test wells are shown in Figure 19-53 (a) through (d).

Figure 19-53: (a) Test well to observe condition of underlying substrate and reinforcement.

Figure 19-53: (b) Measuring extent of rebar corrosion.

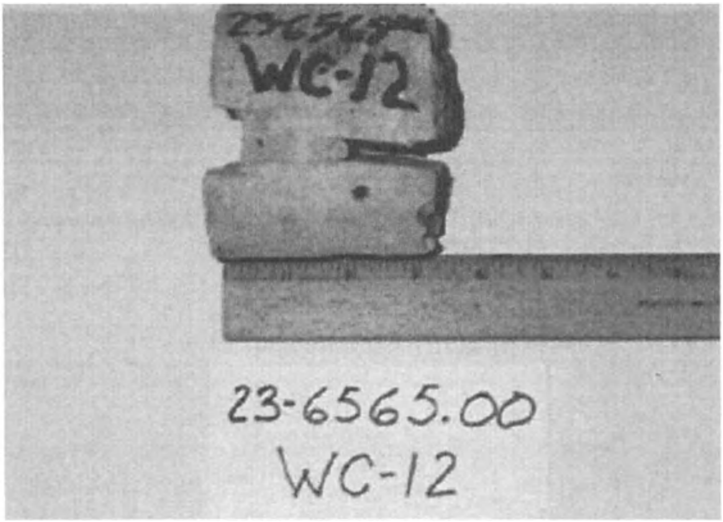


Figure 19-53(c): Core through joint sealant.

Most nondestructive testing described earlier in this section requires some limited exploratory excavations to correlate the results of the testing. Furthermore, there are no dependable nondestructive test methods currently available to evaluate the condition of prestressing tendons in concrete structural members. The only method available is to chip into the concrete and expose the tendons for visual inspection. Refer to ACI 423.4R, "Corrosion and Repair of Unbonded Single Strand Tendons" for discussion on limitations of nondestructive testing and exploratory excavations and other methods of tendon evaluation.

.Figure 19-53 *(d)* Excavation at precast double tee flange connector.

19.4.11.1 Waterproofing Membranes.

Waterproofing membrane systems quite often have to be removed to physically observe the condition of the underlying slab and to obtain core samples in order to verify the effectiveness of the system. Select test locations in areas with poor drainage conditions and over areas with noticeable water leakage, wet spots, cracks, or efflorescence on the underside of the slab.

Whenever an existing waterproofing membrane is encountered, it is advisable to bring back samples to the office for analysis. The membrane can be observed for weathering, embrittlement, tensile properties, and thickness. In the field the membrane should be observed for cracking, adhesion, and excessive wear. Also, obtain information as to the membrane type and the date of its installation. Refer to Chapter 13 for a more detailed review of protected membranes in plaza deck systems.

19.4.11.2 Post-Tensioning Tendons.

Post-tensioning tendon conditions, especially in older structures, are visually examined for distress by opening test wells. One has to be extremely careful when attempting to open test wells around post-tensioning systems. Also, it is extremely unsafe to stand directly over tendons that are being excavated. These excavations should be directed by an engineer familiar with the design of the structural system and the restoration of prestressed structures.

Locations typically selected for excavation are tendon high points over beams, tendon low points at mid spans, intermediate anchorages at construction joints, and end anchorages. Refer to Section 19.3.1.4 and ACI Report 423.4R for discussion of potential problem areas related to tendon corrosion.

For end anchorage excavation, do not remove the concrete behind the bearing plate. Since the concrete behind the embedded-plate assembly is precompressed, concrete removals may result in anchorage failure due to movement or rotation of the anchorage assembly. At each excavated location, note concrete cover of tendons, and condition of tendons. If corrosion damage is not apparent and a tendon is broken, a sample of the tendon should be obtained at the fracture location for further metallurgical examination to determine the failure cause.

19.4.12 Data Evaluation

The data evaluation consists of: (1) analyzing and correlating the results of the field observations, measurements, testing, and (2) reviewing laboratory test results. The objective is to determine the primary cause(s) of observed deterioration and its impact on structural members. Analysis of the field, laboratory, and testing data require the application of knowledge and judgment by a restoration specialist in determining the cause(s) of distress.

19.4.12.1 Cause(s) of Deterioration and Contributing Factors. The primary cause of deterioration must be supported by field observations, measurements, and laboratory testing. For example, corrosion-induced deterioration must be verified by results obtained from delamination, pachometer, and half-cell testing surveys and the chloride ion content of the concrete at the level of the reinforcement. Coring and a test well can further provide information regarding the extent of reinforcement corrosion.

Cracking is a symptom of distress that may have a variety of causes and contributing factors. Refer to Section 19.3.3. The selection of the correct repair method will depend on determining the primary cause of cracking and the contributing factor(s), if any. The crack pattern, location, depth, and size observed in the structure must be supported by analytical and/or laboratory test results.

Very often there are other factors that also contribute to the observed deterioration; try to determine them. For instance, a primary cause of deterioration is reinforcement corrosion, but contributing factors may also include lack of air-entrainment and freeze-thaw deterioration, shallow concrete cover, poor-quality concrete, and inadequate drainage. Understanding the contributing factors will help to recommend better repairs by specifying appropriate repair methods and materials.

Review of original drawings, specifications, inspection reports, and shop drawings can also be useful in determining the cause(s) of a problem. For instance, it is not unusual to find a variation in an as-built condition from that specified in structural drawings, which can contribute to distress, such as concrete cracking and spalling in structural elements. For such deficiencies, supplemental reinforcement or strengthening may be required to restore the load-carrying capacity or integrity of the member.

19.4.12.2 Impact of Deterioration.

The next step is to determine the impact of the observed deterioration. This is done by tallying quantities of the various forms of deterioration, such as spalling, delaminations, cracking, and scaling from the field survey sheet on a tier-by-tier basis. For example, determine the extent of floor-slab spalling and delaminations. Consider the impact from the standpoint of the extent of present deterioration, as well as the potential for future deterioration. Present floor-slab spalling and delaminations may be only 5% of the floor area, but a half-cell potential survey may indicate a strong probability for continuing corrosion over most of the remaining floor area. The repairs recommended must correct the present deterioration and address the potential for continuing deterioration of the floor-slab due to corrosion of the embedded reinforcement.

The impact of the deterioration observed on the individual elements of the structure can be categorized based on the priority of repairs as follows: (1) structural/safety related, (2) serviceability/durability related, or (3) preventive (maintenance) in nature.

Deterioration can adversely affect structural integrity, safety, and serviceability of members. Estimating the loss of structural integrity due to deterioration is one of the most difficult aspects of an investigation. Structural engineers should consider the effect of cracking, partial loss of the reinforcement bond due to delaminations, loss of the cross-sectional area of primary reinforcement, and loss of strength and toughness. In some cases load testing is the only alternative to determine structural capacity of a deteriorated structure. This method will determine the load-carrying capacity of the member at the time of the test. The influence of other large forces, such as those due to restrained volume change or lateral load forces, can be evaluated analytically, according to Chapter 20 of ACI 318, or by modifying the load test to account for such factors. The ACI 437R report, "Strength Evaluation of Existing Concrete Buildings" provides more information on evaluation procedures to determine the stability, strength and safety of existing structures, analytically or by load testing.

Repairs correct the effects of deterioration and attempt to return structural elements close to their original condition and serviceability. Measures taken primarily to reduce deterioration and prolong the life of the structure are considered to be *maintenance actions* as opposed to repairs. For example, application of a membrane traffic topping or surface sealer is considered to be maintenance action, since this is a preventive action to protect the structure from chloride ion penetration. Repairs must be performed when the load carrying capacity of members is reduced or serviceability of the structure is affected by concrete deterioration. Alternatives for repair of individual members should be developed and a cost-effective repair method selected for implementation.

19.4.13 Reports

The results of the condition appraisal of the parking facility are presented in a report to the owner. The essential elements of the report are identified in Table 19-2. The table also shows the level of effort and the tasks associated with the development of the report. Also refer to ACI 364 Committee Report, "Guide for Evaluation of Concrete Structures Prior to Rehabilitation" for more details on the content of the report.

The primary purpose of a condition appraisal is to provide a plan to manage and implement needed repairs to the structure. Such a plan must be based on the technical information and data collected during the condition survey. For most owners, the management plan should address the following six key questions also listed in Section 19.2.

- Do I have a problem?
- How bad is my problem?
- How can I fix it?
- What will it cost?
- How do I fund the project?
- Can I survive the construction?

A sample report format is included in Appendix 19-1, Figure A-9, "Guide Format for Walker Condition Appraisal Reports". The format is structured to focus on the owner's concerns and development of a management plan to implement the repairs, as opposed to the traditional technical reports that are focused more on presenting the technical facts and data. All the technical details necessary to support the plan are included as appendices to the report. This report format is easy to follow and addresses the non-technical as well as the technical readers.

APPENDIX 19-1

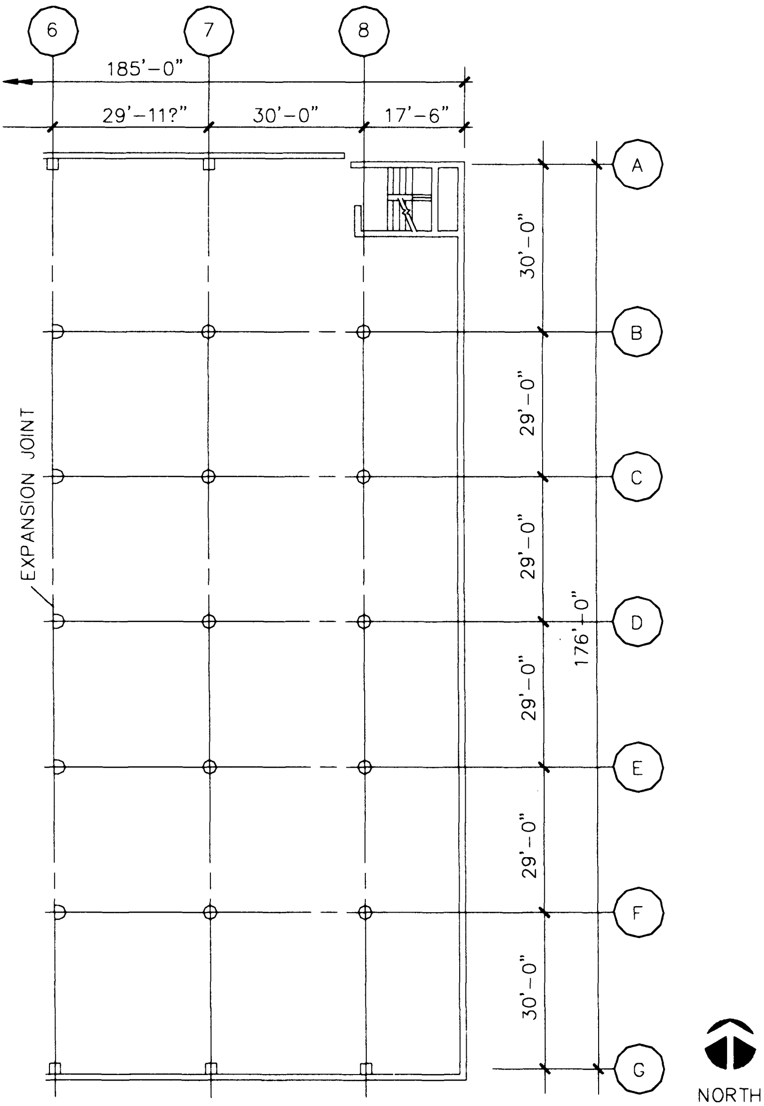


Figure A-1: Field survey blank sheet to record data.

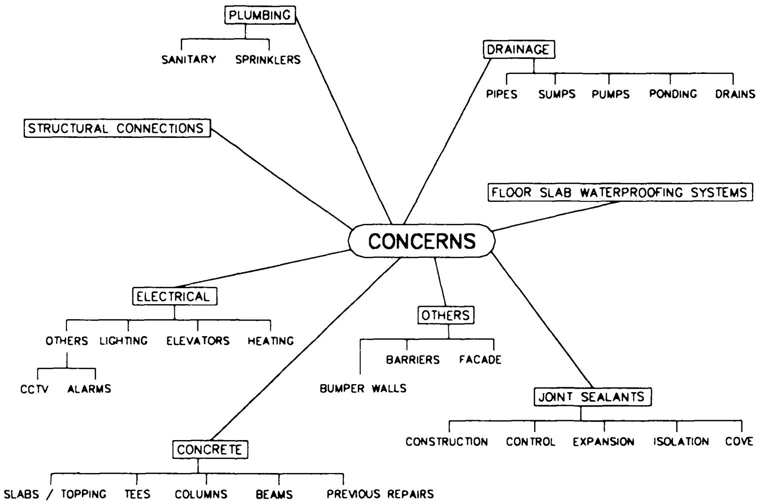


Figure A-2: Field survey structural and operational elements.

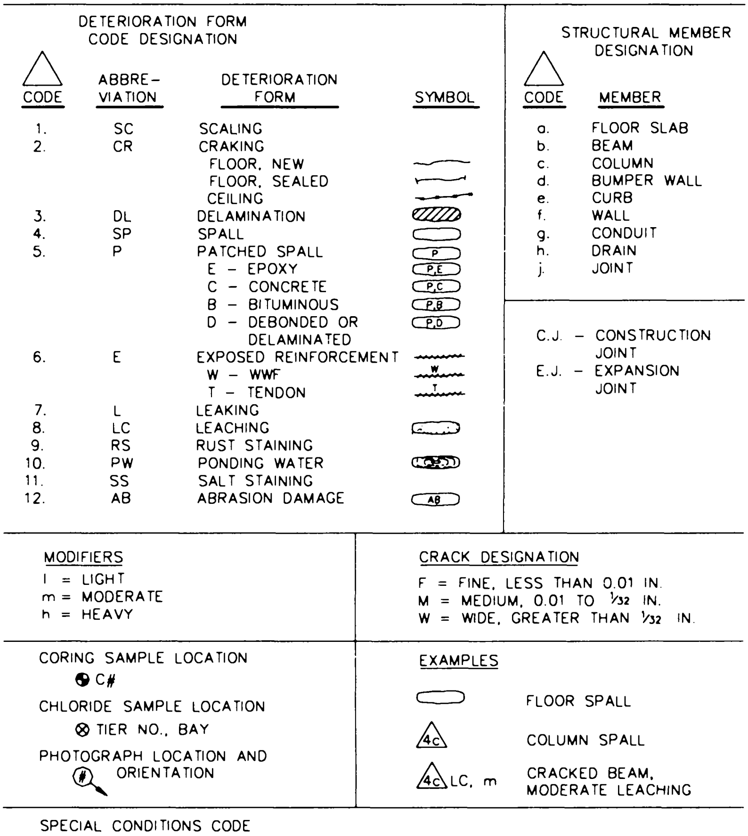


Figure A-3: Field survey legend.

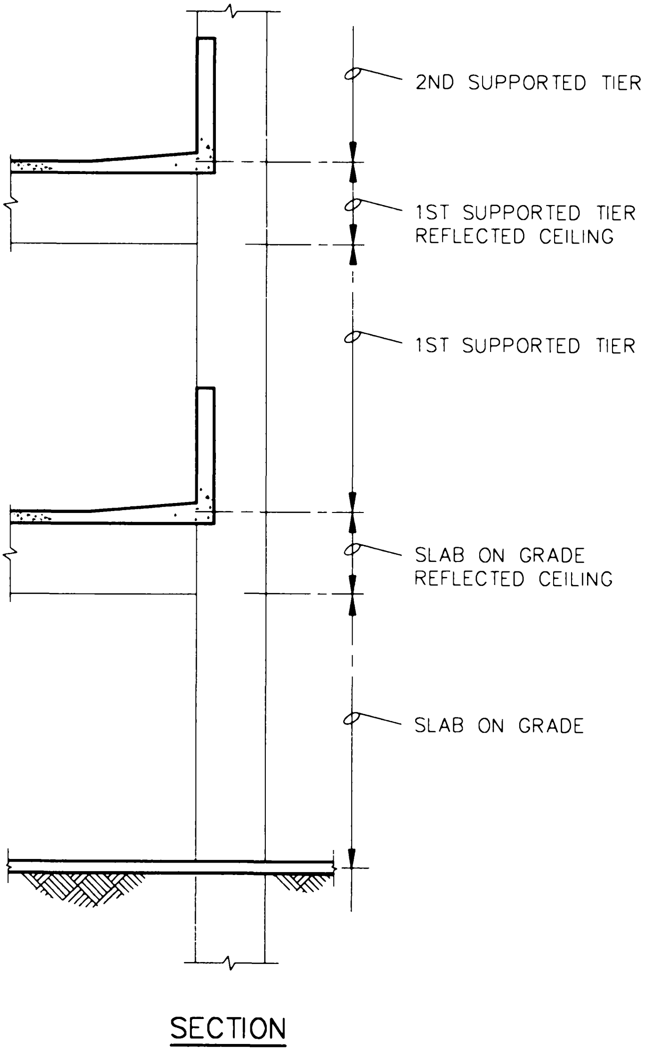


Figure A-4: Setting appropriate reference for noting floor slab and ceiling data on field sheets.

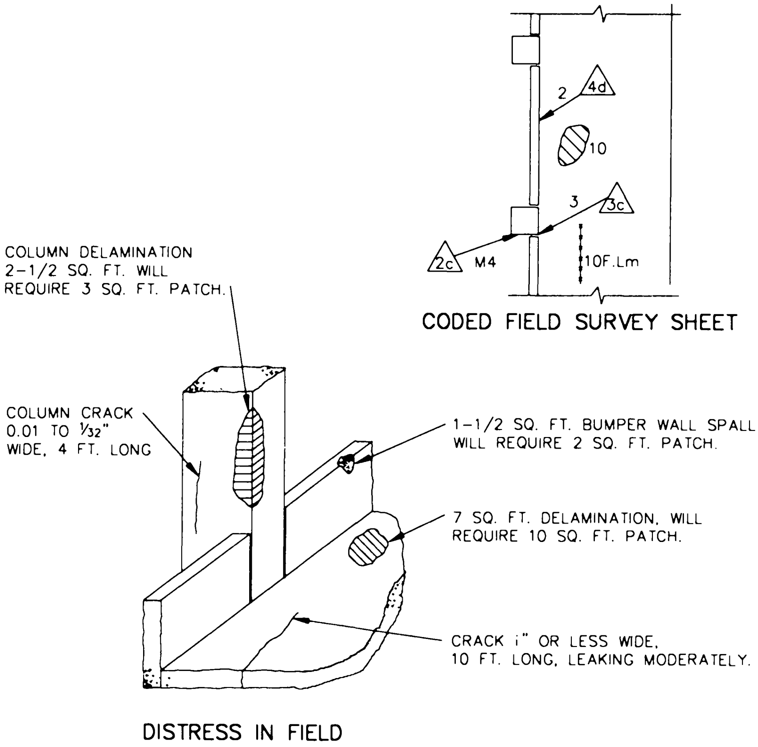


Figure A-5: Use of field survey legend to record data systematically.

