Innovative Solutions in Steel:

Open-Deck Parking Structures

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Cover Photo

Tufts Health Plan Facility
Watertown, MA
1,400 spaces
Hybrid™ Parking Solutions, LLC.

Allegheny General Hospital
Pittsburgh, Pennsylvania
1,100 spaces

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EXECUTIVE SUMMARY

"Steel Parking Structures Making a Comeback!" reads the headline in a recent issue of *Parking Today*, the leading independent trade publication of the U.S. parking industry. Steel-framed parking structures today are radically different than their predecessors. New high-performance paint systems and modern galvanizing techniques have satisfied corrosion concerns and provide a protective, attractive finish that lasts for decades. Choosing a steel framing system will improve the return on your investment through benefits that concrete cannot provide including:

- lower construction costs
- greater parking density providing more parking spaces
- bright, open interiors enhancing patron security and comfort
- earlier occupancy from reduced construction time and simplified construction practices
- reduced maintenance costs as opposed to escalating restoration costs
- superior long-term durability
- unlimited opportunity for aesthetic expression
- greater design flexibility
- simplified maintenance procedures
- adaptability to irregular sites
- reduced foundation requirements resulting from a lighter structure
- convenience and ease of future vertical expansion

In every way, steel is the logical choice for your next parking project.

This *Design Aid* provides you with the information you need to make that choice. It won't turn you into a parking designer. It will help you work with your design professional to select the ideal framing system—steel. Don't get caught in the trap of tradition—break away from that same old, tired concrete parking garage! Read on and discover why the "we've always done it that way" myths of parking just don't apply in the 21st Century. Discover how to build tomorrow's parking structure today, with STEEL!

Need additional assistance?

Contact the Steel Solutions Center at 866.ASK.AISC or by email at solutions@aisc.org.
Trained staff is available to discuss your next *parking project* and assist you with *preliminary design studies* and *comparative pricing*.

Cologne/Bonn Airport
Bonn, Germany
5,850 spaces

SECTION 1

AN INTRODUCTION TO STEEL-FRAMED OPEN-DECK PARKING STRUCTURES

PARKING STRUCTURES-AN INTRODUCTION

During the past several decades, the open, above-ground, multi-level parking structure has been increasingly dotting the country's urban and suburban landscape. The scarcity and cost of urban sites for inefficient grade-level parking lots together with the growth of large suburban malls and office parks have propelled structured parking to a prominent position in the nation's building inventory.

Open-deck parking structures typically provide multi-level parking for at least 150 vehicles and have at least two sides that are a minimum 50 percent open to the outside. The open parking structure is preferable to enclosed structures in that it does not require mechanical ventilation and specialized fire protection systems. Open-deck structures also create an increased sense of security for the patron and are easier and less expensive to construct. A vehicle is designed to be exposed to weather conditions and is ideally suited to the environment of an open deck structure.

Open-deck parking structures have two major structural systems: the framing system which forms the skeleton of the structure and the deck system upon which the vehicles drive and park.

There are three basic material choices that owners and developers have for the framing systems:

- Fabricated structural steel framing (beams, girders and columns) supporting a concrete deck.
- Cast-in-place concrete framing (concrete formed, poured and cured on the construction site), conventionally reinforced or post-tensioned,
- Precast/prestressed (manufactured off-site) concrete framing using long-span double tees for deck.

Three deck options are generally utilized:

- Precast systems utilizing long-span double tees (40 ft to 60 ft long concrete sections that have two "T" stems extending down from the deck).
- Cast-in-place floor slabs with conventional steel reinforcing utilizing stay-in-place steel deck.
- Cast-in-place post-tensioned floor slabs utilizing steel cables to compress the slab after curing by placing the cables or tendons in tension.

The steel-framed parking structure provides the opportunity to use any of the three concrete deck systems, a major advantage in choosing structural steel for a parking structure. Before discussing the important factors to be considered in designing and building an open, steel-framed parking structure, it is worthwhile to review many of the other advantages that are driving an increasing number of owners and developers to make the change from concrete and choose structural steel framing.

1.1 The Advantages of Steel-Framed Parking Structures

- *Lower construction costs*. Structural steel construction is very competitive with beam-and-column systems constructed with cast-in-place or precast/prestressed concrete. Typically, steel-framed systems can be constructed with a cost savings of 10 percent to 20 percent over a concrete alternative. Structural steel fabricators (firms that prepare steel framing for assembly into a building) representing wide geographical areas can compete for open deck parking structure work around the country. More than 500 structural steel fabricators now participate in the American Institute of Steel Construction's (AISC) Quality Certification program, many of which have experience in parking structure fabrication.

Bechton Dickinson
Franklin Lakes, NJ
1,600 spaces

JFK International Airport, New York, New York
1,800 spaces - Port Authority of New York & New Jersey
Precast double tees on steel frame

Winthrop University Hospital, Mineola, New York
630 spaces - Carl Walker Construction Group
Post-tensioned deck on steel frame

- *Greater parking efficiency*. Steel columns require 80 percent less floor space than equivalent concrete columns providing more parking spaces in the same building footprint. When coupled with the opportunity to use long-span steel beams, smaller columns provide the owner with the most flexibility in layout, capacity and efficiency. Wide-flange steel beams as shallow as 24 in. can span up to 60 ft in a passenger vehicle parking structure.
- *Patron comfort, safety and security*. Small columns, bright finishes, long spans, relatively flat ceilings and braced or moment frames make a steel-framed parking structure easier to illuminate and secure. This feeling of openness, particularly in walkways, creates a positive feeling of passive security. Users often comment on how "open and bright" the decks of a steel-framed garage are. In contrast, concrete structures often require solid interior shear walls in order to resist lateral (horizontal) loads, which create visual obstructions and a "closed-in" feeling.
- *Early occupancy*. Often the timely completion of a parking structure is keyed to the opening of a commercial, residential or public facility. Unlike most buildings, the occupancy date of a parking structure is often governed by the speed of construction of the framing and floor system alone. One structural system combines the speed of prefabrication and erection of structural steel with precast long-span double tees and offers the fastest erection time for any type of open-deck parking structure. The framing systems for steel-framed parking structures are fabricated off-site and are ready for erection upon delivery. The process of assembling the steel framing for a parking structure consists of bolting proper steel segments together in a prescribed sequence. Because of the smaller member sizes, the use of steel framing simplifies erection in locations with limited delivery or construction access and allows construction in cold weather conditions. A steel framing system can be erected in a period of weeks rather than months.
- *Reduced maintenance costs*. Life-cycle cost is the average annual maintenance and repair costs to be expected over the life of the parking structure. Structural engineers and others who have studied life-cycle costs conclude that steel-framed structures are usually less expensive (J. Englot, and Davidson, R.; "Steel-Framed Parking Garages Take Off at JFK and Newark International Airports", *Modern Steel Construction*, April 2001). Parking industry experts have indicated that over a 50-year life, the cost to maintain a precast concrete deck and frame system will be between $0.05 and $0.08 per square foot, while the cost to maintain a post-tensioned deck on a steel frame will be between $0.03 and $0.05 per square foot, a savings of 40 percent. High-performance coatings (paints), galvanizing and metalizing systems are demonstrating superior long-term corrosion protection for exposed structural steel. If deterioration of the concrete deck itself occurs, a steel-frame supporting that deck will minimize the cost and time required for rehabilitation of the slab and may even save the facility from demolition and total reconstruction.
- *Superior durability*. Innovative techniques have revolutionized the corrosion-resisting capabilities of structural steel. Structural steel-frames that are coated with a high-performance, multi-coat paint system using a zinc rich primer can be expected to perform well with little maintenance for 25 to 30 years. When properly applied over a prepared surface, a three-coat paint system can provide over 30 years of corrosion protection. Recent studies have shown that after 15 years less than half of one percent of the surface area of the steel has required any form of maintenance attention (Pope, G.; "Coatings for Parking Structures", *Modern Steel Construction*, April 2001). Some parking structure owners have chosen to protect their structures by using galvanized steel. This process, which cleans steel in an acid bath followed by dipping in a hot zinc bath, can provide effective protection from corrosion in excess of 40 years. Galvanized surfaces can be painted for aesthetic purposes and enhanced durability.
- *Ease of expansion and conversion*. Structural steel simplifies future expansion, or the conversion of a parking structure to a different use. Designing for future *vertical expansion* is a desired feature for many new parking structures. Vertical expansion can be easily accomplished in a steel-framed structure through the splicing of existing columns and the placement of steel members with readily available cranes. In most cases only the top level of the existing parking structure needs to be taken out of service. The remainder of the parking structure can remain open. Steel framing facilitates the incorporation of tenant space

SMI Steel Products
Long-Span Castellated Beams
Conventional deck on steel frame

Crickelwood Hill Apartments - Built in 1974
Pittsburgh, Pennsylvania
Mulach Parking Structures
Post-tensioned deck on steel frame

in occupied lower levels or in occupied space above. The ability to penetrate, weld, bolt and reinforce structural steel in the field makes even unanticipated changes and retrofit practical.