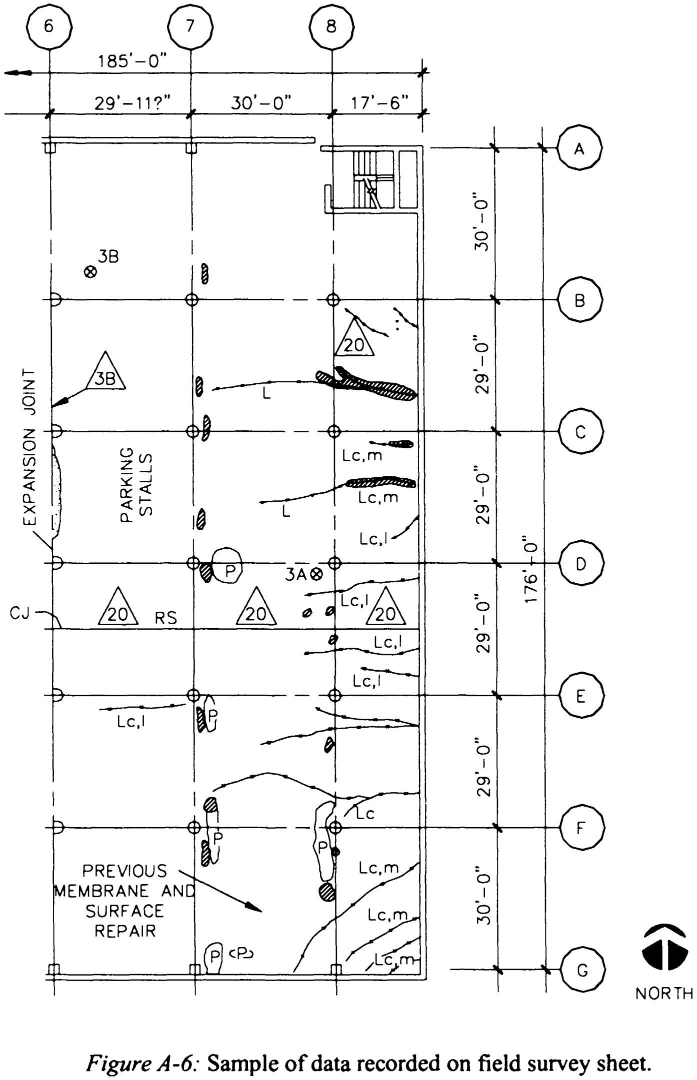


Figure A-6: Sample of data recorded on field survey sheet.

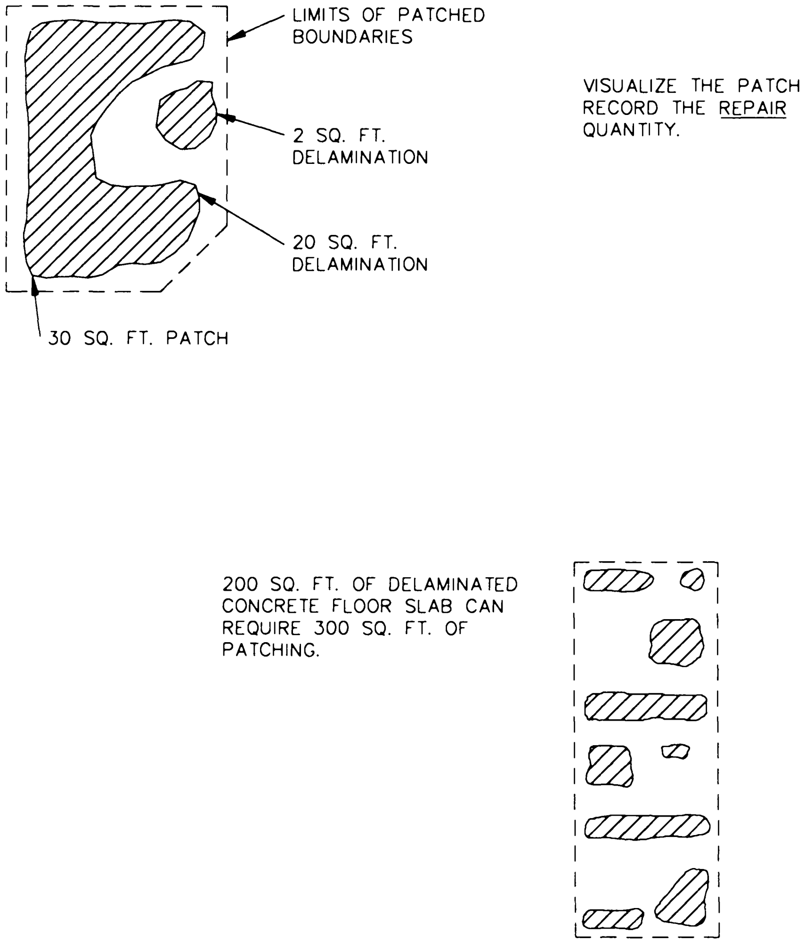
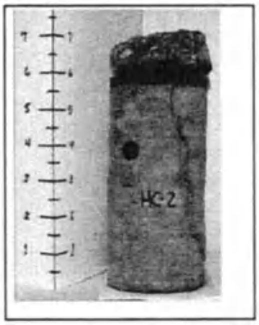


Figure A-7: Procedure for estimating and recording concrete deterioration.

VISUAL CORE DATA/DESCRIPTION

WALKER
PARKING CONSULTANTS

Project Name:			
Project #:			
Reported by:			
Date:			
Core ID#:			
Core Location:			
Diameter (inches)			
Length (inches)			
Max. Size Aggregate:			
Page		of	



Consolidation: ______________________

Segregation: ______________________

Gradation: ______________________

Entrapped Air: ______________________

Cracking (Extent/Depth, etc.): ______________________

Depth of Steel: ______________________

Size of Steel: ______________________

Condition of Steel: ______________________

Presence of Patch Material?: ______________________

General Comments (overlays, membranes, T.T., debonding, etc.): ______________________

____

____

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____

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Figure A-8: Core log.

GUIDE FORMAT FOR WALKER CONDITION APPRAISAL REPORTS

WALKER
PARKING CONSULTANTS

REVISED OCTOBER 7, 1999

GUIDE FORMAT FOR CONTENT - TABLE OF CONTENTS

EXECUTIVE SUMMARY

INTRODUCTION
- Objective
- Facility (Structure) Description
- Background Information

RECOMMENDATIONS
- Immediate Repairs
- Recommended Base Repair
- Preventive Maintenance
- Enhancement Options
- Cost Estimate
- Implementation

SUMMARY DISCUSSION
- Recommendations/Conclusion/Analysis
- Observations
- Repair Alternatives
- Testing
- Routine Maintenance
- Limitations

APPENDICES

A. Definitions and Terminology
   - Deterioration Terminology
   - Summary of Repair Methods
   - Glossary of Terms

B. Photographs
C. Visual Observations
D. Estimate of Probable Construction Cost
E. Repair Alternatives
F. Testing
G. Typical Floor Plan Drawings
H. Scope of Services
I. References
J. Routine Maintenance

Figure A-9: Sample Report Format

Chapter 20

REPAIR - IMPLEMENTATION

Sam Bhuyan

20.1 INTRODUCTION

A comprehensive investigation is necessary to implement appropriate repairs that will effectively restore a parking structure. The primary purpose of the investigation is to determine the cause(s) for the accelerated or premature deterioration of the structure. The process requires documenting the symptoms of concrete deterioration, obtaining material samples for laboratory testing and evaluation of the field and laboratory data. In addition to determining the primary cause(s) of the deterioration, the investigation also helps to recognize adverse conditions that can impact the service life of the restored structure. Repair investigation is covered in Chapter 19.

Repair implementation essentially consists of utilizing the finding of the investigation to select appropriate repair schemes, repair materials and methods. Preparation of contract documents and providing resident services during construction are also essential for proper implementation. Refer to Chapter 19, Section 19.2, which refers to the systematic approach to restoring parking structures.

20.2 REPAIR METHODS

20.2.1 General

There is a significant amount of literature on concrete repair methods and materials that has been published during the past several years. Many committees of the ACI have now published reports that directly or indirectly relate to the repair and restoration of concrete structures. The results of research and the application of repair methods and materials have been

A. P. Chrest et al., *Parking Structures*

reported in publications presented by the Federal Highway Administration research programs, the Portland Cement Association, the Corps of Engineers, and in articles presented in various trade journals. Therefore, this section of the chapter will only attempt to summarize the basic requirements for durable repair techniques that are more commonly used to restore a parking structure. Other less frequently used techniques have not been included. However, do not be limited by the basic material presented here, and where necessary, attempt to incorporate special repair techniques that are appropriate for your situation. Refer to ACI 546R, "Concrete Repair Guide," for a more complete review of repair materials and methods, including strengthening of structures.

The restoration of parking facilities requires the use of several repair methods to address existing deterioration of structural members and provide effective protection to extend the service life of the restored structure. Table 20-1 summarizes the repair objectives and the methods commonly utilized to repair various structural elements. The horizontal floor-slabs generally experience the most deterioration and usually require implementing a combination of repair methods to develop an approach that will effectively restore the structure. For instance, the approach might consist of a combination of repair methods that includes patching to restore floor-slab integrity and membrane protection to effectively waterproof and minimize future corrosion induced concrete deterioration.

Table 20-1. Repair Objectives and Methods

Repair Objective	Repair Method	Primary Applications
Restore integrity	Patching	
	a. Partial-depth	Floor-slab, beam, column, wall, etc.
	b. Full-depth	Floor-slab
	Replacement	Floor-slab, beam, columns
Provide protection		
Abrasion	Coating	Floor-slab
Freeze-Thaw	Replacement	Floor-slab
	a. Partial-depth	
	b. Full-depth	
	Coating	Floor-slab
Corrosion	Cathodic protection	Floor-slab
	Replacement	Floor-slab
	Coating	Floor-slab, beam, columns, wall
Waterproofing	Sealing	Floor-slab, joints, cracks

Some of the currently available built-in and externally applied corrosion protection systems are discussed in Chapter 15. Figure 20-1 summarizes the various corrosion protection systems currently available to extend the service life of parking structures. In this figure, the external systems that are applied directly onto the wearing surface are included in the zone designated

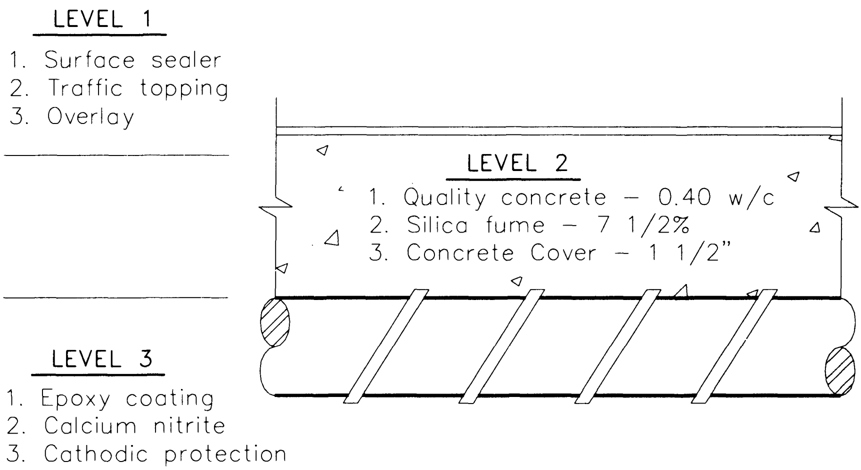


Figure 20-1: Corrosion protection of embedded reinforcement.

as Level 1. The built-in systems are included in the zones designated as Level 2 and Level 3. When repairing existing parking facilities, the depth of concrete removal will usually dictate the corrosion protection that can be implemented to protect a restored structure. For instance, regular maintenance actions generally do not require extensive concrete removals. Therefore, such maintenance actions will be limited to application of surface applied Level 1 systems. On the other hand, full-depth removal and replacement of floor-slabs provide an opportunity to implement corrosion protection systems included in zones at Level 2 and Level 3. Therefore, the service life of a reconstructed slab will be considerably more in comparison to the life expectancy of a slab that is simply patched and sealed by a surface-applied corrosion protection system. The type or the combination of corrosion protection systems selected will impact the life expectancy of the repairs that are implemented. Refer to Section 20.4, which includes further discussion on development and selection of repair alternatives to restore floor-slabs.

20.2.2 Basic Requirements for Concrete Repairs

A repair is generally successful if the repair material is compatible with the original substrate and has the required strength and durability. Other considerations are appearance and economy. The four basic requirements for a satisfactory concrete repair are:

- Concrete removal and surface preparation
- Application of bonding medium
- Proper selection of repair material
- Proper material application

20.2.2.1 Concrete Removal.

For all concrete repair situations, regardless of the type of structural member, a basic requirement is to remove all the deteriorated, delaminated, and unsound concrete prior to placing any new patch material. When complete removal of the deteriorated concrete is not accomplished, there is a good probability of patch failures.

Concrete removal in parking structures is more commonly performed by light (15 lbs. maximum) chipping hammers. See Figure 20-2. These light chipping hammers are very convenient for concrete removal around and below the existing reinforcement. The size of the chipping hammer is limited to minimize damage to the surrounding area. Under certain circumstances, such as a relatively thick (8-12 inch) slab, the use of heavier hammers can be permitted by preapproved operators only. Other factors which can influence the selection of hammer size are overall thickness of the member, relative depth of removal to the overall member-thickness (partial or full-depth) removals, orientation of members (vertical or horizontal), and location (vertical or confined area) of removal. Special care should be applied in removing unsound concrete from around reinforcing steel and embedded anchorages to prevent a loss of bond in the remaining sound concrete.

Removal of relatively thin layers of concrete over large areas, such as shallow concrete removal from the surface in preparation for placement of an overlay, may be more effectively done with a scabbler, scarifier or planer, than with chipping hammers. See Figure 20-3 (a). These machines are particularly effective in cleaning the surface by removing the top surface contamination of traffic oils and greases. In addition, high-pressure sand and water blasters are capable of removing deteriorated concrete and many surface contaminants. Scarification of concrete surfaces using an abraded metal-shot-rebound method has also been used in the preparation of surfaces for installing a membrane or overlay. Some other methods utilized for very extensive full-depth slab removals include saw cutting and large, mechanically operated breakers. See Figure 20-3 (b) and (c).

Figure 20-2: Concrete removal by chipping hammer.

Figure 20-3: (a): Scarifier with cutter bits

(b)

(c)

Figure 20-3: (b) Full-depth of slab removal by saw cutting *(c)* Full-depth slab removal using a mounted breaker.

The reader is referred to the Corps of Engineers Manual, EM 1110-2-2002 and the National Cooperative Highway Research Program Report #99 for a more detailed treatment of concrete removal techniques and advantages and disadvantages of the various removal methods.

20.2.2.2 Surface Preparation.

Another important step in the repair of concrete structures is the preparation of the surface to be repaired. The repair is only as good as the surface preparation, regardless of the repair method or materials selected. For reinforced concrete structures, repairs must include proper preparation of the reinforcing steel in order to develop a bond with the replacement concrete.

Removal of concrete using impact-type devices, such as scabblers, bush hammers, and hammers may cause "bruising" of the concrete surface remaining in place. Be particularly careful of bruising of lightweight concrete surfaces during concrete removals. See Figure 20-4. The bruising can contribute to the debonding of the patch overlay material. Also, cleaning the surface by sand blasting or high-pressure water is required as a final step to remove any damaged surface material that can potentially contribute to the debonding of the repaired section. Hydrodemolition and abrading methods generally tend to leave a surface that is less likely to be bruised or damaged.

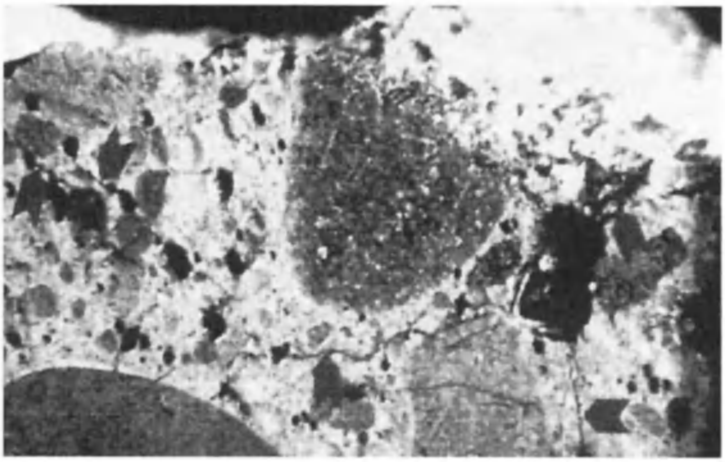


Figure 20-4: Bruised or damaged substrate with micro-cracking caused by concrete removal. From: Article entitled "Surface Preparation for Overlays," by James Warner, Sam Bhuyan, W. Glenn Smoak, Kai R. Hindo and Michael M. Sprinkel, Concrete International Journal, American Concrete Institute, May 1998.

A repair specification should include specific requirements for locating and marking work areas on a structure, inspection of the surface and reinforcement after concrete removal, replacement of deteriorated or damaged reinforcement, placement of supplemental reinforcement, cleaning of reinforcement, and preparation of surface for patch/overlay placement.

20.2.2.3 Bonding Medium.

Bonding of the new patch or overlay to the concrete substrate is essential for a durable repair. An adequate bond between the patch or overlay material is required to resist stresses due to differential volume change between the patching material and the substrate. The failure can occur either at the bond interface or adjacent to the interface within the section of the lower strength material.

Once debonding is initiated, the effects of freeze-thaw cycling and dynamic impact of vehicle wheel loads can contribute to the progressive deterioration of the repaired area. Debonded areas are generally prone to cracking. The cracking is usually through the entire thickness of the patch or overlay material, which can permit water leakage to the interface and the underlying substrate. See Figure 19-51(a).

As indicated in the National Cooperative Highway Research Report #99, various bonding media have been studied, including sand-cement and water-cement grouts, neat cement, epoxies, and latex. From these studies and field experiences, the sand-cement and water-cement grout are considered to be the most practical and commonly used bonding mediums. The sand-cement bonding grout consists of one part cement to one part sand by volume, and sufficient water to achieve the consistency of "pancake batter". Limit the water-to-cement ratio of the grout to be at least the same as or better than the concrete repair material. The grout should be applied at a uniform thickness of 1/16 inch and should not exceed 1/8 inch. See Figure 20-5. The grout should be applied to a damp, but not saturated concrete surface. The surface is dampened to assist in preventing rapid drying of the grout. The bond mechanism consists of the grout penetrating the surface pores of the existing substrate. When the substrate is saturated, the pores are filled with water, which can adversely affect the penetration of the bonding grout into the pores of the substrate.

20.2.2.4 Repair Materials.

The selection of the repair material is covered in Section 20.3.

20.2.2.5 Material Application.

Concrete repair materials must be properly placed, consolidated, and cured. Follow the appropriate placement and curing procedures of repair materials specified in ACI Recommended Practices or in accordance with each manufacturer's instructions. A repair specification should include specific requirements for concrete placement, consolidation, and curing for patches and overlay. The most common application and placement methods include the following:

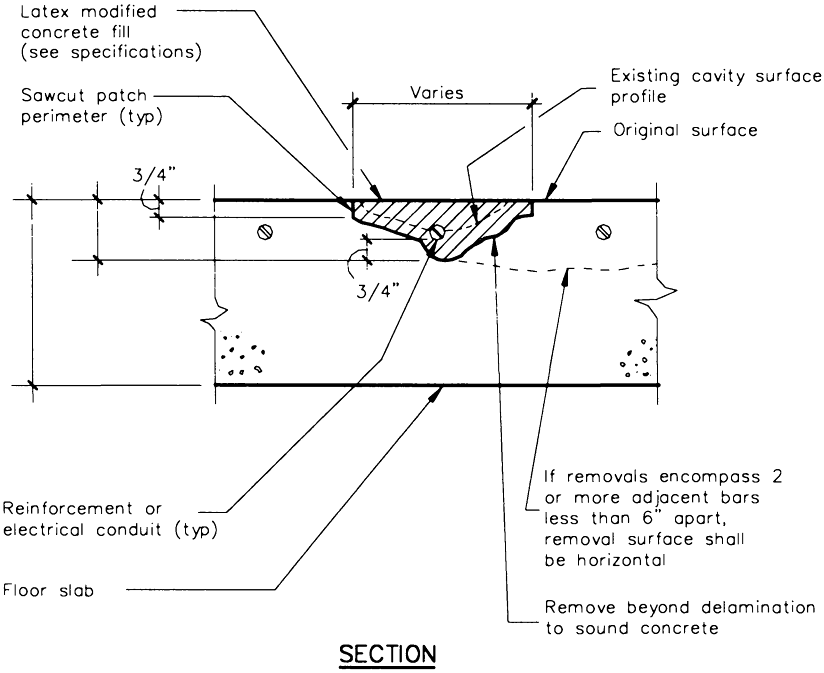
- Cast-in-place concrete for patches, overlays and floor-slab replacements.
- Shotcrete repairs for overhead and vertical patches.
- Formed and pumped concrete or mortar for deep repairs to slab, beam and columns sections.
- Trowel applied mortars for shallow overhead and vertical patches.

Figure 20-5: Application of bonding grout prior to overlay placement.

20.2.3 Patching

Patching replaces deteriorated concrete on the surface of horizontal and vertical members. When properly implemented, patching will restore structural integrity, as well as improve serviceability or correct cosmetic damage. However, in some instances, this may not be the correct repair approach. Evaluation of appropriate repair approaches is discussed in Section 20.4.

Patching can be referred to as "partial-depth" or "full-depth" based on the extent of concrete removed. Quite often, for thin slab sections (less than 5 inches thick) it is difficult to perform shallow concrete removals and usually results in full-depth concrete removal. As a general rule of thumb, a full-



Notes:

1. Remove and replace all sound and unsound concrete within section shown cross-hatched.
2. Deep removal shall consist of concrete removals that extend beyond two layers of reinforcement.
3. Pay unit = s.f.
4. Detail not to scale.

Figure 20-6: Shallow patch detail.

depth patch is specified when concrete removal equals or exceeds half the slab's thickness.

As shown in Figures 20-6 through 20-9, patching consists of removing the unsound concrete, cleaning the reinforcing steel exposed by removals, preparing the exposed surface, and installing a specialty concrete patching material. Patch edges for partial-depth removals are often chipped or saw-cut to near vertical to a depth of at least 3/4-inch, as opposed to leaving a "feather-edge".

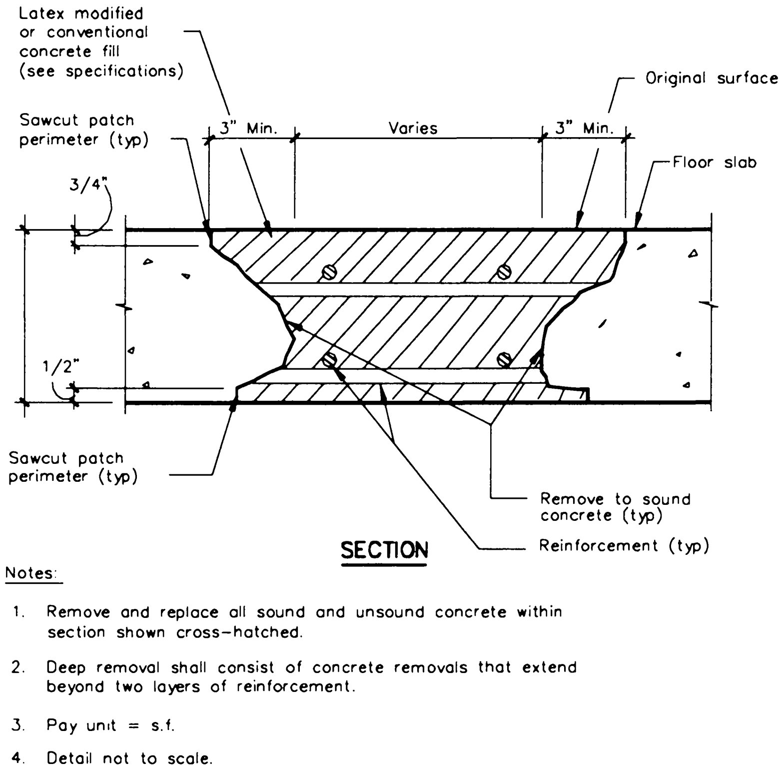
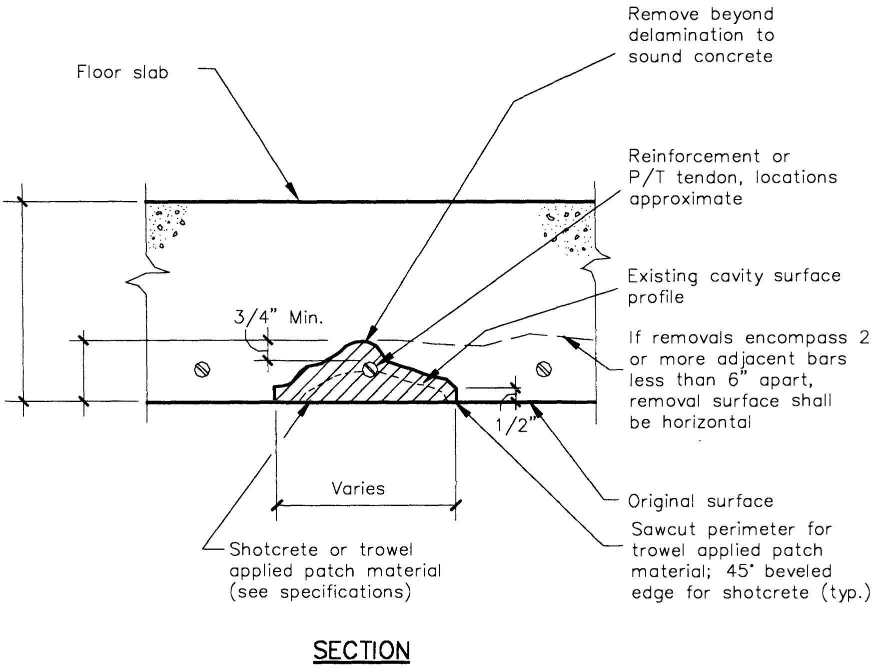


Figure 20-7: Full-depth patch detail.

Although patches of high-quality (low permeability) material are installed, the adjacent surface tends to have lower durability. In chloride-contaminated slabs, the durability of this repair system is adversely affected by delamination and spalling of floor-slab areas due to continuing corrosion of reinforcement beyond the patch limits. Patching can, however, rapidly restore the structural integrity of the member and limit further damage to embedded reinforcement. The emphasis is on repairs that address only existing damage.



Notes:

1. Remove and replace all sound and unsound concrete within section shown cross–hatched.
2. Deep removal shall consist of concrete removals that extend beyond two layers of reinforcement.
3. Pay unit = s.f.
4. Detail not to scale.

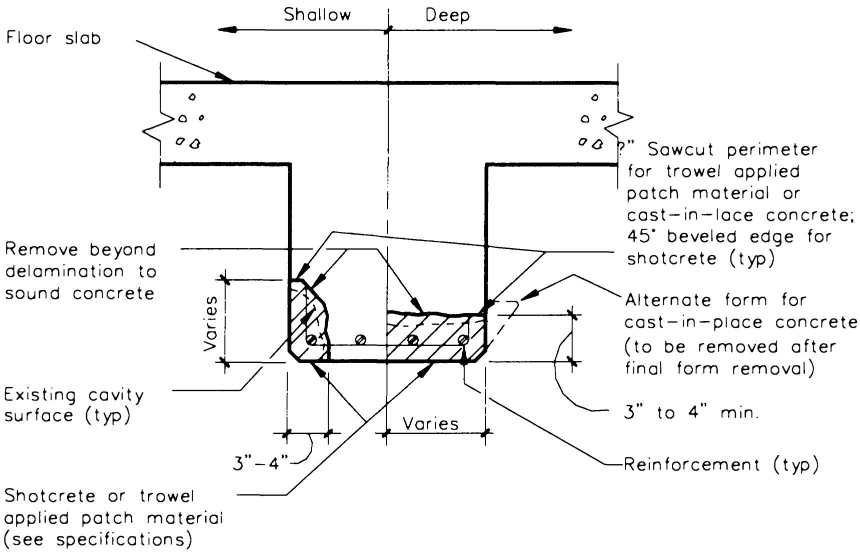
Figure 20-8: Overhead patching detail.

20.2.4 Coating

Coating consists of applying surface sealers, elastomeric traffic-bearing membrane systems, rigid concrete, or specialty concrete overlays. Refer to Chapter 15 for a description of these coatings. Although a sealer can be applied to vertical and overhead surfaces, membranes and overlays are usually applied on horizontal floor-slabs. Some of the characteristics of protective coatings are discussed here, relative to their use in repair of parking structures.

20.2.4.1 Sealer.

A repaired slab surface is usually protected by application of a concrete sealer to reduce moisture and chloride ion penetration. The original



SECTION

Notes:

1. Remove and replace all soun and unsound concrete within section shown cross-hatched. Remove minimum ?" behind all reinforcement.
2. Forms (if used) shall remain in place until concrete has attained 3000 psi minimum compressive strength.
3. The final coat of shotcrete (if used) shall be troweled to original dimensions and configuration.
4. Cast-in-place concrete may be used for deep repairs at contractors option.
5. Pay unit = s.f. (face of beam for shallow)
   (bottom of beam for deep)
6. Detail not to scale.

Figure 20-9: Shallow and deep beam patching detail.

concrete surface requires cleaning by special means, such as high-pressure water, sand or shotblasting to remove all old coatings or sealer, and/or surface laitance. Regular reapplication of the sealer every 3-5 years is to be anticipated depending on the severity of exposure conditions and sealer selection. A sealer is ineffective when applied to a cracked concrete surface, primarily due to its inability to bridge cracks. Sealers are also relatively ineffective when applied to surfaces of poorly air-entrained concrete or concrete that is chloride contaminated. Sealers are usually most effective when applied to a relatively new structure, primarily as a preventive measure for corrosion-induced deterioration. However, a sealer will eventually permit chloride ions to penetrate to the level of the embedded reinforcement. Regular sealer application only helps to extend the "time-to-corrosion", but is not capable by itself of preventing corrosion-induced deterioration and ensuring long-term durability. A chloride monitoring program is required to evaluate the effectiveness and time for reapplication of sealers. Refer to Section 18.2 and Appendix 18-1 for chloride ion monitoring.

20.2.4.2 Waterproofing Membranes (Traffic Topping).

A traffic topping is an elastomeric waterproofing membrane with a coating on the top that contains aggregate to resist traffic wear and abrasion. The membrane and top coat is applied on the surface as a liquid and squeegeed onto the surface. It is built-up in several layers and the composite is approximately 70 mils thick. A traffic-bearing membrane waterproofs the slab and reduces chloride ion penetration more effectively than a sealer. See Figure 20-10 (a) and (b). It also reduces the oxygen supply and moisture that supports corrosion and assists in extending the service life of slabs. A membrane can effectively bridge active cracks and is suitable for floor systems with extensive through-slab cracking.

Where membranes have been applied to existing decks, surveys indicate the continuation of corrosion activity if all chloride-contaminated concrete is removed. The long-term effect of membranes on continuing corrosion of embedded reinforcement is not well established. The performance of these systems on chloride-contaminated decks is highly variable due to membrane effectiveness, existing deck conditions, and the extent of removal of contaminated concrete. Some future concrete spalling beneath the membrane is to be expected due to corrosion-induced concrete spalling.

In heavy traffic areas, such as drive aisles, frequent maintenance will be required to extend the life of the membrane system. Use of a "wear-balanced" membrane system consisting of different grades of the membranes will reduce maintenance frequency. Membranes are also susceptible to snowplow damage, but plows can be raised or tipped with rubber guards and follow manufacturer-provided guidelines for snow removal to reduce damage.

20.2.4.3 Bonded-Concrete Overlay.

A bonded-concrete overlay provides a more durable repair of deteriorated concrete floors. A bonded-concrete overlay requires the removal and preparation of all deteriorated exposed surfaces prior to system installation. The surface is scarified to remove all contaminants, such as oil spots, from the surface. Exposed reinforcing is either cleaned or removed and replaced with one that is epoxy coated. After surface preparations are complete, a bonded overlay is installed to restore slab integrity while providing a new wearing surface. Figure 20-11 (a) and (b).

(a)

(b)

Figure 20-10: (a) Failed traffic bearing waterproofing membrane. *(b)* Floor-slab coated with traffic bearing waterproofing membrane.

With overlays, the new surface profile can be adjusted for improved drainage and reduced ponding. Concrete overlays are not appropriate for floor-slabs with active cracking. Reflective cracking in an overlay is likely to reduce the service life of restored slabs. Where applicable, the additional superimposed load due to the overlay must be evaluated.

The overlay is a coating that can be designed to protect the underlying substrate effectively. In addition, overlays can also be used in partial-depth slab replacement.

The reader should refer to the National Cooperative Highway Research Program Report #57 for further details regarding surface preparation, placement, and curing of concrete overlays. A more detailed discussion on advantages and disadvantages of overlays is also provided in the report.

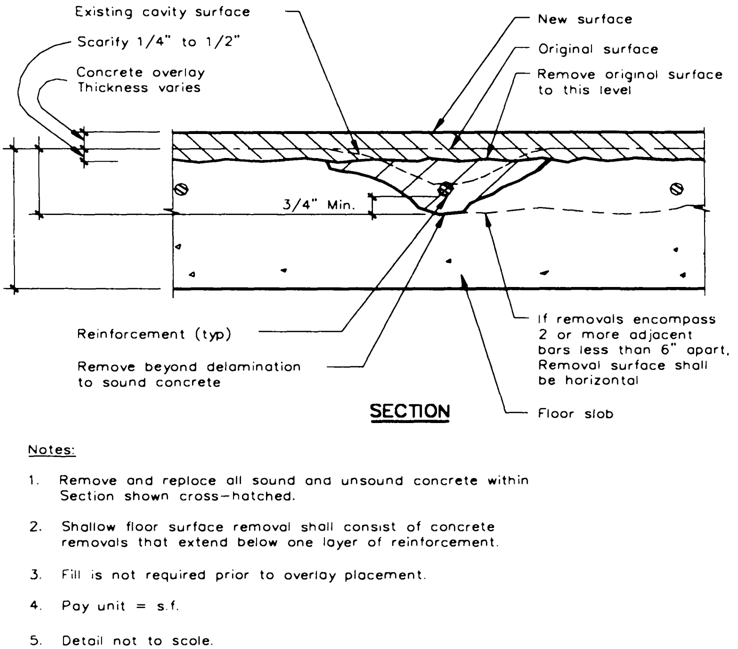


Figure 20-11: (a) Concrete overlay detail

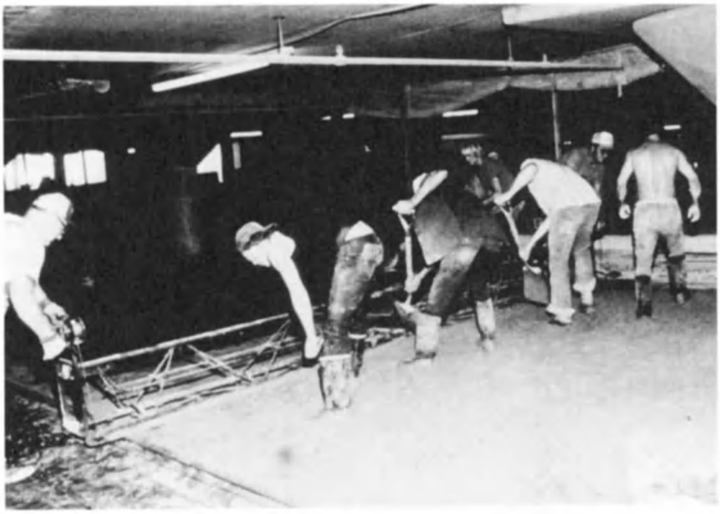


Figure 20-11: (b) Concrete overlay placement with vibratory screed.

Figure 20-12: Full-depth slab removal (pan-joist system).

20.2.5 Replacement

When a floor slab is extensively deteriorated, removal and replacement of the slab may be a viable repair alternative, provided the underlying members are in relatively good condition. This is referred to as "partial-depth" replacement. Floor-slabs which are less than 5 inches thick are difficult to repair. Concrete removals on pan-joist, waffle-slab, and one-way slab systems usually result in complete removal of the thin slab. See Figure 20-12. The existing underlying beams and waffle or pan-joist ribs are used to support the new slab, provided adequate measures are taken to ensure composite behavior of the rebuilt floor system. The new slab can be reconstructed with durable concrete and epoxy-coated reinforcement and other internally-built corrosion protection systems to extend the service life of the facility. However, the new slab is susceptible to cracking due to volume-change restraint offered by the existing underlying members. In extreme cases, "full-depth" replacement of the floor system (slab and underlying elements) may be necessary. See Figure 20-13.