- *Opportunity for aesthetic expression*. The ability of a steel-framed parking structure to easily accommodate a facade (the visible exterior of the structure) of exposed steel, concrete, precast concrete, masonry, glass, fiber-glass reinforced concrete (EIFS), aluminum, etc.—or combinations thereof—allows total aesthetic flexibility. Unlike concrete structures where the facade system is integral to the structural system and controlled by it, facades on steel-framed structures simply attach to the frame allowing total freedom of choice of material and configuration. This feature is increasingly important with the advent of sustainable design and architectural scrutiny by public agencies, neighborhoods and preservation or historical groups.
- *Greater design flexibility*. Steel-framed parking structures allow for well-controlled drainage systems and pipe locations. Embedded conduits, ceiling-mounted light fixtures and optimal signage placement is simplified for a tight, efficient and well-constructed parking structure with neat, clean lines. In fact, electrical conduit and other ceiling-mounted fixtures can be run through holes drilled in the steel beams rather than having to be bent under and around concrete columns. The openness of steel-framed parking structures with minimal column sizes and open ceiling plans allow for the simplified tailoring of the parking structure design to meet current and future ADA requirements.
- *Simplified maintenance procedures*. Exposed beams, girders and columns permit direct inspection, evaluation, accessibility of the frame and ease of maintenance of steel surfaces. Localized breakdown of a coating system on a steel beam is a good indication of a developing problem with the concrete deck above, such as water or chlorides (road salts) leaking through a crack or a joint. Early detection of deck leakage permits timely corrective measures to be implemented. The “sacrificial” aspect of most concrete decks on steel beams means that major deck repair and rehabilitation can be accomplished with minimum disruption and cost. Many state bridge departments appreciate steel structures for this reason.
- *Adaptability to irregular sites*. Steel framing systems are easily adaptable to non-rectangular configurations that are difficult to address with cast-in-place or precast framing systems. Smaller column footprints with the associated gain in parking efficiency allow the designer to provide more efficient parking solutions tailored to sites where traditional solutions are unworkable.
- *Reduced foundation requirements*. A steel structure can weigh up to one quarter less than a concrete structure, often an important factor in controlling seismic design, foundation and erection cost and construction schedule. This weight saving can allow steel-framed parking structures to be built economically even in areas with marginal soil conditions.
- *Seismic resistance*. As more jurisdictions adopt building codes requiring structural design and detailing for earthquake loads, the ductility (ability to flex without permanent deformation), durability and reliability of structural steel framing provides this material with distinct advantages over concrete alternatives.
- *Inherent quality control*. Shop fabrication of steel framing eliminates weather as a factor and minimizes the difficulties in quality control inherent with labor-intensive, on-site placement of reinforcing steel and forming and casting of concrete columns and beams. The selection of a steel fabricator, as well as the concrete deck subcontractor or precast/prestressed deck fabricator, should be based on experience, reputation, AISC certification, capability and the quality systems that are in place and being implemented.
- *Utilization of a recycled resource*. More than 95 percent of structural steel manufactured in the United States is fully recycled from previously used steel materials. At the end of its useful life, the steel framing system of a parking structure can be recycled into new structural steel for new buildings and other applications.

Steel-framed parking structures are the quality solution for building tomorrow’s parking structures today. A steel solution will provide years of service requiring minimal maintenance and aesthetic pleasure.

1.2 Background of Steel-Framed Parking Structures

The primary disadvantage of structural steel framing for open parking structures until the early 1970s was the cost and disruption of structural fire protection required by the model building codes. In 1972 the steel industry sponsored the full-scale Scranton Fire Test, the results of which finally put the fire safety issue to rest.

The test showed that a car fire in an open parking structure does not spread to fully involve adjacent vehicles, and temperatures of unprotected steel during this exposure are well below those at which the strength of structural steel begins to diminish (Gewain, R.; "Fire Experience and Fire Tests in Automobile Parking Structures", *Fire Journal*, 1973). As a result of intense building code and education activity during the 1970s and 1980s by local and national steel industry organizations, acceptance and application of "unprotected" steel in open parking structures accelerated quickly.

Today, under the International Building Code and other model building codes, including NFPA 5000, open, detached parking structures 70 to 80 ft high can be framed with unprotected steel in most jurisdictions. In fact, studies by the Parking Market Research Company have shown that less than $55,000 of structural damage has occurred in over 400 recent parking structure fires ("Parking Garage Fires", D. Denda. Parking Market Research Company, McLean, Virginia, 1992).

With the fire safety question resolved, the concrete industry focused negative attention on the issues of deterioration and maintenance of exposed structural steel, especially in middle and northern tier states where road salts are used. Concrete, owners were told, is "maintenance-free," while structural steel corrodes and requires frequent repainting. The steel industry's response was to encourage development of improved coating systems, which are now available for the steel framing systems including highway bridges. Experience has also alerted owners to the extent to which leakage of water and chlorides have taken their toll on parking structures framed in concrete. Today's reality is that, while regular preventative maintenance is important for every parking structure, steel framing systems require only maintenance while their concrete counterparts face expensive restoration procedures. One measure of concrete's corrosion susceptibility is the sheer number of products being marketed to:

- reduce the concrete deck's permeability
- waterproof or seal deck surfaces
- improve durability and stability
- protect all types of reinforcing steel
- prevent leakage through contraction, isolation and construction joints

"I've been in steel-framed structures built by Mulach Parking Systems more than 20 years ago. Mulach blasted the steel down to white metal and then used a high-quality three-coat epoxy paint system to protect the structural steel. All field connections were bolted—no field welding. The steel structures I saw looked better than some cast-in-place concrete frames of the same age."

(Chrest, A.; talk given at the American Concrete Institute Annual Convention, Philadelphia, PA, March, 2001.)

It is widely recognized today that steel-framed parking structures can resist deterioration at least as well, if not better than comparable concrete systems.

Coupled with the impact of the severity of the corrosive environment, there has been a lack of appreciation that the open parking structure demands closer attention to floor system design, construction and inspection than the typical building regardless of whether the parking structure is steel or concrete framed. Minor imperfections in construction that are acceptable and expected in concrete floor slabs in office or residential buildings (such as hairline shrinkage cracks) cannot withstand the severe open structure environment prevalent in many areas of the country. Once chloride corrosion of embedded reinforcing steel begins, there appears to be no way to totally halt the process, short of deck replacement or costly deck reconstruction with cathodic protection achieved by applying a permanent electric charge to the reinforcing steel. Remedial work will, at best, only extend the life of the deck. The good news is that the importance of deck design, corrosion protection, construction quality and maintenance has become recognized. Techniques required to build and maintain durable concrete decks are available. Converting recognition and availability into reality, by convincing the owner/developer to invest in sound design and construction practice, is another matter.