20.2.6 Cathodic Protection

In concept, the only method which will effectively stop the corrosion of embedded reinforcement in chloride contaminated slabs is cathodic protection. Cathodic protection works by putting energy in the form of electrical current into the concrete to be protected. The introduced energy prevents corrosion in the steel reinforcement. Corrosion of metal is, put simply, a loss of energy from that metal. Feeding in more energy prevents that corrosion. Cathodic protection is the only protective measure which prevents corrosion from starting. If corrosion has already started before cathodic protection is introduced, it is the only protective measure which will stop corrosion. All other measures described in this chapter are but delaying actions, though some are very effective; they will slow corrosion, but not stop it. See Figure 20-14 for a schematic diagram of a cathodic protection system.

Industry experience in the application of cathodic protection to parking structure floor systems is limited. However, there are several reported applications of cathodic protection to parking structures. Field applications of cathodic protection systems in bridge decks have been in operation since 1974.

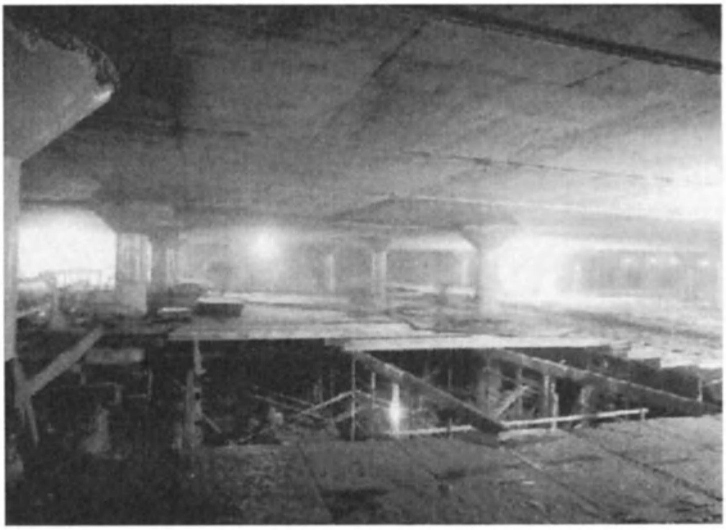


Figure 20-13: Full-depth slab removal (flat slab).

Application of cathodic protection can only mitigate corrosion; repairs to restore structural integrity and serviceability must still be performed. Therefore, a cathodic protection system is more cost-effective when it is applied to structures with limited concrete deterioration, such as floor-slabs in the initial stages of deterioration. Refer to Figure 19-15 for description of the four stages of deterioration. Also, a cathodic protection system is not economical when applied to structures with less than 10 years of planned or anticipated life expectancy. Presently, only conventionally reinforced concrete structures have been cathodically protected. Cathodic protection of prestressing steel is still in a developmental stage. The concern is due to evolution of hydrogen ions as a result of application of cathodic protection to concrete structures. Hydrogen ions can potentially contribute to embrittlement of the high strength prestressing steel and abrupt tendon failures. Hydrogen embrittlement is not a concern for conventional mild steel reinforcement.

At present, several types of cathodic protection systems are being marketed. It is difficult to evaluate the life expectancy and effectiveness of the installed systems over an extended period. Presently cathodic protection systems costs range from $3 to $5 per square foot. This cost is in addition to that required for concrete repairs. If the floor-slab is extensively cracked, a protective coating will also be required to prevent deterioration of other underlying members due to water leakage; therefore, the overall initial repair costs for some structures can be very high.

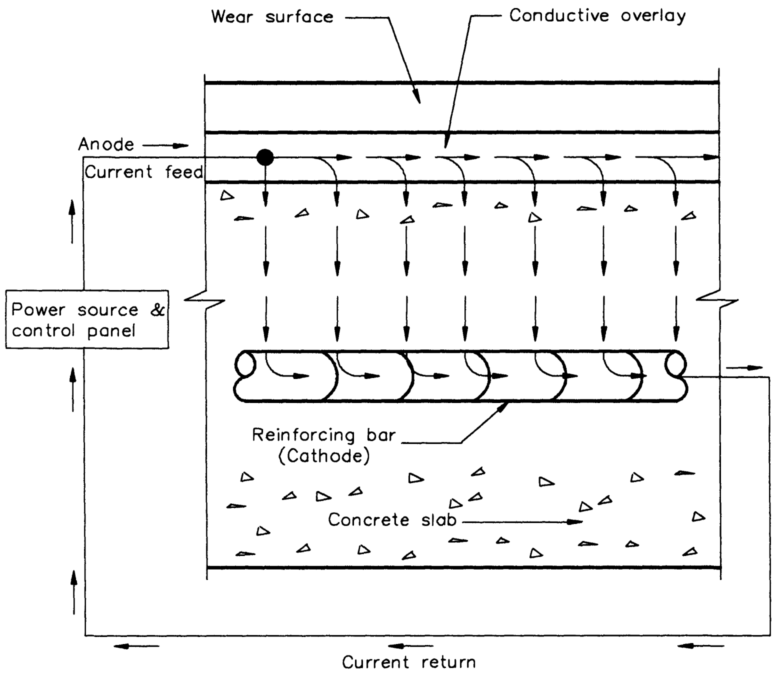
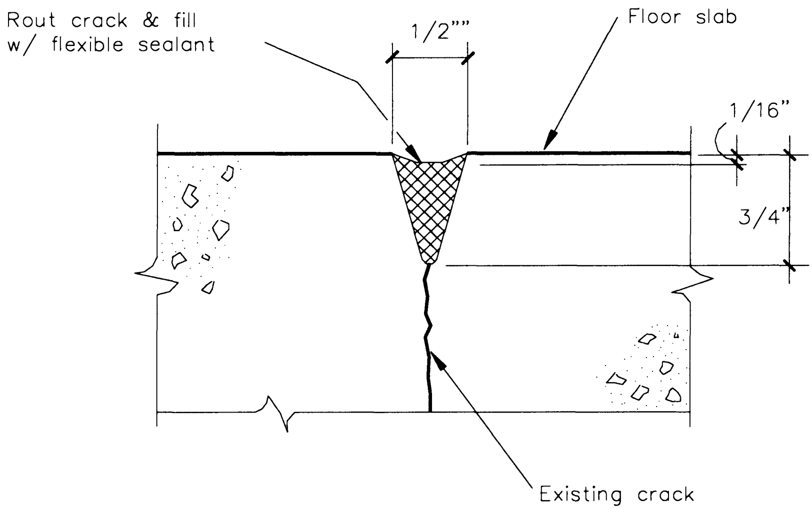


Figure 20-14: Schematic diagram of cathodic protection.

20.2.7 Sealing

Sealing consists of performing repairs that will reduce water leakage through floor-slab cracks and joints. Since sealing by itself cannot be considered a repair method, it must always be performed in conjunction with the other repair methods described earlier. Potential sources of water leakage are: 1) expansion-joints, 2) construction joints, 3) control or isolation joints, and 4) construction- or service-related cracks.
Refer to Sections 19.3.3 and 19.3.4 for a discussion of the distress associated with cracking and failure of joints. Also, refer to Figures 20-15 through 20-17 for typical details related to sealing cracks and joints.
Design, detailing, material, and installation methods for joint seals are also discussed in detail in ACI 224.1R, "Causes, Evaluation and Repair of Cracks in Concrete Structures," and ACI 504R, "Guide to Sealing Joints in Concrete Structures."



SECTION

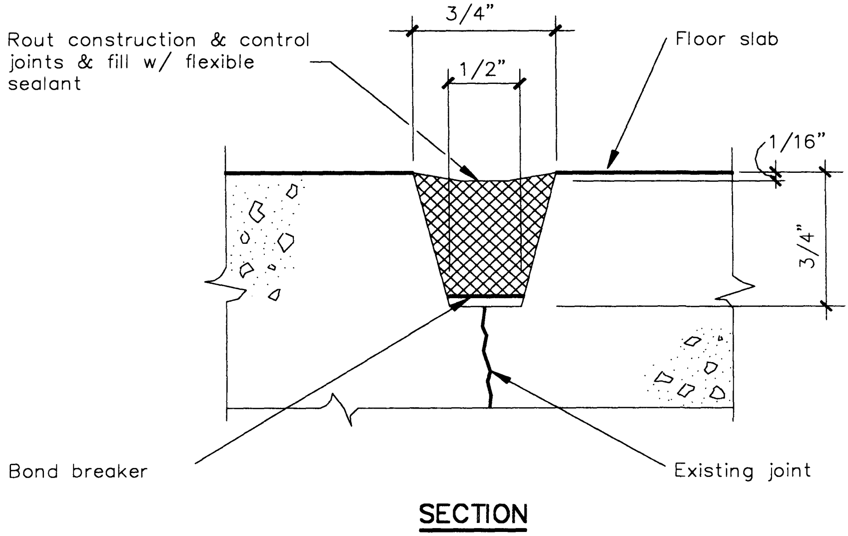
Notes:

1. Center routed groove on crack.
2. Prepare and allow for primer to cure properly prior to installing sealant.
3. See specifications for approved materials.
4. Install sealant evenly and recess 1/16" below surface. Install sealant flush under traffic topping. Do not overfill joint.
5. Pay unit = l.f.
6. Detail not to scale.

Figure 20-15: Detail for sealing control joints and random cracks.

Under certain circumstances, cracks can be repaired by epoxy injection. The material and its application are described in ACI 224.1R. Epoxy injection of service-related (active) cracks usually results in cracking adjacent to previously injected cracks. Active cracks should be treated with a flexible joint sealant material.

Surface or pattern cracks that are inactive can be treated by application of high molecular weight methacrylate (HMWM). The concrete surface is soaked to fill and heal the cracks. These "crack healers" have a viscosity slightly greater than water. Surface cracks can also be treated with a



Notes:

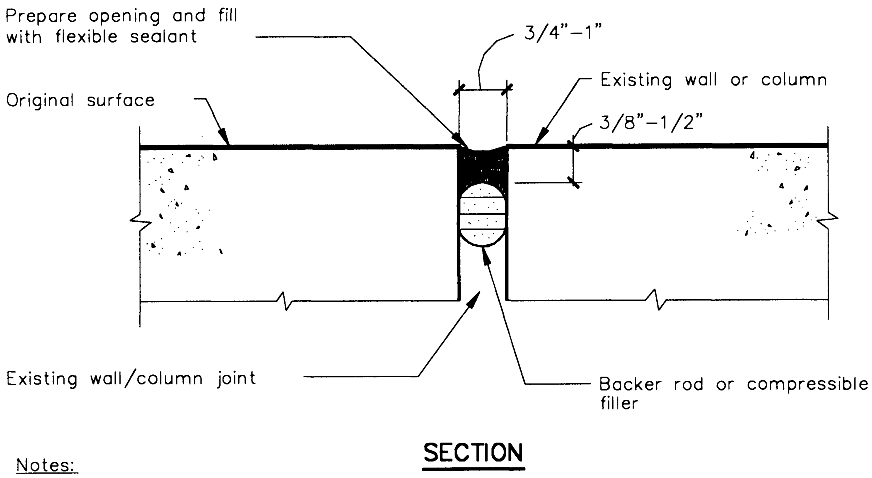
1. Center routed groove on construction/control joints.
2. Prepare and allow for primer to cure properly prior to installing sealant.
3. See specifications for approved materials.
4. Install sealant evenly and recess 1/16" below surface. Install sealant flush under traffic topping. Do not overfill joint.
5. Pay unit = l.f.
6. Detail not to scale.

Figure 20-16: Detail for sealing construction joints.

traffic bearing elastomeric membrane. In addition, these membranes also have the ability to bridge and protect the surface from active cracks. Application of silane sealer is also sometimes effective in keeping moisture out of fine hairline surface cracks that are not active.

20.2.8 Post-tensioned Structures

Recently, an increase has been noted in the number of cast-in-place post-tensioned structures with performance related problems due to tendon corrosion. Most of these structures were built in the late 1960s and early 1970s. The performance problems are discussed in Section 19.3.1.4. Repairing these prestressed structures requires an understanding of the



Notes:

1. Remove existing joint sealant material.
2. Grind joint edges.
3. Install backer rod.
4. Prepare and allow for primer to cure properly prior to installing sealant.
5. See specifications for approved materials.
6. Install sealant evenly and recess 1/16" below surface Do not overfill joint.
7. Pay unit = l.f.
8. Detail not to scale.

Figure 20-17: Detail for sealing isolation joints.

structural system to provide appropriate shoring and bracing during intermediate stages of the construction process. For instance, floor-slab removals (dead load) prior to replacement by a new slab may require schemes to counteract the existing beam post-tensioning forces. Repair of post-tensioned structures should only be attempted by experienced specialists.

Again, most of the post-tensioning repairs are directed at the floor-slab tendons. Occasionally, beam tendon repairs are necessary due to end anchorage corrosion. Currently, there is no reliable method to detect the true extent of tendon problems in slabs and beams. One has to rely solely on visual review and exploratory excavations to get a sense of the extent of the problem. The types of slab tendon repair that may be utilized are as follows:

1. *Partial Tendon Replacement.* Partial tendon replacement is possible when the corrosion of floor-slab tendons is localized and limited to an area such as, the tendon and anchorages, tendon high points or construction joints. See Figures 20-18 (a) through (c), 20-19 (a) and (b), and 20-20 (a) and (b). Corrosion induced damage of the high points may be attributed to shallow concrete cover and/or tendon that is exposed to traffic abrasion at open floor-slab spalls. Tendon corrosion at construction joints is attributed primarily to continued water leakage through the joint. The affected section of the tendon is replaced by a new section attached to the existing tendon by couplers. The actual splice detail will vary depending on the type of prestressing element in the existing tendon, the stressing method, and the manufacturer of the prestressing system. Sample tendon splice and end anchorage repair details are shown in Figures 20-21 through 20-26.

Figure 20-18: (a) Field button heading of wire tendons.

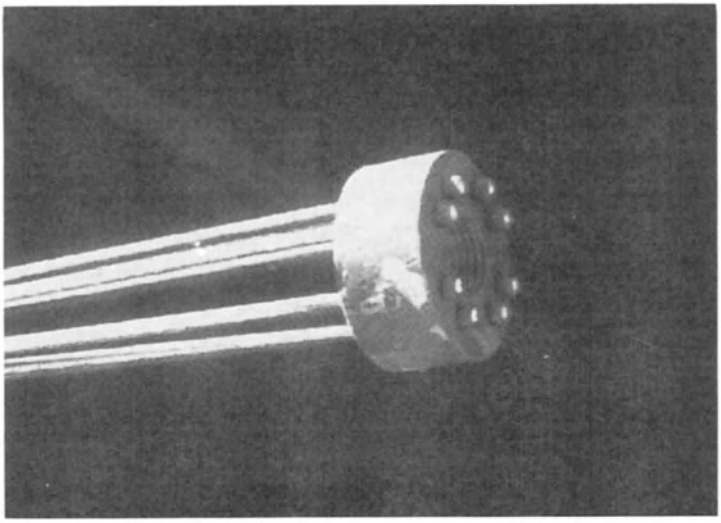


Figure 20-18: (b) Coupler with button head wires.

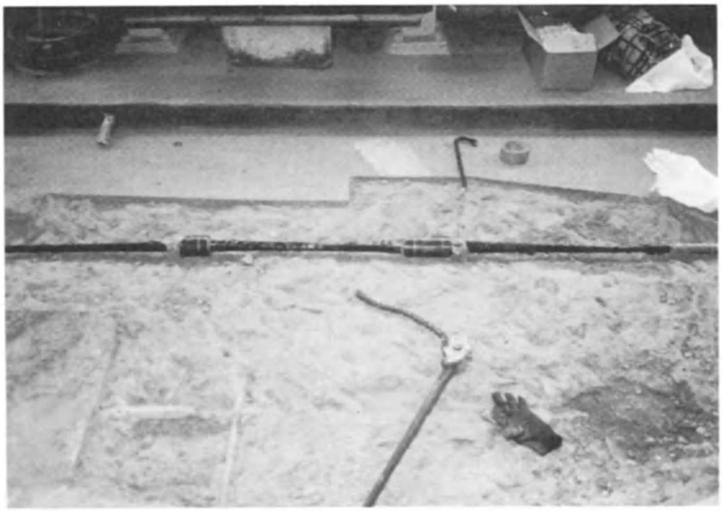


Figure 20-18(c): Partial tendon replacement at tendon profile high point.

Figure 20-19: (a) Partial tendon replacement over beam.

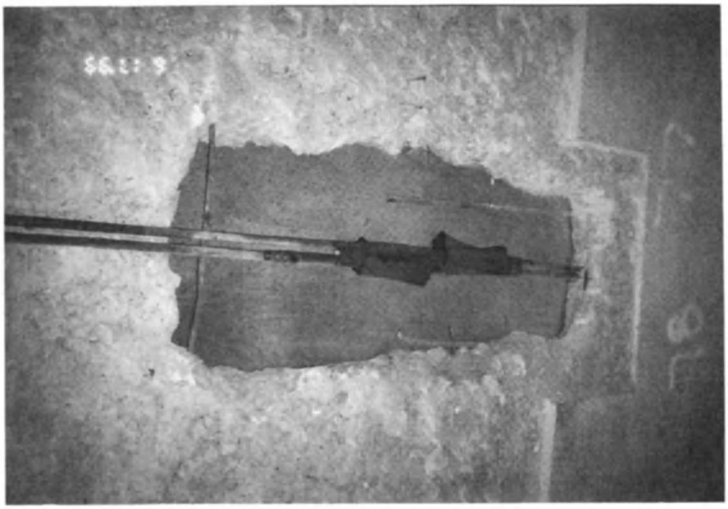


Figure 20-19(b): Tendon splice (strand system).

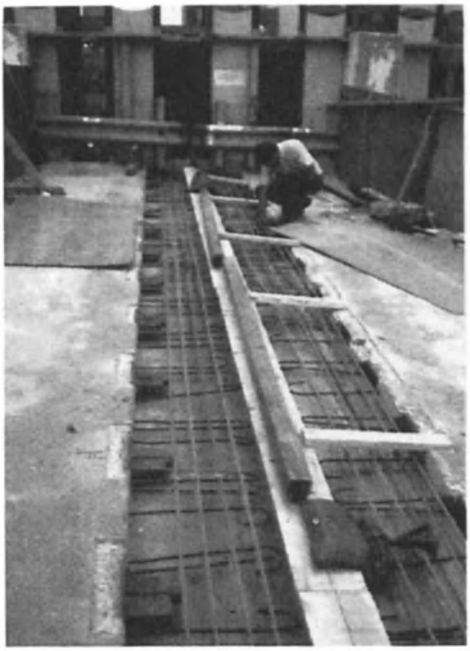
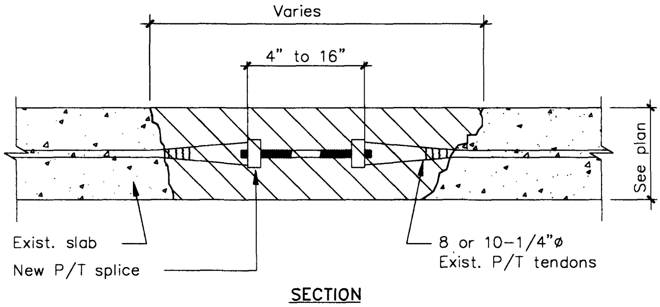


Figure 20-20(a) End anchorage replacement at pour strip (button head system).

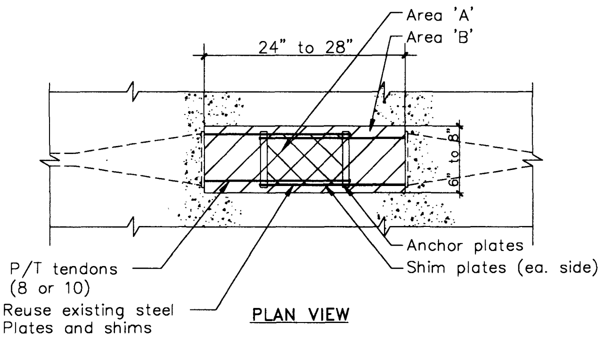
Figure 20-20(b) End anchorage replacement (strand system).



NOTE:

1. See Specification for concrete removal and patch.
2. Detension tendons prior to splice installation.
3. Grease and wrap tendons.
4. Install splice(s) and new tendons if required and retension.
5. Pay units:
   A. New splice(s) = EA.
   B. New tendons = L.F.

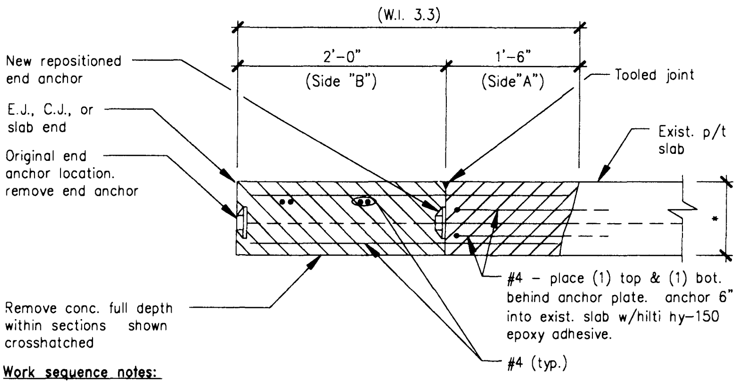
Figure 20-21: Button head tendon splice detail at construction joint.



Notes:

1. Remove all sound and unsound concrete within sections shown cross–hatched. Remove concrete in area 'A' first, taking care not to disturb existing steel shims, place hydraulic jack then remove concrete in area 'b'.
2. Do not sawcut patch perimeter until all P/T tendons have been expossed by chipping for examination by engineer.
3. Detension P/T tendons for associated repairs, then retension tendons per specifications.
4. Sandblast all exposed steel plates, shims and wires and epoxy coat steel plates and shims, grease and wrap tendons.
5. Place patch in accordance with specifications.
6. Pay unit = ea.

Figure 20-22: Center stressing detail.



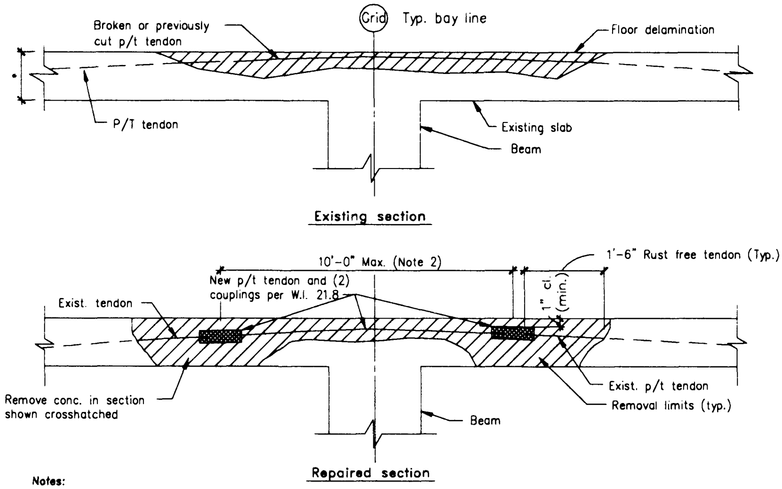
Work sequence notes:

1. Verify tendon fully detensioned
2. Remove concrete full depth per w.i. 3.3.
3. Install & reposition new p/t anchor.
4. Place concrete in side "a". allow adequate conc. strength gain.
5. Stress p/t tendon.
6. Place concrete in side "b".

Notes:

1. Concrete repair work shall be performed and paid for under work item series w.i. 3.0
2. If necessary, pull tendon into side "b" to provide tail for stressing. (make adjustment at tendon splice repair location.)

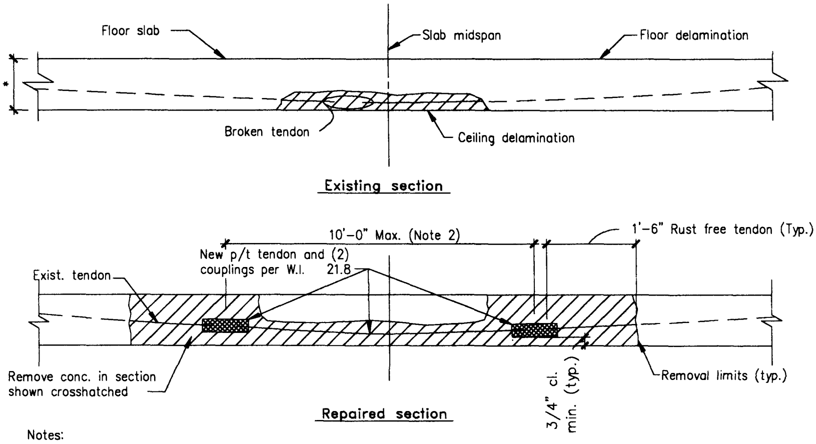
Figure 20-23: End anchorage repair detail.



Notes:

1. If two or more failed tendons per run, stagger the couplers as req'd. for stressing operations.
2. New tendon length beyond 10'-0" shall be paid for under W.I. 21.9.
3. Concrete repair work shall be performed and paid for under work item series 3.0.

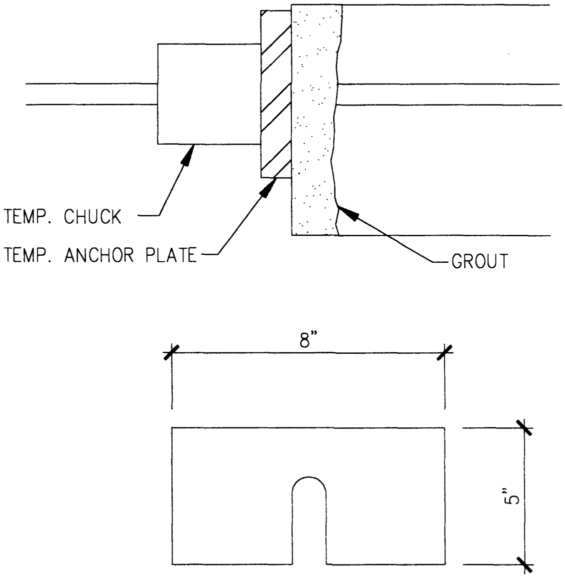
Figure 20-24: Tendon splice detail over beam.



Notes:

1. If two or more failed tendons per run, stagger the couplers as req'd. for stressing operations.
2. New tendon length beyond 10'-0" shall be paid for under W.I. 21.9.
3. Concrete repair work shall be performed and paid for under work item series 3.0.

Figure 20-25: **Tendon splice detail on underside of slab.**



NOTES:

1. THIS WORK TO BE PERFORMED ONLY AS DIRECTED BY ENGINEER IN LIEU OF DE-TENSIONING TENDON.
2. USE 3/4" U-PLATE AGAINST VERT. SMOOTH GROUT SURFACE WITH TEMPORARY OPEN THROAT BARREL CHUCK.

Figure 20-26: **Temporary tendon anchor detail.**

2. *Complete Tendon Replacement.* It becomes cost effective to replace a tendon that has been affected by corrosion at several points along the tendon. The tendon replacement requires threading a new tendon through the existing short trenches cut into the top and bottom surfaces of the slab. These trenches overlap so new 1/2 inch diameter, totally encapsulated tendons can be installed in a parabolic profile, identical to the original design. The trenches are then patched with a latex-modified or low-slump dense concrete, and the tendons are stressed to appropriate levels. Additional top reinforcing steel can be added to the slab in the trenches to update the structure to meet current minimum requirements. This system has been successfully used in several parking structures in the Midwest. The trenching method of repair is considered a long-term repair. See Figure 20-27.
3. *External Tendons.* External tendons are more commonly used in repair and strengthening of beams as opposed to repair of slabs. See Figures 20-28 and 20-29 (a) and (b). The strength capacity of the beam is restored by adding tendons to the outside of the existing beam section. After they are installed and stressed, the externally applied tendons have to be encased in concrete or other non-combustible material for fire protection.
4. *Full-depth Slab Removals.* In extreme cases, it may be necessary to remove and replace the entire slab section. This can be a design as well as a construction challenge. The beam section will require in-depth analysis for all the load conditions encountered during the slab reconstruction with cross-sections that are altered by concrete removal and replacement. Also, removal of the slab dead load from the existing beam will result in uplift forces that have to be controlled during the repairs.

   So far, only partial replacement of the post-tensioned slab has been attempted. Removal and replacement of the post-tensioned slab over the entire floor area of the facility has not been attempted. In many instances, it is probably more cost effective and expedient to demolish and replace the entire structure. Such a repair scheme would require that the underlying beams be in good condition. Currently there are no reliable methods to determine the condition of beam tendons. One can only rely on visual observations and limited exploratory excavations that may not reveal the true extent of the concealed beam tendon problems.
5. *Continuous Acoustical Monitoring System.* The acoustical monitoring system cannot truly be considered to be a repair method. However, it can be used prior to implementing the repair or in conjunction with some of the repair methods discussed in this Section. This is a proprietary monitoring system that can assist in locating and

Figure 20-27: Trench method for tendon replacement.

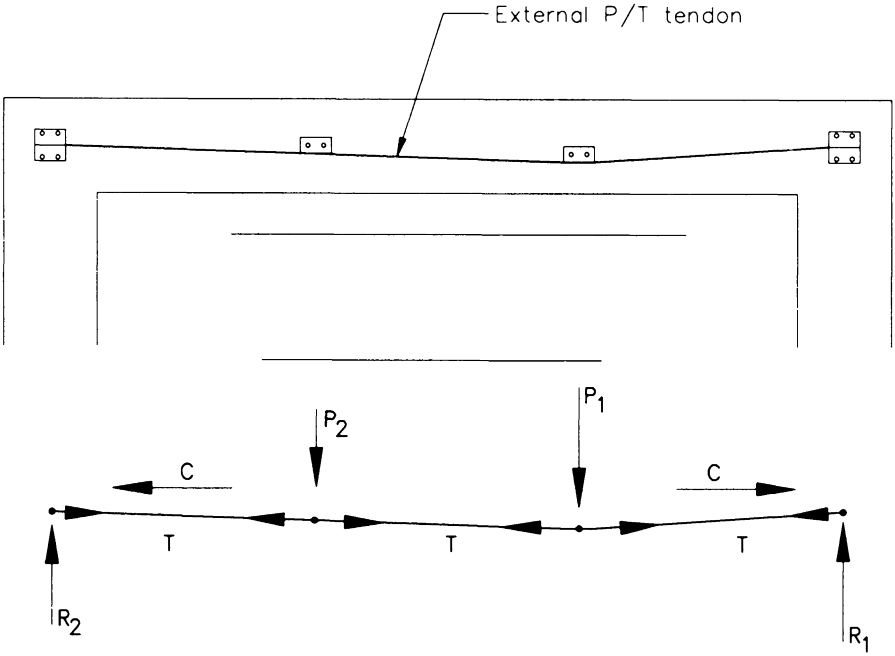
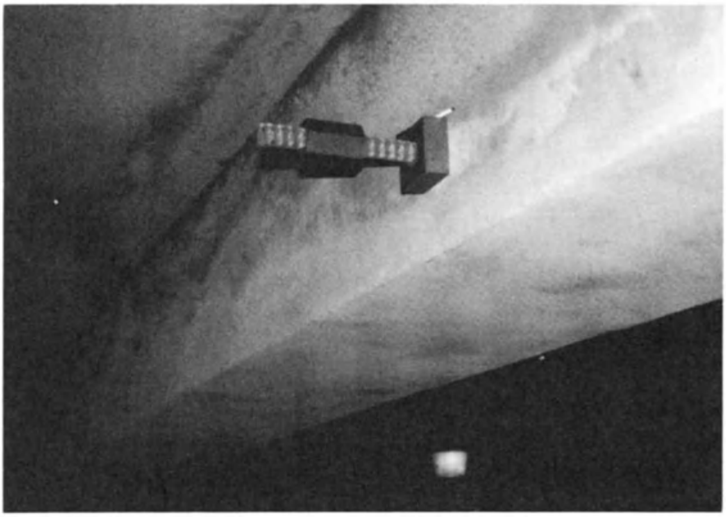
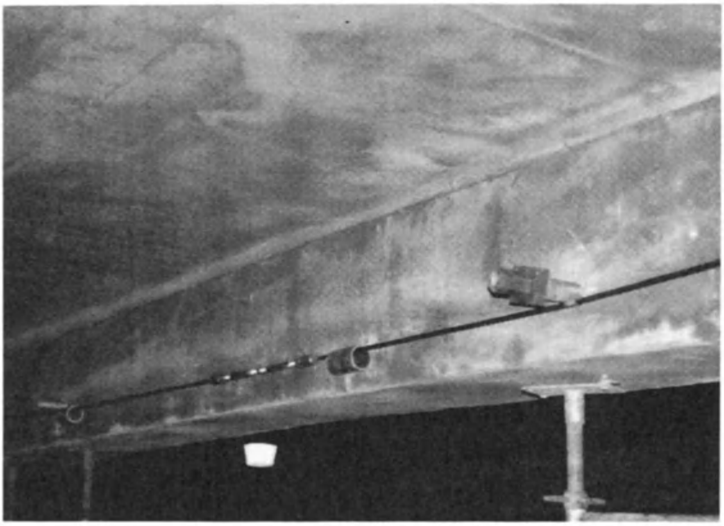


Figure 20-28: Application of external prestressing to beam.



(a)



(b)

Figure 20-29: (a) Deflector to maintain profile of external post-tensioning tendon. *(b)* Strand installed with deflector.

documenting the time of tendon breaks. When a tendon breaks there is a sudden release of energy. Strategically located sensors can detect this release of energy and location of the break. By gathering information about the rate and extent of tendon breakage, the monitoring system can assist in planning and scheduling of tendon repairs within the entire structure. Tendon repairs can be performed when required, while maintaining necessary structural integrity for safe use of the facility.

20.2.9 Summary

The intent of these sections was to discuss the commonly used repair approaches and methods for restoring parking structures. Construction and design deficiencies, along with errors in design or construction, may require strengthening or stiffening of the structural element. Also, severely deteriorated structural elements in a parking facility may require strengthening. In these instances, the primary cause of the distress must be first determined, and the appropriate corrective actions taken by following the approach discussed in Section 19.4. Also, refer to ACI 437R, "Strength Evaluation of Existing Buildings." These situations are generally uncommon. If construction and design deficiencies are present, then repair and/or strengthening methods must address the specific conditions encountered. Some of these strengthening techniques are discussed in ACI 546R, "Concrete Repair Guide."

20.3 REPAIR MATERIALS

20.3.1 Patching Materials

The selection of patching and concrete material is based on the consideration of the following five characteristics, as they relate to the member being repaired:

- Thermal compatibility or incompatibility
- Shrinkage
- Strength of repair material and the substrate
- Durability of the repair material and the substrate
- Ability to permit vapor transmission

The compatibility of the repair materials with the existing concrete is an important concern in the selection of appropriate repair materials. Since parking structures are exposed to temperature extremes, a difference in thermal properties of the repair material and the existing concrete will contribute to the debonding and failure of repaired areas. For instance, failure of epoxy-mortar patches can often be attributed to thermal incompatibly. Even for sand-filled epoxy mortars, the thermal coefficient of expansion may be four to five times that of the underlying concrete. The high stress developed between the epoxy patch and the underlying concrete is less forgiving of deficiencies in workmanship related to patch preparation and placement, resulting in more frequent failures.

For parking structures, Portland cement-based patching and overlay materials generally perform better than any other material. Even in moderate climates, the use of Portland cement-based materials should be preferred over other polymer concrete materials. Portland cement-based materials also reduce failures associated with a difference in the modulus of elasticity between the repaired material and existing concrete.

The differential shrinkage between the original concrete and the repair material can also contribute to debonding and cracking due to development of shear stresses along the interface. Reduce shrinkage of concrete repair materials by using a low water-to-cement ratio concrete, the maximum permissible size of coarse aggregate, and the lowest slump that will permit proper consolidation and finishing of the concrete. Reducing the shrinkage potential of the concrete repair material is particularly important for full-depth patches and floor-slab replacements. Cracking of full-depth patching and floor-slab replacements is a common occurrence. The use of additional reinforcement and control joints is another effective way to control, but not eliminate concrete cracking. Also refer to ACI 224R.

Always specify a strength of the repair material that is equal to or exceeds the strength of the underlying concrete. Also, patches placed over poor quality concrete with less than 3000 or 4000 psi concrete-compressive strength are susceptible to debonding. In such instances, the failure may occur in the underlying concrete. The extent of the failure will be affected by the concrete removal method, bonding medium, and patch material used. For suspect or questionable quality of the underlying concrete, verify performance of the repair technique by field testing of various concrete removal methods, surface preparation, and placement methods based on shear-bond test results.

A substrate that is marginally or inadequately air entrained is susceptible to progressive deterioration due to freeze-thaw damage if enough moisture is available or trapped at the interface to critically saturate the underlying concrete. Under these conditions, the repair material selected should not behave as a vapor barrier. Also, cracking or defects in the repair material that permit water to reach the interface will contribute to deterioration of the repair. For instance, an elastomeric-waterproofing membrane system (traffic topping) placed over a non-air-entrained concrete surface is likely to be subjected to progressive deterioration at pinholes and defects due to scaling of the underlying concrete. Another example is the reduced life expectancy of the patches and overlays (<3/4 inch thick) due to cracking that extends through to the underlying substrate.