1.3 Management and Technical Issues in the Design and Maintenance of Parking Structures

The technical issues that arise in building durable parking structures are well known and have been addressed by design, construction and parking professionals. However, if the owner and the design and building team do not commit to implementing the required preventive measures both during construction and operation, it is unlikely the finished product will live up to the owner's expectations. Each individual on the team has to adopt an attitude and response different from those normally associated with conventional building design and construction. As pointed out in the previous section, the service conditions of the average open-deck parking structure are more severe than for standard building construction.

The *private owner or developer* wants to build an office, commercial, residential or other income-producing property. Due to local ordinance, market conditions, or insufficient land, it may be necessary to provide structured parking. Since parking is usually not the income-producing space, the owner's attention and resources are focused on other buildings or facilities in the development. Even if the parking structure is viewed as an important ingredient in the marketing plan, the owner might be inclined to upgrade finished prime space rather than invest in long-term dura-

Station Square
Pittsburgh, Pennsylvania
Original structure: 800 spaces
Expansion added: 400 spaces

bility for the parking structure. The same indifference also applies to investments in periodic or annual maintenance.

Perhaps ownership of the parking facility will be transfered to others in the future. The original owner must expect the prospective new owner to thoroughly examine the condition of the parking structure prior to the purchase. A facility that will be in need of a substantial investment in remedial work is unlikely to be an attractive proposition to the prospective buyer.

The *public owner* often has less budget flexibility, both in initial cost and annual funds for routine maintenance. Also, the public owner is generally required to accept the low bid independent of contractor quality when awarding contracts for structural work, especially for building construction.

The *architect* must weigh the impact of aesthetic treatments on the economy, efficiency, durability and maintainability of the parking structure. There are also important human issues to consider including safety, security, accessibility, signage, lighting, ventilation and visibility. However, since the primary "tenant" is an automobile, the ultimate goal of the design professional is to develop an acceptable program for parking, movement and processing of vehicles.

The *structural engineer* must learn how to deal with the corrosion of concrete due to chlorides, and the distress caused by restraint to volume change and dimensional changes in concrete elements due to curing and thermal effects. The usual criteria for selecting column grids in conventional buildings are replaced by factors such as stall design and layout, ramping, safety, parking capacity and traffic pattern. Efforts normally spent designing and constructing floor slabs to achieve a level surface in occupied buildings must now focus on achieving non-level, drainable surfaces that are essential for long-term durability in a parking structure. The structural engineer must also assume the lead in assuring quality of the finished product.

The *general contractor* is most comfortable constructing the open parking structure to the same specifications as other buildings. However, the care required to build a durable parking deck is far beyond that required for the conventional floor slab. The contractor must accept responsibility for implementing the special procedures and precautions outlined in the project specification and on the design plans.

Long-term performance of the parking structure ultimately depends upon the quality of construction by the key *subcontractors*—those firms that place reinforcing or prestressing steel, post-tension, cast and cure the concrete, install joints, apply sealers or membranes, fabricate and erect the structural steel, and paint, galvanize or metallize the steel. Regrettably, on most public projects, prequalification of subcontractors is not permitted. And yet it is vital that the structural subcontractors have the experience, capability and commitment to produce the quality work required for the durable open parking structure. It is recommended that the selected structural steel fabricator maintain quality certification through AISC Quality Certification (for more information on the AISC Certification process please visit the AISC web site, www.aisc.org). If precast/prestressed concrete elements are used as the deck system, precasting plants should be certified by the Prestressed Concrete Institute (PCI).

The primary management issue is that the design and construction of durable open parking requires implementation of an effective *problem control system* during construction and an effective plan for regular preventive and remedial maintenance. The concept, design and specifications for the concrete deck and the supporting steel frame will largely determine the success of the facility: its initial cost and its ability to perform, relatively problem free, for the design life expectancy. Therefore, it is recommended that the structural engineer for the parking structure, at the least, share the lead role as prime designer, in close association with others charged with developing the optimum parking concept.

1.4 Specifying a Steel-Framed Parking Structure

If you are an owner or a developer, how do you avoid the pitfalls inherent in parking structure construction and gain the advantages of using steel in the framing system for your next parking structure? And more importantly, what steps do you need to take to ensure that you will obtain a quality steel structure?

Burlington International Airport
Burlington, Vermont
1,140 spaces
Hybrid™ Parking Solutions

1. Select a designer familiar with the intricacies of parking structure design and the use of steel framing systems. Indicate that you want to explore the benefits that steel will bring to your project. If you choose to approach your next project on a design-build basis, several firms are prepared to provide both design and construction services for steel-framed parking structures. References are available through the Steel Solutions Center at 1.866.ASK.AISC.
2. Working with your designer, identify an AISC Certified steel fabricator who will be able to work with you on the design, detailing, fabrication and erection of your new parking structure.
3. Select the proper deck system that meets your durability, performance and financial criteria. Make sure the deck design provides a proper slope for drainage and correct placement of drains and stormwater discharges. A discussion of non-structural design criteria for parking structures can be found in Appendix B.
4. Specify a high performance coating or galvanizing system to provide long-term corrosion protection for your structure. Follow the guidelines of the coating system manufacturer with respect to surface preparation, number of required coats and application. For galvanizing specify the minimum zinc thickness (generally at least 4 mils).
5. During construction ensure that care is taken in the fabricating and erecting process. No field welding should take place and galvanized bolts should be used. Any erection damage should be immediately addressed by properly cleaning the area. The multi-coat system or metalizing compound should then be applied.
6. After the completion of construction, institute a regular program of preventative maintenance as outlined in Appendix A including regular visual inspection of the parking structure and the touch-up of the minimal areas in need of maintenance.

Additional information regarding steel-framed parking structures, assistance in locating a certified steel fabricator or experienced design-builder of parking structures, the development of a conceptual solution for your parking structure and technical support during design and construction is available by contacting the AISC Steel Solutions Center at 1.866.ASK.AISC or solutions@aisc.org.

Portland International Airport
Portland, Oregon
3,300 spaces added
KPFF Consulting Engineers and
Zimmer Gunsel Frasca Architects

SECTION 2

GENERAL CONSIDERATIONS FOR OPEN-DECK PARKING STRUCTURES

PLANNING PARAMETERS

There are many parameters that parking structure developers, municipalities and consultants must consider in planning and designing a new facility. Some of these are:

- Environmental impact
- Parking demand
- Financial feasibility
- Circulation patterns
- Operational systems
- Parking space and module design
- Neighborhood concerns
- Security and comfort
- Ventilation
- Illumination
- Signage
- Revenue control
- Traffic access
- Site constraints
- Life expectancy
- Maintenance

Organizations such as the National Parking Association (NPA) and the Institutional and Municipal Parking Congress (IMPC) publish guidelines for the planning, design and construction of parking structures (*Recommended Guidelines for Parking Geometrics*, Parking Consultants Council, National Parking Association, 1989).

In recent years, firms specializing in open parking structure design have emerged across the country to satisfy a growing demand for this expertise. However, a parking structure consultant may prefer a certain type of deck or framing system, and the owner should confirm the consultant's familiarity with local market and environmental conditions where the facility is to be built. Regional differences in market conditions, contractor expertise and availability of materials may influence selection of the concrete deck system for a steel parking structure.

The remainder of this section discusses the general parameters that influence the design of the deck system and structural frame, which may account for more than 50 percent of the total construction cost.