The repair material itself must be durable enough to resist freeze-thaw cycling. The patch or overlay material should be properly air-entrained. For horizontal floor-slab surfaces, low-slump high-density and microsilica modified concrete patching materials that are properly proportioned and adequately air entrained tend to perform well. Also, latex-modified concrete patching materials perform well since they are not as susceptible to freeze-thaw damage. For full-depth floor-slab replacements specify a concrete mix with low potential for shrinkage.

Performance of rapid-setting prepackaged patching materials has generally been poor due to its inability to control air-entrainment. However, prepackaged Portland cement and polymer-concrete-based patching materials have been used to maintain serviceability for a limited time as temporary measures to reduce safety hazards. In some instances, asphalt has been used. Since asphalt tends to trap moisture and chlorides, patching with asphalt may accelerate damage to the underlying concrete due to freeze-thaw and corrosion.

The patching material used for overhead and vertical surfaces is less susceptible to freeze-thaw deterioration than that used for the floor-slab or horizontal surface. For areas that are protected from direct exposure to moisture, such as the ceiling, rapid-setting prepackaged Portland cement-based repair materials have been used successfully. Other successfully, but not widely used patching materials are various epoxy and polymer concretes. Polymer concretes are classed as thermosetting and hydrating. Examples of thermosetting polymer concretes are those containing epoxy and those containing methyl methacrylate. Examples of hydrating polymer concretes are those containing styrene-butadiene ("latex") additives which enhance the bond and reduce permeability. Limit the use of thermosetting polymer concrete materials for cosmetic or aesthetic repairs. For large shallow areas, pneumatically applied concrete (shotcrete) has also been used effectively. Specify the wet process with air-entrainment when there is a potential for saturation of the surface by moisture. For the majority of applications, dry process shotcrete may be adequate.

20.3.2 Sealers

Concrete sealer is a liquid that is sprayed, squeegeed, or brushed onto the concrete surface. A sealer makes the concrete less permeable to keep chloride ions, moisture and water out of the concrete. However, it cannot completely screen out the chloride ion or moisture like a traffic topping. Many generic types and brands of sealers are available with considerable variation in effectiveness and performance. It is important to select a sealer that will perform. Silanes are considered to be most effective because of their ability to penetrate deeper into the concrete. However, all silanes do not perform equally. The desirable properties of a good sealer are:

- Reduce water absorption
- Effective chloride ion screen and chemical stability when exposed to road salt
- Ability to "breath" which permits moisture vapor transmission
- Resist ultraviolet exposure
- Provide a skid resistant surface after application
- Ability to penetrate to the concrete surface

Some of the more commonly accepted laboratory test procedures that are available to evaluate sealer performance are summarized in Table 20-2.

Table 20-2. Sealer Testing

Test Objective	Standard Designation	Remarks
1. Chloride screening ability	NCHRP 244 Series II	Sealer performance evaluated based on water absorption and chloride ion content of test specimens that are submerged in saltwater.
2. Chloride ion intrusion	AASHTO T259 AASHTO T260	Slab test specimens are ponded with saltwater for the test period. Chloride ion content of concrete is determined at various increments of depth to evaluate sealer performance.
3. Water absorption	ASTM C642	Water absorption of core samples. Absorption permitted only from the slab top side or bottom. Effectiveness of sealer application can be evaluated by comparison of water absorption for sealed slab top surface and the unsealed slab bottom surface.
4. Impact of surface abrasion (penetration)	Alberta DOT (Canada) 1989	Abraded samples are tested for chloride ion screening ability to simulate impact of traffic abrasion on horizontal surfaces. Penetrating sealers perform better than sealers that only tend to form a film on the surface.
5. Ultraviolet exposure	NCHRP 244 Southern exposure test	Stability to UV exposure.

6. Scaling resistance	ASTM C672	Must be performed on non-air entrained concrete test specimens. Evaluates ability to keep moisture away from the concrete surface.
7. Moisture vapor transmission	ASTM E96	Measures the ability of the sealer to "breath."
8. Skid resistance	ASTM C303	Generally not a concern with penetrating sealers such as a silane. Film forming sealers tend to "glaze," which can be a slip hazard.

A combination of several of the test methods that are listed is necessary to properly distinguish sealer performance. Also refer to ACI 546R, "Concrete Repair Guide," for a more detailed listing of other test methods that can be specified to evaluate sealer performance.

The better performance of silanes is due to their smaller molecular structure. These sealers can penetrate as much as 1/8 inch into the concrete surface. Depth of penetration is obviously related to the concrete porosity and permeability. Concrete with a higher water-to-cement ratio is more porous and will permit greater sealer penetration than a concrete which is less porous. Also, the sealer effectiveness is influenced by the sealer application rate and the concrete porosity. Some other factors that can affect sealer performance are condition of the surface at the time of sealer application, surface preparation, moisture content of the concrete and sealer concentration. The effectiveness of the sealer under service condition and/or frequency of reapplication can be monitored by chloride ion testing. See Chapter 18 for chloride ion monitoring.

One recent development is the use of water based solvents for silanes. The more volatile alcohol based solvent carriers that were traditionally required have been replaced by water based solvents. This is due to the very stringent regulations for Volatile Organic Compounds (VOC) that have been imposed by several states. These state standards exceed the current Environmental Protection Agency's Clean Air Act Amendment standards. It is anticipated that many more states will adopt these current regulations and some will tighten them even more. Therefore, some manufacturers have already developed solvent-free 100% silane sealers. This highly concentrated sealer is obviously more expensive than current sealers packaged at 20 to 40% silane content. The new sealers can potentially last longer due to greater penetration into the concrete surface and provide better corrosion protection due to their high solids content.

20.3.3 Membranes (Traffic Topping)

The present ASTM test methods for testing properties of traffic-bearing membranes are not adequate to evaluate the performance and the abrasion resistance of systems. There are many manufactures that supply the membrane but, all membrane systems do not perform equally. Some basic characteristics that help to evaluate the systems are:

- Impermeability - Should be impermeable to water under normal use.
- Tear Resistance - Membrane should be capable of bridging cracks under normal as well as cold-weather conditions.
- Adhesion - Intercoat as well as adhesion to the substrate.
- Moisture Vapor Transmission - The membrane should be capable of breathing.
- Material Stability - Stability under service-exposure conditions to perform over extended time period.
- Chemical Resistance - Should be resistant to gasoline, oil, and antifreeze spills.
- Ease of Installation - The waterproofing material and installation procedures must be tolerant of site conditions, as opposed to ideal laboratory conditions.

Select membrane systems based on performance history, compatibility with other sealant systems, cost and the manufacturer's reputation to properly install and service the topping. Improper application of polyurethane membranes can result in localized imperfections, such as blistering and pinholes. Therefore, the performance of the membrane systems is affected by the care taken to install the systems. These systems require more frequent maintenance in high traffic areas. The service life and the level of maintenance are affected by the abrasion resistance of the system. Current ASTM abrasion test methods are not effective in distinguishing the performance of membranes manufactured by the various vendors.

A test that has unofficially gained considerable acceptance in the industry is the comparison of the abrasion resistance of the membrane systems when tested against oak blocks. The oak blocks are placed in a specially designed wear test machine that can apply a constant predefined pressure against membrane samples cast on an aluminum strip. The test samples (strips) are clamped onto a moving bed that moves back and forth underneath the stationary oak blocks. This wear test machine was originally designed and developed by the 3M Company, Minneapolis, Minnesota. The author has successfully used this tester to evaluate the performance of the various membrane systems over the last 8 years, based on a detailed membrane performance specification developed by Walker Parking Consultants.

The stricter VOC regulations imposed by several states have led to the recent development of some solvent-free (100% solids) membrane systems. Currently, most of the urethane membrane systems are solvent based. Also, low-odor systems are offered by many manufacturers for membrane installation in enclosed areas or areas adjacent to occupied spaces in buildings. Presently, there are no standards to measure or compare the odor characteristics. After all, odor is a very subjective issue and cannot be defined.

The life expectancy of a properly applied and maintained state-of-the-art traffic topping is approximately 15 years, requiring top coat reapplication to the entire surface to further extend the service life. For surfaces exposed to direct sunlight and ultraviolet lights, the life expectancy is reduced to 10 years.

Traffic topping has a high initial application cost that is 6 to 8 times the cost of a protective concrete sealer. The membrane is susceptible to traffic abrasion and wear, requiring more frequent maintenance in heavy traffic areas such as entry/exit points, drive aisles and turn areas. Also, traffic topping will require use of mechanized scrubbers and sweepers to clean the surface. It is normal for the traffic topping to gradually discolor when directly exposed to sunlight. Black or dark membranes will reduce the light levels within the facility, particularly in the lower covered levels.

20.3.4. Overlays

The most widely used specialty concrete overlay systems that have demonstrated a satisfactory long-term performance history are latex-modified concrete (LMC) and low-slump high-density concrete (LSDC). LMC is more effective at preventing additional water and salt penetrations into the base slab than LSDC. However, the long-term durability of both systems appears to be equivalent. Polymer-concrete overlays have been used only on a limited scale and have not been fully evaluated. Such systems, whether referred to as polymer or epoxy concrete, can offer solutions to surface deterioration problems and should not be excluded from consideration. Another specialty concrete overlay utilizing silica-fume-modified, high-density concrete is currently available. The installation cost of the silica-fume modified overlay is lower than that of the LMC system.

20.4 SELECTION OF REPAIR APPROACH AND METHOD

20.4.1 General

Floor-slab surfaces experience the most deterioration due to direct exposure to the service environment. The deterioration is accelerated by design deficiencies or construction practices that contribute to poor quality concrete, shallow cover over embedded reinforcement, inadequately air-entrained concrete, cracking, and ponding. The repair objective is to correct many of these deficiencies and improve other adverse conditions. This action will reduce the deterioration rate of the restored structure and extend the service life of the facility. Several repair alternatives are developed to extend the service life of the facility and then the most cost-effective repair approach is selected.

It is not unusual for floor-slab repairs to consume as much as 50-80% of the total restoration cost. Therefore, floor-slab repairs generally offer the greatest potential for cost savings by evaluating appropriate repair alternatives. In most instances, repairs to underlying members, such as columns, haunches, bearing ledges, and walls represent a much smaller portion of the total restoration cost. Repairs of the structural members, other than the floor-slab, are performed by patching, strengthening or replacement. The selection of repair schemes to restore the floor-slab of a parking structure is related to the following six basic issues:

- Nature of distress
- Extent of deterioration
- Type of structure
- Repair alternatives
- Life expectancy of the repaired structure
- Economics

The same repair approach cannot be used for all structures. The approach selected to restore a structure damaged by corrosion of embedded reinforcement will be different from that selected for a slab damaged by freezing and thawing. In addition, the repair approach selected must address the adverse effect of other contributing factors, such as the quality of the concrete, poor drainage, floor-slab cracking, shallow concrete cover over reinforcement, and lack of adequate air-entrainment.

The extent of the deterioration and type of structural system will also influence the selection of the repair scheme. For instance, if a 4-inch thick slab of a pan-joist system is extensively damaged due to corrosion, then patching, sealing, or cathodic protection may not be an acceptable solution. The appropriate repair scheme in this instance is probably going to be the replacement of the slab of the floor system. Slab replacement will be required, since it is difficult to perform partial-depth repair of slabs that are less than 5 inches thick. On the other hand if the 4-inch slab is damaged by surface scaling, an elastomeric-waterproofing membrane or an overlay may be acceptable solutions. However, if the extent of the freeze-thaw damage extends 1-2 inches below the surface, replacement may be a more appropriate repair method.

In summary, from a technical standpoint, consider the nature and extent of the deterioration, the pros and cons of the repair methods that are technically acceptable, and the impact of the repair on factors contributing to the deterioration. Also, make certain that the structure can be repaired (as opposed to replaced), and that all elements of the structure will support additional loads imposed by the repair work.

20.4.2 Life Expectancy of Repairs

The life expectancy of repair methods is at best an estimate. Also, estimating the service life of repaired structures is only an educated opinion, based on experience gained from conditions observed in structures with a similar framing system. Therefore, difficulty in estimating the service life of repaired structures complicates the selection of a cost effective repair method. Removal of sound, but chloride contaminated concrete has a significant impact on the life expectancy of repairs. The impact of concrete removal on the various repair methods can be best illustrated by considering the life expectancy of structures repaired by patching.

A distinction can sometimes be made between temporary and permanent repair patches. However, because of the progressive nature of corrosive processes, the service life of even a "permanent" patch is limited. As shown in Figure 20-30, in a temporary patch the concrete is removed only to the level of reinforcement. This situation contributes to progressive deterioration within and adjacent to the patch boundary as illustrated in Figure 20-31. Also, the life expectancy of the patch may be limited to only 1 or 2 years. This method of patch repair may be appropriate for structures when serviceability is to be maintained for a limited time, or when constraints are imposed due to available funds or weather conditions.

In the instance of a relatively permanent patch, the concrete is removed below the existing reinforcement to minimize potential for corrosion within the patch boundary. See Figure 20-32. Also, to control corrosion adjacent to the patch boundary, the existing reinforcement may be epoxy coated. The entire floor surface is then sealed to reduce the deterioration rate of areas beyond the patch boundary. Under these conditions, the life expectancy of the patch repairs is 3 to 5 years.

In certain instances, where longer life expectancy is desirable, concrete removal along the entire length of reinforcement can be specified. For conditions shown in Figure 20-33 (a) and (b), the life expectancy of the "strip-patch" repair may be estimated at 10 - 20 years, limited primarily by other contributing factors, such as cracking, lack of air-entrainment and poor drainage that may adversely affect the service life of the structure. However, it is not feasible to implement the strip-patch-repair approach in structures with relatively thin slabs (less than 5 inches thick). Therefore, considerations, such as the structural system involved and the existing reinforcement, size, placement and pattern, will limit the ability to implement this repair approach.

At present, the only way to be assured of a "permanent" repair requiring little maintenance is to remove all concrete that contains chlorides in excess of the corrosion threshold. However, in most instances, this can amount to complete removal of the floor-slab. See Figure 20-13. The emphasis should be on selective, but cost-effective, removals of chloride-contaminated concrete, based on consideration of overall repair strategies and the desired life expectancy of the repairs.

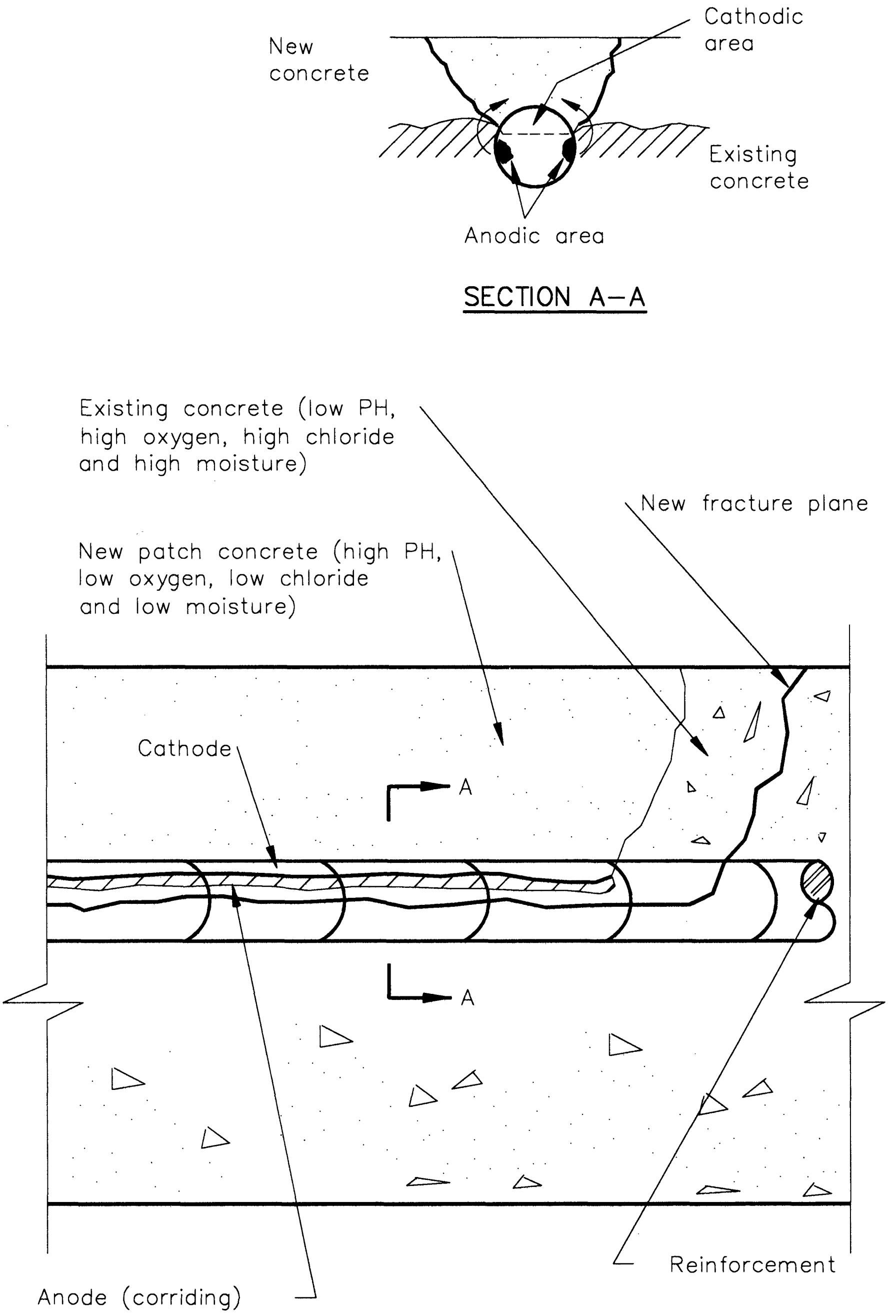


Figure 20-30: **Development of corrosion cell in a patch limited to removal of only the unsound concrete.**

Figure 20-31: Delamination due to continuing corrosion within and beyond patch boundaries.