2.1 Economy and Initial Costs

The initial costs of a parking structure are determined by the selection of a site, subsurface conditions, the choice of a framing and deck system, local labor and material prices and financing costs during the construction period. The speed of design and construction is particularly critical to revenue-generating parking structures or in situations where an adjacent office building or similar structure cannot be fully leased until adequate parking is provided. The parking designer should take each of these factors into account in the original budget provided to the owner. Cost reductions can be accomplished through:

- the choice of structural systems that may minimize overall structure weight reducing the foundation requirements
- optimizing bay sizes for maximum parking capacity within the structure's footprint (or minimizing structure size for a given parking requirement)
- the evaluation of various facade options

2.2 Economy and Life-Cycle Costs

The expenses of ownership of a parking structure do not end when the first car is parked. Ongoing maintenance programs are critical to the long-term life of the parking structure. A regular program of preventive maintenance at a reasonable annual cost can avoid the future expense of major renovation ("Pay a little now or a lot later"). The cost of these preventive maintenance programs and the anticipation of future remedial actions must be taken into account when evaluating the true cost of ownership and the life-cycle cost of the structure. Items to be considered for maintenance and remedial action are:

- the expected life of the concrete system including the quality of the wearing surface and joints
- the replacement of concrete sealers and membranes
- the structural integrity of the concrete deck, columns and beams
- the performance of the coating system on steel members
- the integrity of the drainage system
- the condition of rails and facades

The choice of framing system can greatly impact the life-cycle cost of a parking structure. A comprehensive life-cycle cost study was recently performed by an outside consultant of a steel-framed parking structure at Newark Airport for the Port Authority of New York and New Jersey. The findings of that study verified that their steel-framed structure was the most cost-effective solution both in terms of construction and life-cycle costs (J. Englot, and R. David-

Newark International Airport-Newark, New Jersey
3,300 spaces
Port Authority of New York and New Jersey

son; "Steel-Framed Parking Garages Take Off at JFK and Newark International Airports", *Modern Steel Construction*, April 2001).

2.3 Structural Durability

Closely related to life-cycle costs is the evaluation of the long-term structural durability of the structure. Concrete decks and structural members deteriorate as a result of chloride migration compromising the structural integrity of the parking structure. This may necessitate the removal and replacement of deck slabs or the need to structurally reinforce concrete columns and beams through the use of steel bands or concrete encasement techniques. To address these structural concerns is a costly, time-consuming process that will take the structure out of operation and often results in reduced parking capacity. When a concrete deck on a concrete framed structure requires replacement, the entire structure may have to be demolished while in a steel-framed structure, the original framing system can be cleaned, repainted and reused in the rehabilitated structure.

2.4 Ease of Maintenance

Maintenance of "life-cycle" costs are directly impacted by the ease of maintenance of the parking structure. Ease of maintenance should be considered in the initial design of the structure, including:

- drains should be located at points of easy access
- structural connections should be exposed for inspection
- expansion joints should be laid out for easy replacement of the seals
- storm water discharges should be accessible
- a defined procedure simplifying upper deck snow removal should be included
- visual inspection opportunities should be optimized
- areas of the structure should be able to be easily catalogued for tracking progressive deterioration

2.5 Ease of Construction

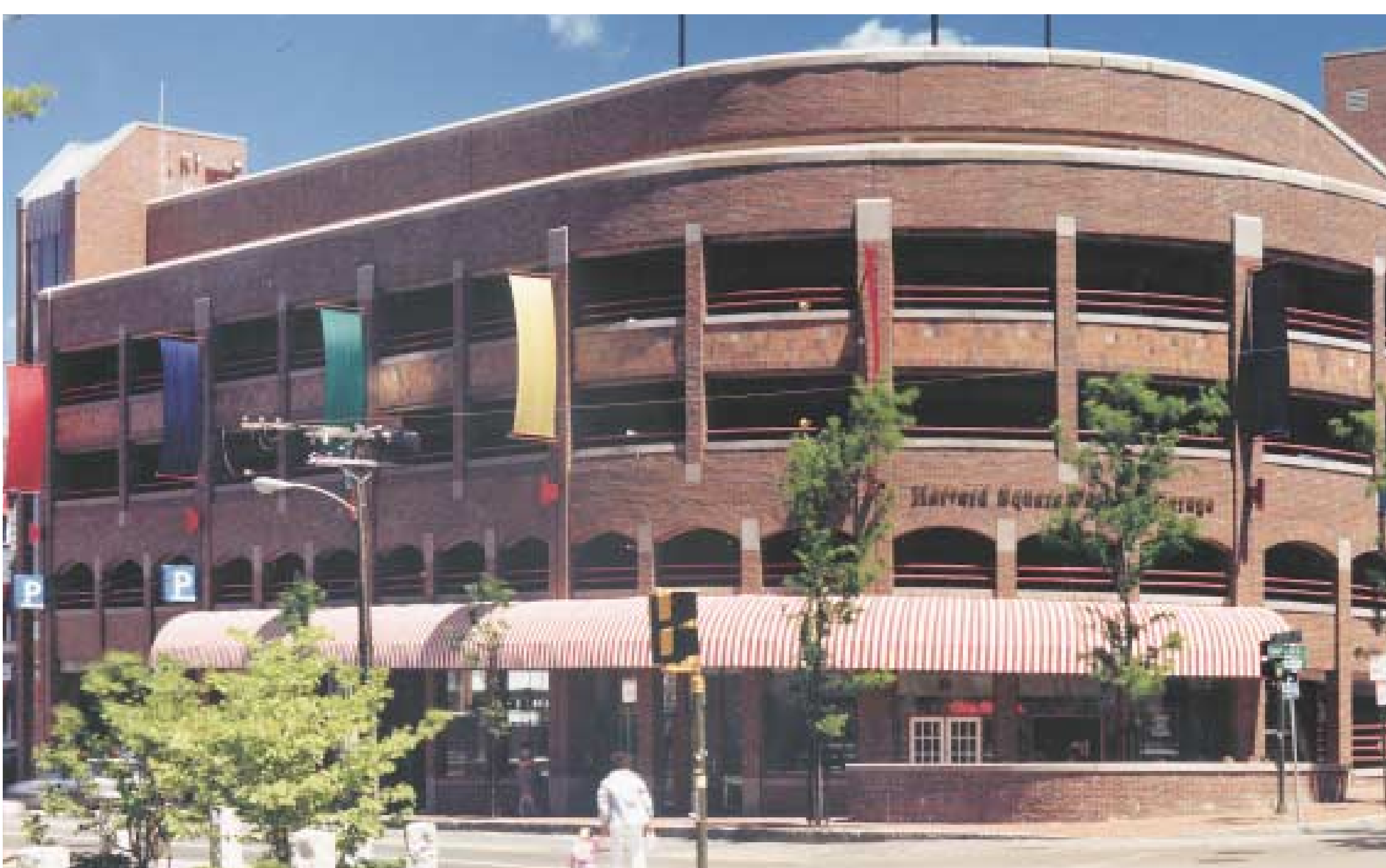
For many parking structures, the ease of construction will have a direct bearing on the construction costs of the project. Issues to evaluate should include:

- availability of storage space on the site for material delivery
- foundation conditions
- the ability of structural materials to be placed in winter conditions
- crane setup locations
- tight erection clearances
- the ability of trucks to deliver components in congested areas
- the erection sequence of components
- the ability of the partially erected structure to be self-supporting
- the need for shoring and bracing

2.6 Seismic Performance

In seismic regions the design of the parking structure must take into account lateral forces due to seismic (earthquake) loading. In seismic design, the dead load, full live load and the seismic loads are combined and the structure is designed for combinations of these effects. Common lateral load resisting systems used in steel parking structures are:

- Braced frames where the lateral load is resisted by diagonal members including K, X, or V (chevron) braces (this is often the most economical).
- Moment frames where the lateral load is resisted in the stiffness of the connections between the steel members. Moment frames



may be more expensive, but may need to be used in areas such as ramps where braced frames cannot be used due to traffic flow requirements.

- Flexible moment connections or semi-rigid frames designed to distribute the lateral load through controlled displacements are one of the lesser used systems but often have the best balance of stiffness and strength under low to moderate seismic load. They are both economical and efficient.
- Composite systems consisting of steel and reinforced concrete can be very economical in seismic areas for use in parking structures. This is particularly the case if the structure requires fireproofing as the encasement of the steel with concrete satisfies both painting and fireproofing requirements.