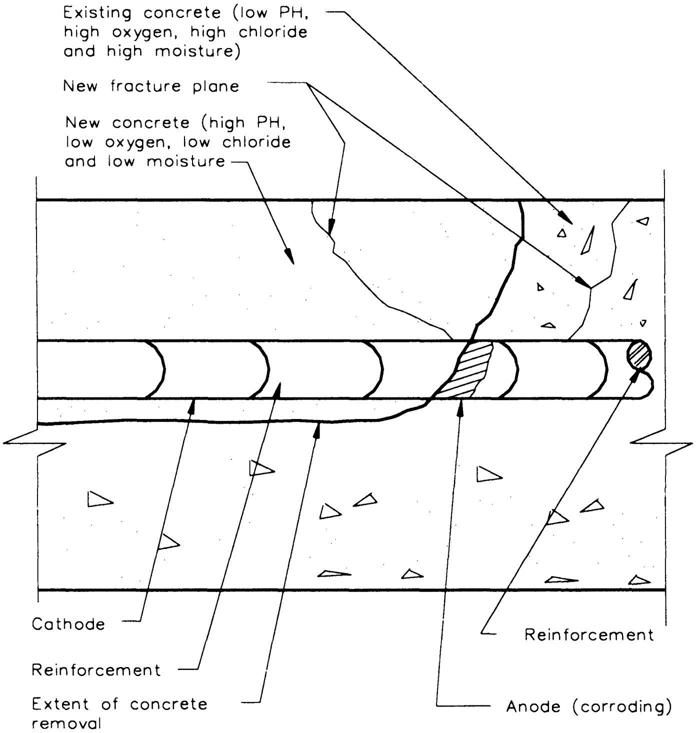
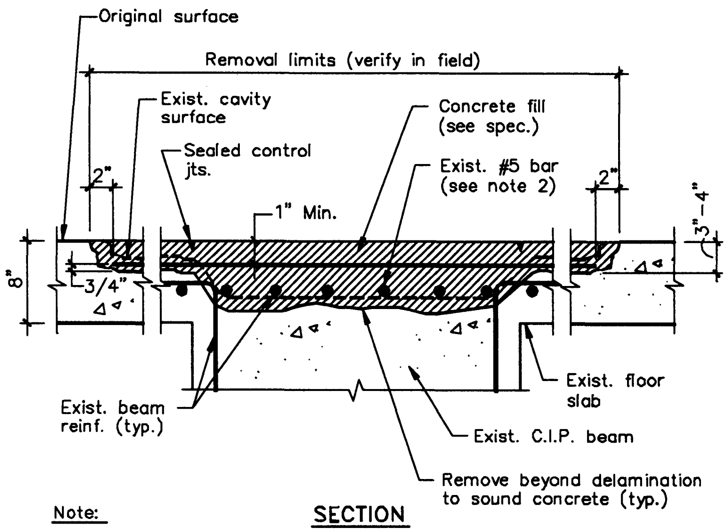


Figure 20-32: Development of corrosion cell in a patch with concrete removals extending below the reinforcement.



Note:

1. Remove and replace all sound and unsound concrete within sections shown cross-hatched.
2. Remove existing top reinforcement and replace with new epoxy coated reinforcement of same size.

Figure 20-33(a): Strip patch repair detail.

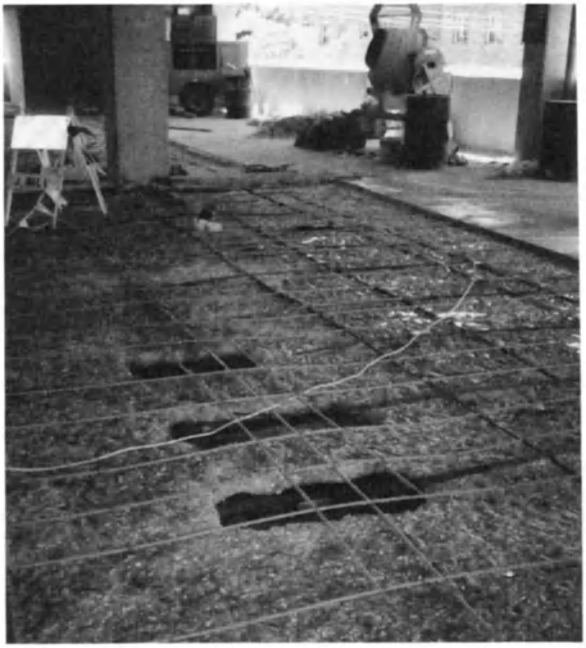


Figure 20-33(b): Strip patch repair showing removal of all top slab reinforcement over beam.

Based on the extent of concrete removals, the structural system involved, and the concrete cover over existing reinforcement, patching and then coating the floor-slab with a waterproofing membrane is likely to extend the service life of the structure 5 - 10 years. An overlay can extend the service life of structures 10 - 20 years. In concept, the only method that will mitigate corrosion of the embedded reinforcement without removal of sound concrete is cathodic protection. Application of cathodic protection is estimated to extend the service life of structures beyond 20 years. Full-depth slab and floor removal can be designed to be rebuilt with a life expectancy of 20 - 40 years. A probable estimate of repair service life of various repair approaches is summarized in Table 20-3. As previously mentioned, estimating the service life of repairs is not easy. Currently there is no industry standard or guide to assess service life of repairs. The only avenue currently available is to rely on experience gained from past performance of the repairs under actual service conditions. Therefore, the table should only serve as a guide. Some of the factors that can influence the service of the repairs include:

- Age of the facility
- Type of structural system and pattern of reinforcement
- Quality of material specified for the original construction and for the repairs
- Extent of deterioration
- Degree of chloride contamination
- Nature of the deterioration
- Adverse conditions
- Geographic location of the structure
- Exposure conditions
- Preventive maintenance

Table 20-3. Estimate of Repair Service Life

Repair Approach	Service Life (Years)
Patching (shallow)	1 - 2
Patching (deep)	3 – 5
Patching and Sealer	3 – 5
Patching and Traffic Topping	5 – 8
Concrete Overlay	10 – 15
Strip Patching and Sealer	10 - 15
Strip Patch and Traffic Topping	10 – 20
Partial-depth Slab Removal and Replacement	10 – 20
Full-depth Slab Removal and Replacement	20 - 30

The table suggests that it is possible to match the service life of the repairs to meet the strategic objectives of the owner. For instance, patching cannot be considered as the primary repair method if the strategic objective is to keep the structure in service for long term (20 years or more). It is also apparent that repair schemes with longer service life will incur higher repair costs. The repair methods also tend to get more aggressive and disruptive with increased service life expectancy. Therefore, the selection of the repair approach will have an impact on the repair budget, construction schedule, and operations of the facility.

20.4.3 Repair Alternatives

It is not uncommon to develop several technically acceptable repair alternatives for a structure based on the following overall repair strategies:

1. Do nothing and use up the remaining useful life of the structure.
2. Perform repairs to address only potentially unsafe conditions that presently exist. This approach amounts to performing only "band-aid type" repairs either prior to implementing a comprehensive restoration program or demolishing the structure.
3. Perform necessary repairs to extend the life of the structure 5 - 10 years.
4. Perform necessary repairs to extend the life of the structure 10 - 20 years.
5. Perform repairs to extend the life of the structure 25 years or more.

The selection and evaluation of repair alternatives are important elements of the restoration process. Select repair alternatives based on the overall strategies. This process assists in selecting schemes that will address future plans for use of the structure based on funds that are presently available or obtainable. However, do not consider technically unacceptable alternatives primarily to limit restoration costs.

The nature and the extent of the deterioration will also limit the selection of repair alternatives. For instance, it may not be appropriate to extend the life of a structure 5 - 10 years simply by patching, if the slab is likely to undergo progressive damage due to freezing and thawing. Also, it may not be possible to assure safe operating conditions by performing only limited repairs to a structure that is extensively damaged.

As previously mentioned, the majority of the repair cost for a restoration program can be attributed to the floor-slab. Therefore, the floor-slab provides the greatest potential for evaluation of repair alternatives. Two important objectives to restore the floor-slab are:

- Restore structural integrity, and

- Provide floor-slab protection to extend the life of the repairs and the service life of the structure.

The above objectives provide an opportunity to generate repair alternatives, individually and in combination. For instance the following alternatives can be generated for initial consideration based on the two repair objectives:

- **Do nothing** – It is important to show the adverse impact of this approach on structural integrity, future repairs, maintenance, available spaces, and operation of the facility.
- **Patch and Seal** – In this alternative the floor-slab is first patched to restore structural integrity and serviceability. Then, applying a concrete sealer to protect and extend the service life of the repaired floor-slab.
- **Patch and Traffic Topping** – Floor-slab repairs to restore integrity is same as for the alternative above. In this instance, the floor-slab protection is upgraded to a traffic topping membrane to realize a longer life expectancy for the floor-slab repairs. The traffic topping also helps to reduce the rate of deterioration of the floor-slab areas beyond the patch limits that tend to undermine effectiveness of floor-slab repairs.
- **Concrete Overlay** – This alternative is essentially the same as the one above with the exception that an overlay is substituted for the traffic topping. The overlay may be a consideration to reflect the service and exposure conditions that demand a more durable wearing surface. The overlay will also tend to reduce the maintenance and disruption of operation associated with membrane abrasion in high traffic areas.
- **Strip Patch and Traffic Topping** – This repair approach will require the removal of sound and unsound concrete to expose and replace all the top reinforcement in the slab. The removal depth varies from 3 to 5 inches based on the size of reinforcement, depth of reinforcement and the number of layers of top reinforcement in the slab. See Figure 20-33 (a) and (b). This method works well for one-way slab and beam floor system as well as the two-way flat slab system. Strip removal works best for slabs that are greater than 6 inches thick. If the slab thickness is less than 6 inches, there is a greater potential for slab punch-through during concrete removal. Consideration of a surface sealer in place of the traffic topping will generate another sub-alternative.
- **Partial-depth Slab Removal and Replacement** – This alternative is feasible for floor-slabs with a minimum thickness of 6 inches. Two-way flat slab structures offer the greatest potential for consideration of this alternative. In this repair approach, the top 3 to 4 inches of the floor-slab are removed and all the top slab reinforcement is replaced, prior to putting back a 3 to 5 inch thick conventional concrete overlay.

Considering different overlay materials and application of sealer or traffic topping to protect the finished surface can generate a series of other sub-alternatives.

- **Full-depth Slab Removal and Traffic Topping** – Concrete removals on pan-joist, waffle slab and one-way slab will result in complete removal of the thin slab section. See Figure 20-12. The slab is replaced with conventional concrete, internally applied corrosion protection additives, and epoxy coated reinforcement. Since the new slab is susceptible to cracking, a traffic topping protects the repair. A sub-alternative for this repair approach is to look at an alternative to remove the entire floor-slab system, which will include the slab and underlying beam or joist sections.

  In two-way flat systems, full-depth slab removal wills essential result in removal of the entire floor. See Figure 20-13. The replacement slab may include epoxy-coated reinforcement and other internally applied corrosion protection systems. A sealer or a traffic topping is applied to protect the finished slab.

20.4.4 Selection of Repair Approach

The mechanics of selecting the repair approach involves generating technically feasible repair schemes that are applicable to the structure. This will require the understanding and knowledge of the following:

- **Existing Conditions** –Concrete deterioration is covered in Section 19.3. Condition appraisal of the structure as covered in Section 19.2. and Section 19.4. Includes references to applicable industry standards.
- **Repair methods** – The repair methods are discussed in Sections 20.2.1 through 20.2.9. Also industry references are cited for more detail and information.
- **Repair materials** – Repair materials are discussed in Section 20.3.
- **Advantages and Disadvantages of Repair Methods** – The advantages and disadvantages of various repair methods are discussed in Sections 20.1.3 through 20.1.8. Also, applicable industry references are cited for more detail and information.
- **Repair Alternatives** – Repair alternatives are covered in Section 20.4.3.
- **Life Expectancy of Repairs** – Estimate of repair life expectancy for various repair approaches is covered in Section 20.5.

The information covered by the items shown above can be conveniently qualified to assist in the selection of a technically appropriate repair approach by using a decision matrix as shown in Table 20-4. The concept of the decision matrix was developed by the Ontario Ministry of Transportation, Research and Development Branch. This decision matrix concept has been used for selection of bridge-deck rehabilitation methods. The decision matrix presented in Table 20-4 has been adapted from the material published in the Ministry of Transportation's manual. The table assists in the selection of a repair approach with the least amount of technically unfavorable elements. Note that patching or sealing, as a repair approach by itself, will be ineffective in restoring the slab. Patching and sealing is usually done in conjunction with application of a surface sealer, traffic topping, or an overlay. The exception could be the use of patching and sealing by itself for the purpose of preventive maintenance.

The decision matrix leads, by elimination, to the selection of repair approaches with the least disadvantages. In some cases, most of the schemes considered may be inappropriate. For instance, a structure that is extensively cracked, consisting primarily of active cracks and delaminated over 30% of the floor area, will necessitate working through the selection process and examining the implication of violating each criterion in turn for the selected alternatives. If the structure is considered to be important, then the scheme may consist of slab replacement with a traffic topping to minimize leakage through active floor-slab cracks. The criteria contained in Table 20-4 is not rigid, but serves only as a useful starting point from a technical standpoint. Repair strategies, life expectancy, and economic issues usually influence the selection of the final repair scheme.

20.4.5 Economics

The selection of a cost-effective repair method consists of: 1) preparing cost estimates of technically acceptable repair alternatives, and 2) estimating the service life of the repaired structure. Repair costs can vary significantly even for the same method of repair. Factors contributing to cost variations are geographic location of the structure, scope of the overall contract, size and volume of the repair work, and availability of materials and qualified contractors. Constraints associated with maintaining traffic during construction and the overall volume of construction work at the time of bidding can also vary the overall repair costs. Realistic estimates are obtained by using costs from an historical record and assigning appropriate contingency factors to the total cost of the work.

In some instances life cycle cost analysis of repair methods is also performed to select an economical repair method. Once again, the economics are difficult to estimate due to the possible inaccuracy in assessed costs and assumed service life of the repaired structure. Refer to Section 20.5 for life cycle cost analysis of repair alternatives.

Table 20-4. Selection of a Floor-slab Repair Approach

Criterion	Patching (Partial or Full-Depth)	Protective Coatings: Sealer	Protective Coatings: Traffic Topping	Protective Coatings: Overlay	Replacement (Partial or Full-Depth)	Cathodic Protection [1,2]
1. Corrosion-induced deterioration --- > 10% of the floor area	No	No				
2. Corrosion-induced deterioration --- > 30% of the floor area	No	No	No	No		No
3. Moderate scaling --- 10% of the floor area	No	No				Yes/No
4. Non air-entrained concrete	No	No	No			Yes/no
5. High concrete permeability	No	No				
6. Need to improve drainage	No	No	No			Yes/no
7. Shallow concrete cover	No	No	No			
8. Limited structural capacity				No		Yes/no
9. Limited floor clearance				No		Yes/no
10. Remaining life less than 10 yrs.				No	No	No
11. Active cracks	No	No		No	No	

[1] Items 3, 4, and 7 are appropriate if the C.P. system selected consists of anode embedded in a concrete overlay.
[2] Items 8 and 9 will be appropriate if the C.P. system consists of anode embedded in slots cut in the structure.
Adapted from: "Bridge Deck Rehabilitation Manual," Part Two: Contract Preparation, Ontario Ministry of Transportation.

20.5 LIFE CYCLE COST ANALYSIS OF REPAIR ALTERNATIVES

The final selection of a repair scheme to restore a structure requires dealing with two sets of issues; some that are technical in nature and other that are management related. The technical related issues are covered in Section 20.3. The management issues include strategic goals, repair costs, duration of construction, available funds, and impact on revenue and operations. Life cycle analysis of repair alternatives provides the owner with relative cost comparison of the repair alternatives and helps the owner make decisions that are consistent with future management goals. A model for the life cycle cost analysis has three components, which are as follows:

- Initial cost of repair
- Future maintenance costs
- Future repair costs

The accuracy of the results depends on the input for the repair and maintenance costs. An accurate historical database of repair costs should be available to determine the initial costs. Another important element is the realistic prediction of repair life expectancy and the level of maintenance that will be required in future. Experience with past performance of repair materials and methods have to be researched and evaluated to fit the current model under consideration. Finally, a restoration specialist should perform this type of analysis. This specialist must have extensive knowledge and experience with restoration of parking structures, deterioration mechanisms, and repair materials and methods.

An example will be presented to show the mechanics of the life cycle cost analysis with a simple model. This life cycle cost analysis is for a structure with a 10 inch thick two-way flat slab floor system. The floor area is approximately 100,000 sq. ft. The period for the life cycle cost is 25 years.

Step 1: Select the technically feasible alternatives and prepare an estimate of probable construction cost for each of the alternatives.

Based on the results of the condition appraisal, the following four alternatives are considered to be appropriate and technically feasible:

- Alternative 1 – Patch and traffic topping
- Alternative 2 – Strip patch and traffic topping
- Alternative 3 – Partial-depth slab removal and replacement with a traffic topping

- Alternative 4 – Full-depth slab removal and replacement with a traffic topping

For description of the repair alternatives refer to Section 20.4.3. The repair cost for each of the alternatives is shown in Table 20-5. The two lowest cost alternatives are Alternative 1 and Alternative 4. To keep this exercise simple, only the two lowest cost alternatives will be considered in the following steps.

Table 20-5. Alternatives Repair Costs

Item	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Project Mobilization	$300,000	$352,472	$382,392	$334,952
Concrete Repairs	$2,851,000	$3,505,000	$4,012,000	$3,187,000
Protection	$296,000	$296,000	$163,000	$395,000
Plumbing	$25,000	$25,000	$25,000	$25,000
Miscellaneous	$64,500	$64,500	$64,500	$64,500
Mechanical	$225,000	$225,000	$225,000	$225,000
Electrical Lighting	$290,400	$290,400	$290,400	$290,400
Subtotal	$4,051,900	$4,758,372	$5,162,292	$4,521,852
Contingency	$405,000	$476,000	$516,000	$452,000
TOTAL COST	$4,456,900	$5,234,372	$5,678,292	$4,973,852

Step 2: Estimate future repair and maintenance costs.

The future repair and maintenance costs for Alternative 1 and Alternative 4 are shown in Table 20-6. In this model all costs are shown in increments of five years. The table shows that for Alternative 1, the repair cycle or life expectancy of the patch and traffic topping repairs is 10 years. At the end of the 10-year period, the floor-slab will need another round of repairs to extend the service life of the structure. Also, future maintenance costs include repair to floor-slab and maintenance of traffic topping.

For Alternative 4, only minor concrete repairs are shown for the entire 25 years. These minor repairs reflect the need to maintain serviceability by patching. Also, some traffic topping maintenance in high wear areas can be expected. At the end of 15 years, the traffic coating will require re-coating.

Step 3: Set up the life cycle cost model for the alternatives.

Based on the information shown in Table 20-6, a simple life cycle model for the two alternatives is shown in Figure 20-34 (a) and (b).

Step 4: Run the analysis for the life cycle cost of the alternatives.

This step requires performing the necessary calculations to compare the life cycle cost. In this example, the built-in financial analysis functions of the Microsoft Excel program are used to run the analysis. The Present Value for each of the alternatives is determined for the cost comparison based on a discount rate (i) of 3%. The results of the present value analysis are shown in Table 20-7.