Concrete-framed structures typically require the use of large concrete shear walls or complex moment frames. Shear walls disrupt the openness of the parking structure's design and create security concerns. Concrete moment frames require a high degree of field expertise and may extend outside the footprint of the structure requiring additional site area.

2.7 Appearance

For most buildings, the exterior facade is both a major architectural feature and part of the envelope that protects the interior from weather. For the above-grade open parking structure, the facade is the primary architectural feature that often incorporates the exterior safety barrier and acts as a screen to block the viewing of parked cars. Perhaps the major decision for the owner and designer is whether the facility should be identifiable as a parking structure to the prospective patron or if, for some reason, it should not appear to be a parking structure at all. This determination may dictate the facade selection and may depend on whether the patrons are employees, local residents, or out-of-town visitors unfamiliar with the locale. A steel framing system provides the design flexibility to allow the architect to conceive an exterior facade system that is at once economical, attractive, compatible with the surroundings, acceptable to reviewing agencies and "open" to eliminate a fire resistance requirement.

Economical, detached, above-ground steel-framed parking structures have been typically built for $5,000 to $10,000 per space depending on the region of the country (costs are from the year 2002). Cost-per-space of a structure can escalate rapidly if the facade itself is very elaborate, or difficult to fabricate and install, especially if the perimeter-to-floor area ratio is high. A massive, heavy facade can add substantial load to the perimeter foundation and require more costly design, detailing, fabrication and erection for seismic resistance. The most economical facade is simple, serves as a structural safety barrier, and is easily attached to the steel frame.

The selection of the facade treatment on a parking structure is important from a security, aesthetic and cost standpoint. Parking structure owners and developers are now realizing that the first impression a visitor receives of their organization is often conveyed by the parking structure. Many municipalities are now requiring that parking structures blend into the architectural aesthetics of the neighborhoods in which they are located. For these reasons the choice of a facade treatment can be a critical choice for the structure. Facade systems are available to create literally any exterior treatment desired by the owner. Even in cases where a desired facade may not contain the required amount of openness to allow the structure to qualify as an open-deck parking structure, the desired facade may be used on one side of a structure while a more open facade can be used on the other sides allowing the structure to meet the openness requirements.

Harvard Square Parking Garage
Cambridge, Massachusetts
215 spaces
Maguire Group

2.8 Safety and Security

Safety, security and patron comfort issues have a necessary influence on parking structure design. The brightness of interior finishes and smoothness of the ceiling impact the type and quantity of illumination. Light cores that extend to the top of large structures introduce daylight to interior areas and double as snow chutes during winter. From a safety perspective, 90º parking with wide aisle widths may be preferred. The "over-cut basement", in which earth is removed from around below-grade levels, provides an opportunity to eliminate structural fire protection, introduce natural light and eliminate totally enclosed levels. External glass-enclosed elevator and stairwell cores improve visibility and increase the sense of security for patrons. Video monitoring and emergency call systems improve security and help patrons with car trouble to obtain assistance. The owner may wish to retain a special security consultant to review the passive and active security measures that are available or have been incorporated into the design.

2.9 Space Allocation

In establishing the feasibility, size, design concept and cost of a parking structure, the average floor area to be occupied by one parking space must be determined. This figure is obtained by dividing the total square footage of the structure (all levels) by its capacity, in total number of cars to be parked. The area-per-space ratio depends on many factors: size and shape of the buildable area; stall size, aisle width and ramp design; ratio of small to full-size cars; short- or long-span module; traffic flow system; mixed-use occupancy requirements (above or below); and local ordinances. The average area per space can vary from about 280 sq ft to 400 sq ft. For planning purposes 300 sq ft to 325 sq ft is typically used. When comparing *average cost per space (i.e., cost per car)* for design alternatives this ratio must be considered.

In recent years, angle parking has become a popular stall design for self-parking structures, primarily because it is easier for drivers to maneuver and less driving aisle is needed than for 90° stalls. Angle parking, typically 50° to 70°, consumes a larger floor area per space but the parking module, and perhaps even the over-all width of the structure, can be narrower. Angle parking uses one-way aisles, which may reduce congestion, but the narrower aisle may be perceived to be less secure for patrons walking to and from their cars. The 90° stall pattern allows a more uniform grid and appears to simplify ramp design. Section B.8 of this *Design Aid* provides additional information on stall layout.

The Parking Consultants Council of the NPA states that parking space width can vary from 7 ft 4 in. for all-day patrons with small cars, to 8 ft 10 in. for high-turnover patrons with large cars, to about 12 ft for handicapped spaces. For a "one-size-fits-all" design, assuming a 70/30 ratio of large to small cars and 90° parking, an 8-foot-6-inch space width and a 60 foot wall-to-wall module may be used for planning purposes.

Fashion Square Mall-Sherman Oaks, California
1,793 spaces
ANF & Assoc., Kensco Engineering

2.10 Short- versus Long-Span Design

Sometimes the bay sizes and interior spans in a parking structure are dictated by factors other than parking efficiency. Framing for parking below steel-framed multi-story office or residential space having a 25 ft by 27 ft bay size will probably be more economical if the steel columns continue directly down through the parking levels to the foundation, avoiding structural transfers to longer bays at the transition floor. Other incentives for short spans are poor soils that require close footing spacing for load distribution and a limitation on the depth of structure floor construction.

Long-span modules, typically 55 ft to 65 ft, may be heavier, but cost 10 percent less due to fabrication and erection efficiencies. The number of stalls within the structure can be increased or the overall size of the structure can be reduced through the use of long-span design. Advantages of long spans in parking structures include:

- column-free areas that simplify maintenance and improve illumination
- less opportunity for damage to automobiles
- more openness and improved psychological effect on patrons (safety, comfort)
- greater flexibility to re-stripe stalls in the future
- fewer spaces lost to careless parkers in three-car bays
- less surface area of structural steel to be treated for corrosion protection

2.11 Story Height and Floor Depth

Depth of floor construction has emerged as an important factor governing the selection and design of floor systems for many types of buildings. Restriction of floor construction depth arises from local zoning (either total height or headroom), the need to match floors of an existing connected building, ramp grade requirements, and, for below-grade levels, shallow bedrock or a high water table. The minimum recommended clearance or headroom for parking structures is 7 ft 2 in. (sometimes codified), but clearances as low as 7 ft may be used. (The designer should consider detailing for a clearance that is 2 in. greater than the minimum required to allow for tolerances in beam camber and construction.) Where van access by disabled patrons is required, the minimum clearance to the lowest overhead obstruction is 8 ft 2 in. To determine story height the designer should factor in the thickness of any mechanical and electrical services and fire protection that will run below the structural framing systems. Consideration should be given to running these services through web openings in steel-framed structures.

Astute structural engineers have been successful in condensing steel beam floor construction to acceptable depths by the use of

TABLE 2-1				
	UBC Type IIN		**IBC Type IIB**	
Fire Resistive Requirement	None		None	
Definition of Open Side	40% of side length		50% of interior wall area of exterior wall	
	sq ft/tier	# of tiers	sq ft/tier	# of tiers
2 sides open	30,000	8	50,000	8
3 sides open	37,500	9	62,500	9
4 sides open	45,000	9	75,000	9
Exception*	unlimited	height<=75 ft	unlimited	height<=75 ft

*the distance from any point on the deck may not be greater than 200 ft from an open side

LRFD (load and resistance factor design), cambering, composite beams, beam web penetrations, castellated beams and innovative steel beam/concrete floor systems.

In parking structures, as in all buildings, greater floor-to-floor height translates directly into increased cost of facade and other vertical building elements. With a simple and economical facade, the impact of this element on total cost is minimal. Decreasing depth of floor construction, below that of the most economical framing, may increase floor framing cost to some threshold that will exceed the savings accrued through lower total building height.

Depending on the length of horizontal run available, desired ramp grades may influence depth of floor construction. Generally, straight-run ramps with no parking stalls or pedestrian traffic on either side have 10 percent to 15 percent grades (slopes); a 12 percent maximum slope is suggested for long ramps. Any ramp with a slope greater than 14 percent will require a transition slope at the end of the ramp. Single lane ramp widths are usually 12 ft curb-to-curb, but 15 ft to 16 ft is advised if approaches or turns are particularly sharp. For the parking ramp itself, a 5 percent grade is preferred under ADA guidelines, although a 6 percent slope is generally acceptable.

In parking structures with 55 ft to 65 ft spans, total floor depth will depend largely on the steel beam depth. Depending on the bay size, these spans are typically made with W24 to W30 composite design beams of A992 (standard 50 ksi) steel. It would appear that for the long-span parking structure, a minimum total floor depth of around 30 in. must be expected. If shallower floors are required, shorter spans have to be considered. Thus, the designer should determine very early if there is a limitation on the depth of floor construction in the parking structure, because such a restriction can have a significant impact on the column grid and on selection, design and cost of the floor system to be used.

2.12 Structure Height and Fire Safety or Protection Requirements

Under all of the model building codes, no fireproofing is required for structural steel members in an open deck parking structure less than 75 ft in height as long as any point on any parking tier is within 200 ft of an open side. It should be noted that the height of a parking structure is measured to the top of the deck for the top parking tier, not to the top of any facades or parapet walls (this is based on the treatment of the top tier as the "roof" of the parking structure with parking allowed on the roof).

Jefferson at Lenox Park
Atlanta, Georgia
622 spaces
Alliance Structural Engineers; JPI Construction

Portland International Airport
3,300 spaces added
KPFF Consulting Engineers &
Zimmer Gunsel Frasca Architects

However, it is possible for a steel-framed parking structure to exceed the 75 ft limitation based on the square footage of each tier and the number of open sides. Table 2-1 presents the parameters used in determining maximum height and tier area under both the Uniform Building Code and International Building Code. The prospective owner of a parking structure should consult with local building code officials to determine any local modifications of the relevant code provisions.

When evaluating tier area and structure height, the impact of any future vertical expansion should be taken into account.

When parking is being provided on the lower floors of a mixed-use structure, the lower parking floors must be fire separated from the upper floors and be fire rated.

2.13 Ongoing Maintenance

The importance of annual inspection and maintenance of open parking structures cannot be overemphasized. Annual maintenance is required independent of the material selected as a framing system. Corrosion in steel-framed parking structures is similar to most human diseases; inspection and early detection (like regular checkups) preventive maintenance (like a healthy living style), and timely response (treatment) are the keys to controlling deterioration due to corrosion. Steel-framed parking structures allow for visible corrosion inspection. Corrosion also occurs in concrete-framed garages as chlorides migrate through the concrete to the reinforcing bars. As the reinforcing bars corrode, they increase in volume, damaging the surrounding concrete and requiring expensive restoration work. Some of the periodic activities that owners of open parking structures should invest in are:

- preventing clogged drains
- inspecting deck joint seals
- inspecting structural steel surfaces for coating breakdown and evidence of deck leakage
- inspecting and sealing of visible cracks in the deck
- touching up any visible corrosion of the structural system
- thorough washing of the deck each spring
- replenishment of surface and penetrating sealers

Of the above measures, probably the most important and cost-effective inspection activity is that of finding and sealing visible cracks in surface of the concrete deck. Deck cracks are the Achilles heel of open parking structures.

Appendix A of this *Design Aid* contains a suggested checklist for the regular structural maintenance of a steel-framed parking structure.

"Steel was the most cost-effective building material and simultaneously fulfilled all aesthetic expectations, signaling a bright future for its use in similar applications."

Helmut Jahn

Cologne/Bonn Airport
Bonn, Germany
5,850 spaces
Murphy/Jahn Architects

SECTION 3

SUMMARY CONSIDERATIONS

The design and construction of a quality, open deck parking structure in many ways is more complex than it initially may appear. As an owner, consultant or design professional, it takes effort and expertise to reach your goal of a parking structure that will stand the test of time. Structural steel framing systems will help you accomplish that goal by allowing you to construct tomorrow's parking structures today.

In approaching the design of a parking facility it is important to keep the following points in mind:

1. The owner must be able to clearly define the requirements of the parking structure including its capacity, location and type of usage. In addition, the owner should specify the desired life span of the structure and the life-cycle cost parameters that will need to be met. A target construction budget based on dollars per parking space should be developed, and an annual maintenance budget that takes into account periodic maintenance should be established (see Appendix A).
2. The design professional/consultant/design-builder should assist the owner in developing preliminary designs that are generic as to framing and deck options, but explore various parking, deck and ramp configurations. When the owner settles on a specific configuration, the design professional should assist the owner in selecting the optimal framing system and deck type for the location, usage and cost considerations of the structure. Steel framing systems should be evaluated in this process. If necessary, the owner should visit steel-framed parking structures protected with high-performance coating systems to personally verify the long-term durability of steel framing systems. Good performance and longevity can be achieved from a variety of concrete deck systems on steel framing, including cast-in-place, precast/prestressed and post-tensioned.
3. Particular care should be paid to the design of the concrete deck. A primary objective of design and detailing of the concrete deck should be to minimize shrinkage cracking, cracking due to thermal effects, cracking due to structural restraint and discontinuities, and leakage through joints and cracks. Items such as crack control, low water-cement ratio, properly cured concrete, adequate clear cover for top reinforcing bars, and drainage of the deck surface are critical quality criteria for the concrete deck and should be taken into account by the structural designer. If chloride contamination of concrete decks in car parks is a threat, additional measures for corrosion protection, beyond the quality criteria for the concrete itself, should be evaluated and specified in the design. Deck deterioration is the number one maintenance concern and cost for an open-deck parking structure.
4. A high-performance coating system must be applied to structural steel and miscellaneous iron used in parking structures. Both paint systems and hot-dip galvanizing can be used. Proper surface preparation of the steel is critical for a high performance coating system.
5. The owner/developer must accept the responsibility for implementing a program of periodic inspection and maintenance for open-deck parking structures. The designer should provide guidance in this area.

Because of its economy, speed of construction, ease of inspection and long-term durability, structural steel has become a preferred framing material for open parking structures.

After completing work on a major 5,850-car parking structure, noted Chicago architect Helmut Jahn commented "during the design process, several construction systems including cast-in-place concrete, precast concrete, composite systems and steel were considered for the structural system. The car park was designed to accommodate all structural systems and the bidders were asked to propose the most cost-efficient construction. The result of the bidding process showed that steel, in conjunction with composite floor decks, provided the most cost-effective structure. Furthermore, steel has the advantages of shop fabrication, ease of erection and appropriate aesthetics."

Discriminating parking structure owners, consultants, architects and structural engineers are discovering that they agree with the conclusions of Mr. Jahn with respect to parking structure framing systems. Steel is the material of choice for modern parking structures.

Allegheny General Hospital
Pittsburgh, Pennsylvania
1,100 spaces
Mulach Parking Structures

Tufts Health Plan Facility
Watertown, Massachusetts
1,400 spaces

APPENDIX A

THE STRUCTURAL MAINTENANCE OF PARKING GARAGES

Abridged from "The Structural Maintenance of Parking Garages", ***Parking***, November 2001
by Mr. David Monroe, President, Carl Walker Construction, Pittsburgh, Pennsylvania

A regular maintenance program is crucial to preserving the garage, providing a satisfactory level of service, and meeting service-life expectations, without premature deterioration, undue repair expense, interrupted service, inconvenience to patrons, or loss of cash flow. Neglected problems can lead to safety hazards for users, increased liability for owners, and necessitate expensive repairs in the long run.