It is apparent that Alternative 4 is more cost effective than Alternative 1. Although Alternative 1 has a lower initial cost, the long-term cost is almost two times that of Alternative 4. The analysis shows that there is a long-term saving of $5,000,000.00 with an initial investment (cost difference of the Alternatives) of approximately $500,000.00. The results of the analysis are shown graphically in Figure 20-35.

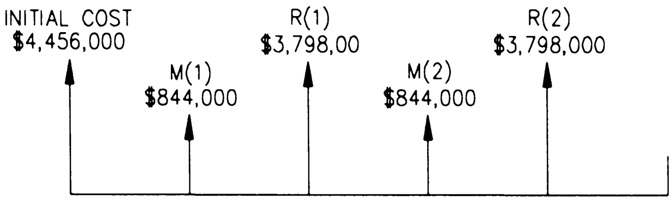
Table 20-6. Future Repair and Maintenance Costs

	Year 0	Year 5	Year 10	Year 15	Year 20
Alternative 1					
Project Mobilization	$300,000	57,000	256,000	57,000	256,000
Concrete Repairs	$2,851,000	$560,000	$2,851,000	$560,000	$2,851,000
Protection	$296,000	$100,000	$296,000	$100,000	$296,000
Plumbing	$25,000	$0	$0	$0	$0
Misc	$64,500	$50,000	$50,000	$50,000	$50,000
Mechanical	$225,000	$0	$0	$0	$0
Electrical Lighting	$290,000	$0	$0	$0	$0
Subtotal	$4,051,500	$767,000	$3,453,000	$767,000	$3,453,000
Contingency	$405,000	$77,000	$345,000	$77,000	$345,000
Project Total	$4,456,500	$844,000	$3,798,000	$844,000	$3,798,000
Alternative 4					
Project Mobilization	335,000	10,000	13,000	24,000	18,000
Concrete Repairs	$3,187,000	$30,000	$65,000	$100,000	$125,000
Protection	$395,000	$46,000	$46,000	$150,000	$46,000
Plumbing	$25,000	$0	$0	$0	$0
Misc	$65,000	$50,000	$50,000	$50,000	$50,000
Mechanical	$225,000	$0	$0	$0	$0
Electrical Lighting	$290,000	$0	$0	$0	$0
Subtotal	$4,522,000	$136,000	$174,000	$324,000	$239,000
Contingency	$452,000	$14,000	$17,000	$32,000	$24,000
Project Total	$4,974,000	$150,000	$191,000	$356,000	$263,000

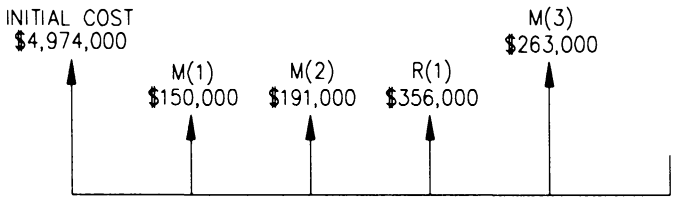
Table 20-7. Present Value of Alternatives

	Expense Type	Year(s)	Amount	Frequency	Present Value
1 **Alternative 1**					
	Initial Repair Cost	1	$4,456,500	1x	4,456,500
	Maintenance (1)	5	$844,000	1x	733,913
	Future Repair (1)	10	$3,798,000	1x	2,871,834
	Maintenance (2)	15	$844,000	1x	554,944
	Future Repair (2)	20	$3,798,000	1x	2,171,519
	Combined Present Value				**$10,788,709**
2 **Alternative 4**					
	Initial Repair Cost	1	$4,974,000	1x	4,974,000
	Maintenance (1)	5	$150,000	1x	130,435
	Maintenance (2)	10	$191,000	1x	144,423
	Future Repair (1)	15	$356,000	1x	234,076
	Maintenance (3)	20	$263,000	1x	150,371
	Combined Present Value				**$5,633,305**

Notes: Period of Analysis 25 years Annual Discount Rate 3%



(a)



(b)

Figure 20-34: (a) Alternative 1 life cycle cost analysis model. (b) Alternative 4 life cost analysis model.

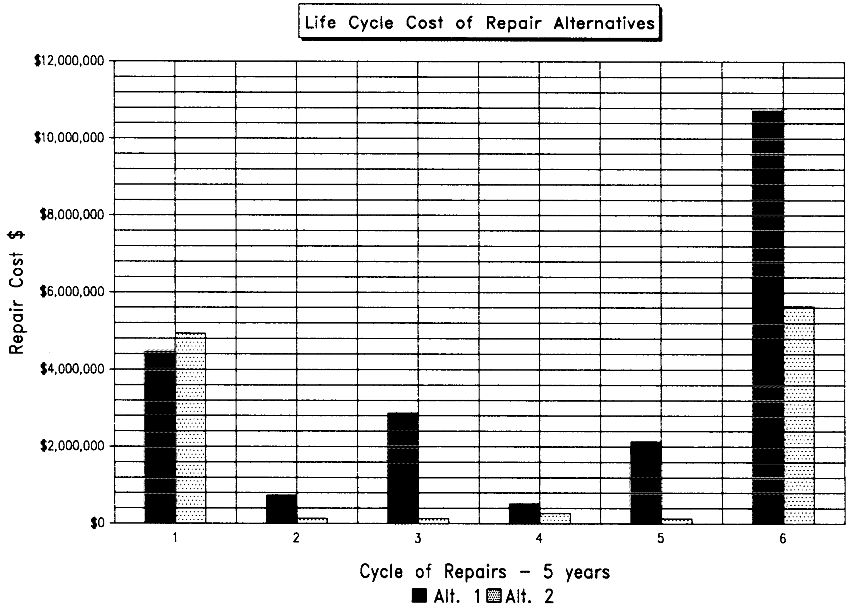


Figure 20-35: Life cycle cost of Repair Alternatives.

20.6 REPAIR DOCUMENTS AND CONSTRUCTION ISSUES

Repair documents implement the findings and recommendations of the condition appraisal. Although most of the information and data gathered during the condition appraisal can be utilized in preparation of the repair documents, another field survey is sometimes necessary to develop more accurate information regarding the following:

- Types of distress
- Extent and locations of distress
- Special conditions
- Boundary conditions
- Limitations related to occupancy, accessibility, and repair methods.

20.6.1 Contract Forms

The two most common contract forms are the negotiated contract and the stipulated lump sum contract; both are based on unit prices and quantities. The stipulated lump sum contract is preferred for restoration work. Using the unit-price approach, repair procedures are identified as separate work items. See Table 20-8. Work items are repair procedures that correct the distress in concrete members. Work items are also used to include any upgrades, improvements or operational elements. The plan sheets are usually condition appraisal field sheets converted to work items based on the field survey observations

Table 20-8. Repair Work Items

Work Item	Description
1.0	Repair damaged floor-slab
2.0	Repair damaged beams and columns
3.0	Install new electrical conduit
4.0	Paint exposed structural steel
5.0	Install new control joints
6.0	Repair bumper guards
7.0	Apply concrete surface sealer
8.0	Install new drain system

20.6.2 Project Specification

The project specifications contain the description of the scope of individual work items, material specifications, and repair procedures. Details describe concrete removal limits, and provide dimensions and material requirements. Selected samples of some repair details are shown in Figures 20-6 through 20-9. Also, refer to Sections 20.2 and 20.3 for some specific technical requirements for repair materials and methods that need to be included in a typical repair specification.

Project specifications for restoration work also include some unique elements that are not commonly addressed in a standard project specification. Many of these are non-technical issues and are related to contract administration and maintaining operation of the facility during construction.

20.6.2.1 Bid Quantities

For unit price contracts, the bid form must include repair quantities for the work items. Providing a common basis (work item quantities) for bidding helps the contractor to arrive at a stipulated lump sum amount for the contract. Selection of the contractor can then be based on the lump sum price received. However, the work item quantities included in the bid form must be adjusted appropriately to reflect the actual work anticipated at the end of the project. The actual quantity as measured in the field (raw quantity) has to be adjusted to account for the following:

- Extrapolation of quantities due to partial or limited survey of the structural
  elements.
- Squaring of patched areas for aesthetics.
- Consolidation of several closely grouped small repair areas into a single large area.
- Additional concrete removals dictated by the type of the floor framing system.
- Additional concrete removals required due to the type of repair method specified (patching, strip-patching, full-depth removal).

20.6.2.2 Cost Estimates

Cost estimates are prepared using the work item listing developed earlier and estimated quantities for each item. Quantities should be estimated on a tier-by-tier basis to aid the contractor in planning and scheduling the work with minimum disruption to the operation of the facility. Always provide funding for contingencies, otherwise, latent conditions found during the repairs may contribute to cost overruns. See Table 20-9.

20.6.2.3 Increase or Decrease in Work Item Quantities

Variation of work item quantities will occur on most projects. It is not possible to account for all the conditions during preparation of the contract documents. Therefore, it is necessary to make a fair adjustment to the bid prices based on the actual work item quantities measured at the end of the project. Generally, if the bid quantity is exceeded then the unit price needs to be reduced. The contractor is already mobilized on the site and this additional work is not likely to incur additional set up costs. For the same reason, if the repair quantity is reduced then the contractor should be compensated by an increase in the unit cost for that work item. Generally, no adjustment is necessary for quantity variations within 25% of the bid quantity. However, this anticipated quantity variation must be clearly stipulated in the project specifications.

20.6.2.4 Construction Schedule & Occupancy

The project specification must set a realistic construction schedule. Construction schedule will impact the level of occupancy of the facility. It is desirable to maintain about 70% of the normal occupancy during construction. This desired level of occupancy may be difficult to achieve if the construction period is too short or the volume of work is too large. Always let the contractor know how many parking spaces will remain open during construction. The number of spaces that are given to the contractor will impact the overall project schedule. A sample construction schedule and allowable loss of parking spaces is included as Table 20-10.

Table 20-9. Repair Cost Estimate

Work Item	Description	Estimated Cost
1.0	Repair damaged floor-slab	$325,000
2.0	Repair damaged beams and columns	75,000
3.0	Install new electrical conduit	25,000
4.0	Paint exposed structural steel	30,000
5.0	Install new control joints	24,000
6.0	Repair bumper guards	28,000
7.0	Apply concrete surface sealer	42,000
8.0	Install new drain system	30,000
	Subtotal	$579,000
	Plans and Specifications	30,000
	Resident services	30,000
	Materials testing	18,000
	Contingency	100,000
	Total	$757,000

20.6.2.5 Phasing and Sequencing of Construction

For owners facing budget constraints, assign priority to repair items to allocate available funds. Also, when repair costs are high, restoration work is sometimes phased over several years. The first priority is to repair structural defects to assure a safe and serviceable condition. Except for emergency repairs, priorities are assigned on a tier basis, not a work item basis. A tier (or area) of a parking deck should be closed only once for repairs. Contract priorities assigned by work items, instead of areas or tiers, can be more annoying to the facility users. Also, confining the work to a designated area minimizes the disruption of traffic circulation during construction.

When restoration work is planned and phased over several years, repair costs will be higher due to the following reasons:

1. Contractor must move on and off site more than once.
2. Smaller repair quantities each year will have higher unit costs.
3. Items not repaired in the first stage will continue to deteriorate, so volume of repairs will increase.
4. Inflation normally results in an annual repair cost increase.

20.6.2.6 Others

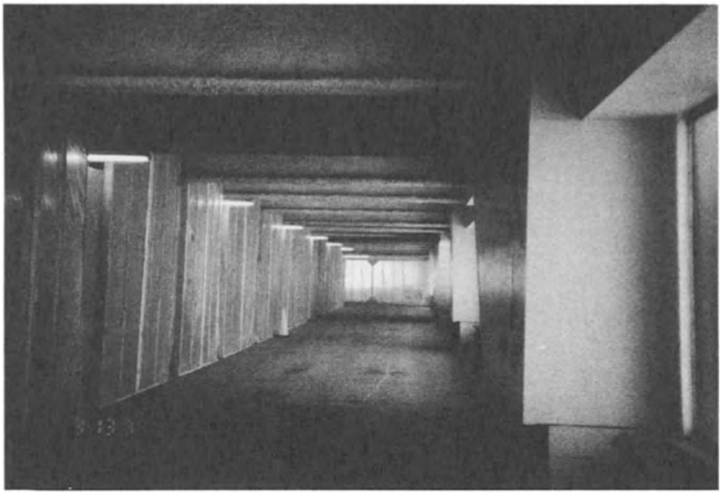
Some other items that must be covered up front in the project specifications include:

- Noise and dust control
- Concrete removal methods
- Removal of Debris
- Traffic control and maintaining accessibility

Some of these conditions that will impact the operations of the facilities during construction are shown in Figures 20-36(a) through (d).

Table 20-10. Preliminary Project Schedule

PRELIMINARY PROJECT SCHEDULE														
WEEKLY SCHEDULE FOR EACH REPAIR ITEM	6/4	6/11	6/18	6/25	7/2	7/9	7/16	7/25	7/30	8/6	8/13	8/20	8/27	9/3
MOBILIZATION	■	■												
CLASS I SURFACE PREPARATION	■	■	■	■	■	■	■	■	■					
CLASS II SURFACE PREPARATION	■	■	■	■	■	■	■	■	■					
CLASS III SURFACE PREPARATION	■	■	■	■	■	■	■	■	■					
CONCRETE OVERLAY			■	■	■	■	■	■	■	■	■			
NEW ROOF EXPANSION JOINT					■	■	■	■	■	■	■	■	■	
NEW ROOF CONSTRUCTION JOINTS					■	■	■	■	■	■	■	■	■	
REPAIRS TO LEVEL 4 EXPANSION/CONTROL JOINTS					■	■	■	■	■	■	■	■	■	
NEW CONTROL JOINTS (LEVELS 2 & 3)		■	■	■	■	■	■	■	■	■	■	■	■	
REPAIR COLUMN SPALLS		■	■	■	■									
REPAIR BEAM SPALLS		■	■	■	■									
REPAIR BUMPER WALL SPALLS		■	■	■	■	■	■	■	■					
NEW BEARING PADS (LEVEL 2 & 3)	■	■	■	■	■	■	■	■	■	■	■	■	■	
DEMOBILIZATION													■	■
DESIGNATED LEVELS	NUMBER OF PARKING SPACES CLOSED FOR CONSTRUCTION													
LEVEL 1	0	10	10	10	10	10	10	10	10	10	10	10	10	0
LEVEL 2	0	60	60	60	60	60	60	60	10	10	10	10	10	0
LEVEL 3	0	10	10	10	10	10	10	10	60	60	60	60	60	0
LEVEL 4	0	250	250	250	250	250	250	250	250	250	250	0	0	0
ROOF LEVEL	250	250	250	250	250	300	300	300	300	300	300	250	250	250
TOTAL	250	340	580	580	580	630	630	630	630	630	630	330	330	250



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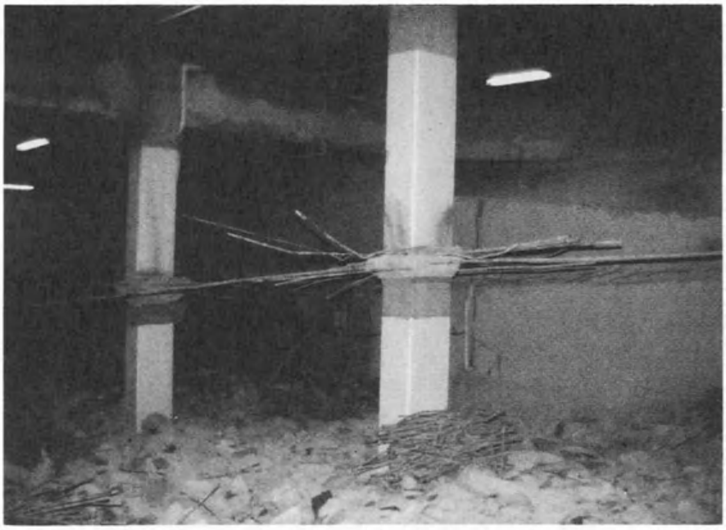
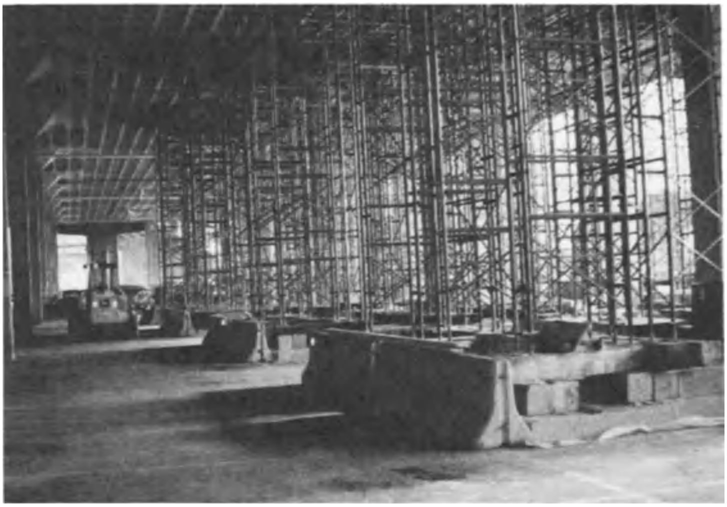


(b)

Figure 20-36: (a) Enclosure for dust control and maintaining traffic. *(b)* Debris removal procedures are specified to minimize inconvenience and disruptions.

(c)



(d)

Figure 20-36: (c) Phasing of ramp repairs to maintain accessibility. *(d)* Shoring designed to maintain traffic flow during construction.

20.6.3 Contractor Selection

Where possible, only experienced general and specialty contractors should be permitted to bid on restoration projects. Qualifications should be closely examined to determine if the contractor is able to perform the work according to specifications. Such an experienced contractor is one who has performed the type of restoration work being bid on, or has personnel who have completed similar work in the past. Evaluate contractors based on the number of similar projects completed, size of projects completed, experience and skill of personnel, bonding capacity, and reputation. Some of the criteria for contractor selection include:

- Financial strength
- Previous experience and expertise to complete the type of work
- Current work load
- Qualifications of project personnel
- Construction management capabilities
- Ability to meet project schedule
- Bid cost

20.6.4 Project Resident

A qualified project resident should observe repair work, verify repair areas, and document actual work item quantities. The resident can also monitor compliance to material requirements, repair procedures, equipment, and construction load restrictions specified by the contract documents. Field problems can be resolved promptly with the assistance of a project resident maintaining the construction schedule and minimizing any inconvenience to facility users.

20.7 MAINTENANCE PROGRAM

Effective maintenance can prolong the life of a restored facility by minimizing the deterioration of the structure, thus protecting the owner's investment. The essential elements of a comprehensive maintenance program for parking facilities are discussed in Chapter 18.

INDEX

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