Preventive Maintenance

Preventive maintenance will reduce repair expenses in the long run and extend the service life of the structure. Maintenance activities should include:

- *Snow removal.* Chlorides, which are in road salt are carried into the garage via vehicles, can be a garage owner's worse enemy because of the damage they do to concrete. Guidelines for deicing the garage are:
    - Clean, plow and scrape off ice and snow without use of any deicing agents. Take care not to damage joint sealants, deck coatings, or the concrete deck elements themselves.
    - Use sand to increase traction; when washing down the deck, be sure to protect the drainage system with temporary burlap or straw filters.
    - Deice with urea or CMA (a proprietary nonchloride deicer)
    - Use a mixture of sand and calcium or sodium chloride, but protect the drainage system from sand.
- *Cleaning.* A good maintenance program will include regular wash-downs with water to remove debris. This is especially important in the spring to remove dust, debris and especially road salt, which contains harmful chlorides.
- *Repairs and Restoration.* When potential problems are identified, a specialty contractor should be retained to perform corrective measures. Typical work includes repair of deteriorated concrete, sealing of cracks and joints, repair of expansion joints, and application of sealers and traffic deck membranes. Sealants have a finite life, so even the most effective will need to be replaced periodically.

Annual Inspections

A walk-through inspection should be conducted at least once a year. Do this in conjunction with a wash down of the structure, so that any active leakage can be noted and its source identified. Look for cracks, leaks, joint sealant failures and general surface deterioration.

Using plan sheets of each floor, proceed with the inspection, walking through the entire garage and marking on the plan sheets any areas where problems are observed. It is helpful to use a code system to denote problems and their locations, for example, "L" for leak, "C" for corrosion, "J" for joint deterioration, and so on. Use lines to show where cracks exist and their sizes. Also, take photos of any deteriorated areas to serve as a record of the damage. It is important—and cost-effective—to take care of cracks, leaks, and joint deterioration early on, before the problems grow.

Sometimes concrete may be damaged, even though there are no visible cracks or surface deterioration. A simple "chain-dragging" survey can help evaluate suspicious areas. Drag a length of chain over the concrete wherever a problem is suspected. A hollow sound indicates that the concrete is delaminating and a significant problem may be developing. A hammer or metal rod may also be used; simply tap on the concrete and listen. If the chain-dragging survey reveals a problem, or if there are noticeable cracks on the faces of concrete columns or on beams, particularly near bearing areas, an engineer with experience in structural forensics should be consulted for follow-up.

Five-Year Inspections

Every five years or so—or whenever structural problems are suspected—consult a structural engineer with experience in the type of framing system utilized in the garage, concrete restoration/repair and waterproofing technology to conduct a comprehensive inspection. These experts know what to look for and can provide the information needed to make sound recommendations as to what corrective measures should be considered. It may also be appropriate to do some physical testing of the structure as part of this inspection to establish baseline performance or to better evaluate potential problems. A specialty contractor with experience in concrete restoration/repair and waterproofing technology can also conduct this type of survey, and will usually do so at no cost to the garage owner. The contractor can also do the required repairs and develop a maintenance budget for the structure.

Summary

Ultimately, it is the parking garage manager's or owner's responsibility to keep an eye out for problems, document these problems and call in engineers and contractors when necessary to perform maintenance and repairs. Implementing a maintenance program and following through with inspections and repairs can increase service life, decrease costs, and prevent small problems from becoming big repair bills.

Decks

- ❑ Are there any cracks? Do they leak?
- ❑ Is the surface sound, or are there areas of surface scaling?
- ❑ Does a chain-dragging test reveal a hollow sound in any areas?
- ❑ Is there any evidence of concrete delamination?
- ❑ Is there any evidence of corrosion of reinforcing steel or surface spalling?
- ❑ Are there any signs of leakage? Describe conditions and note locations.
- ❑ If there is a traffic bearing membrane, does it have any tears, cracks or loss of adhesion?
- ❑ Are there low spots where water ponding occurs?
- ❑ Are there water stains on the underside (soffit) of the deck?
- ❑ Has the concrete been tested for chloride-ion content? When was it last tested?
- ❑ Are records of previous inspections available?

Exposed Steel

- ❑ Are there any signs of corrosion on the beams or columns? Is the corrosion a surface effect or is there a significant loss of section?
- ❑ Is there any other exposed steel (handrails, door frames, barriers, cable, exposed structural connections) where corrosion is visible? Is it surface corrosion or is there significant loss of section?
- ❑ Is repainting required?
- ❑ What is the condition of the interface or attachment point between the steel and the surrounding concrete?
- ❑ Is there any staining that would indicate deck leakage adjacent to the steel member?

Stair and Elevator Towers

- ❑ Are there any signs of a leaking roof?
- ❑ Are there any cracks in the exterior finish?
- ❑ Are there any signs of corrosion-related deterioration of stairs or railings?
- ❑ Are any other corrective actions required?

Expansion Joints

- ❑ Are there leaks through isolation-joint seals?
- ❑ Are leaks related to failure of the seals or the adjacent concrete?
- ❑ Could the cause be snowplows?
- ❑ What type of isolation joint/expansion joint seal is installed?
- ❑ Who is the manufacturer?
- ❑ Is there a warranty in force?
- ❑ Consult the manufacturer for repair recommendations if applicable.

Joint Sealants

- ❑ Are there any signs of leakage, loss of elastic properties, separation from adjacent substrates or cohesive failure of the sealant?
- ❑ Are there failures of the concrete behind the sealant (edge spalls)?

Drains

- ❑ Are drains functioning properly? When were they last cleaned?
- ❑ Are the drains properly located so that they receive the runoff intended?
- ❑ Are seals around the drain bases in good condition?

Previous Repairs

- ❑ Are previous repairs performing satisfactorily?
- ❑ Are the edges of previous patches tight?
- ❑ Do the patches sound solid when tapped?

APPENDIX B

NON-STRUCTURAL DESIGN CONSIDERATIONS FOR OPEN-DECK PARKING STRUCTURES

GENERAL NON-STRUCTURAL DESIGN CONSIDERATIONS

Planning for design and construction of a parking structure is concerned principally with the typical parking floor layout and ground floor configuration. The typical floors usually serve as a part of the ramp systems between the floors. The main floor serves primarily as the traffic control area where customers enter or leave by car or on foot. The design process of the structure must take into account:

- the number of cars that need to be serviced by the facility and the level of service provided
- the dimensions of the selected site
- the subsurface conditions that will be encountered in the placement of the foundation at design capacity
- provisions of national and local building codes
- the required clearance heights, number of decks and light wells
- the traffic flow entering and exiting the facility
- the ramp system within the parking structure
- the stall configuration
- the curbs and bumpers required in the facility
- pedestrian flow through the structure
- street access
- fire codes and protection systems
- drainage of stormwater out of the facility
- security issues
- signage
- lighting

B.1 Capacity Determination

The required capacity of the parking structure can be determined based on the type and capacity of the facility being served. Demand capacities for various types of usages are available from the National Parking Association in Washington, DC, and are based on either square footage calculations or user ratios. For example, 4.5 parking spaces should be allocated for every 1000 sq ft of mall space while a medical facility requires anywhere from .75 to 4 spaces per bed.

For some structures the type of usage also impacts both the sizing of the facility and the layout of the parking area. A major sports arena will require sizing and design to allow a large number of vehicles to exit in a short period of time, while a retail mall will see a more level flow of cars into and out of the facility during the typical business day. Such factors as these along with the mix of occasional and regular parkers will help determine the “Level of Service” that will direct the design process.

B.2 Site Selection

Potential sites should be evaluated based on the following criteria:

- Is the cost of land reasonable for the project?
- Does the site permit an efficient structure plan? (If the width of the site is less than 95 ft, the efficiency of the structure will be seriously impaired.)
- How is the site located relative to the destinations of the users?
- How well does the site lend itself to a parking facility with respect to any municipal development plan?
- Does the site provide opportunities for non-parking use of a part of the structure?
- Can proper access to the site be achieved via the adjacent streets?

B.3 Subsurface Conditions

Once a site is identified, a preliminary environmental and subsurface investigation should be performed. The environmental investigation will determine if any unforeseen environmental conditions may stall the project. The subsurface investigation will determine the ability of the soils at the site to support the parking structure. The type of foundation required, the depth of the foundation and the bearing capacity of the soil will also be determined. If poor soil conditions are encountered, the extra costs can be evaluated early and a determination can be made if the project can proceed on the selected site. When making that determination, alternative framing options should be considered that may reduce the overall weight of the structure and reduce the associated foundation costs.

B.4 Building Code Provisions

The parking structure designer needs to be aware of which of the national building codes (International Building Code 2000 (IBC), BOCA, Uniform Building Code (UBC), Southern Building Code (SBC), and NFPA 5000) is the accepted standard in a given jurisdiction and what local extensions have been made to the code. The building code will determine:

- the classification of the structure
- the requirements for tier openings
- the allowable height and area of the structure without fireproofing
- allowable other occupancies within the parking structure
- required separations between occupancies
- allowable construction types
- distance from adjacent structures
- fire protection requirements
- exit requirements
- provisions for disabled patrons

Code highlights of the 2000 International Building Code are shown in Table B-1.

TABLE B-1		
Structure Classification	**406.3** **406.3.3.1**	*An open deck parking structure is a structure* with the openings as described in Section 406.3 on two or more sides and which is used exclusively for the parking or storage of private motor vehicles as described in Section 406.4. 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 distributed over two opposing sides of the building.
Clear Height	**406.2.2**	Not less than 7 ft.
Guards (barriers)	**406.2.3**	Required in accordance with section 1003.2.12 for any interior or exterior floor areas where the distance to the ground or surface directly below is more than 30 in.
Vehicle Barriers	**406.2.4**	Required including both for parking spaces and at the ends of drive lanes.
Vehicle Ramps	**406.2.5**	Not to be considered as providing required pedestrian exit facilities.
Floor Surface	**406.2.6**	Must be concrete or equivalent non-combustible substance except for ground level, which may be asphalt.
Mixed Use Separation	**406.2.7** **406.3.4**	Must meet standards for mixed-use occupancies. 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 combined total area of not more than 1000 sq ft. Such an area need not be separated from the open parking structure.
Area and height – Type II (steel)	**406.3.5** **406.3.6**	Type II open-parking structures with all sides open can be of unlimited floor area as long as their height does not exceed 75 ft and all portions of the tier are within 200 ft of a side opening. Side openings shall not be less than 50 percent of the interior area of each tier side. Type IIB structures (steel without fireproofing) are allowed a maximum floor area of 50,000 sq ft and a height of 8 tiers if two sides are open. If three sides are open, the structure is allowed a maximum floor area of 62,500 sq ft and a height of 9 tiers. If all four sides are open, the maximum increases to 75,000 sq ft and 9 tiers.
Sprinkler Systems	**406.3.10**	Only if required by other code provisions.
Prohibitions	**406.3.13**	The following uses are prohibited: vehicle repair work; parking of buses, trucks and similar vehicles; partial or complete closing of any required opening by a tarp; dispensing of fuel.

B.5 Clearance Heights, Number of Decks and Light Wells

The minimum required overhead clearance (headroom) for a parking deck is 7 ft. Typical design parameters call for a minimum of 7 ft 2 in. except where handicap vans are allowed access in which case a minimum of 8 ft 2 in. is required. Signing for clearances are typically displayed 2 in. less than the actual clearance height of the structure. The number of decks can be estimated by dividing the required parking area (parking demand x 300 sq ft/vehicle) by the available footprint and rounding up. As noted in section B.4, unlimited parking area is available for non-fire protected steel structures up to and including 8 levels of parking. For large decks, it may be necessary to reserve space and construct light wells to meet the required distance to an opening of 200 ft.

Below grade levels of a parking structure are typically required to be sprinkled and fire protected as they do not meet the openness requirements of the appropriate codes. It is possible on some sites to meet the openness requirements by sloping the grade adjacent to the structure to create a 10-ft wide clear space at the below-grade level.

B.6 Traffic Flow

Traffic flow into and out of the facility as well as traffic flow within the facility must be considered. Generally, entrances are placed on high volume streets and exits on low volume streets. When possible, multiple entrances and exits will ease the flow of traffic into and out of the facility. If traffic flow is continuous throughout the day, one entrance and one exit lane should be allocated for every 800 parking spaces. If the structure is subject to peak hour loading, then one entrance and exit lane should be allocated for every 400 parking spaces. For an event-based facility, one entrance and exit lane should be allocated for every 200 spaces. If payment for parking is required, the number of entrance lanes should be increased by 1.25 and the number of exit lanes increased by 1.5.

B.7 Ramp Systems

Ramp systems provide the means of access for vehicles from the ground level to the various parking decks. A large number of ramp variations exist, including ramps that are designed strictly for vehicle traffic and ramps upon which parking can take place. A representative sample of ramp systems include:

1. Single straight ramp with two-way traffic

All up and down travel takes place on a series of sloping parallel planes, one above the other and wide enough for cars to pass in opposite directions. In a continuous up or down trip, the normal floor driving aisles are used to travel between the beginning and ending of each sloping ramp. The ramp width is usually 24 ft with widenings at the ends for turning movements. There is no parking or walking on the ramps. Slope is 8 to 10 percent but can be as high as 16 percent. If the slope exceeds 14 percent, a transition slope needs to be introduced to smooth the breakover point. Each ramp climbs the full height of the tier.

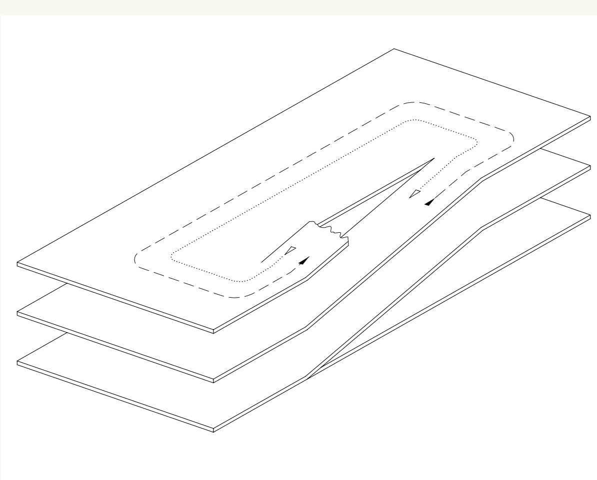
2. Two parallel straight ramps, each with one-way traffic

The ramps provide one-way travel, an advantage in an active traffic situation. The separation of the ramps may be advantageous in the basic layout of the building, especially when planning street access points. Requires travel through full length of structure for circulation. Each ramp is usually 12 to 14 ft wide. There is no parking or walking on the ramps. Slope is 8 to 10 percent but can be as high as 16 percent. If the slope exceeds 14 percent, a transition slope needs to be introduced to smooth the breakover point. Each ramp climbs the full height of the tier.

3. Continuous sloping floor ramp with two-way traffic (single helix)

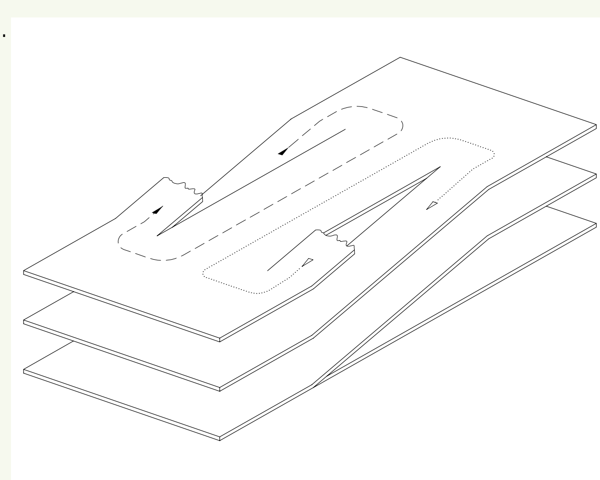
A near continuous rectangular spiral ramp with the slope being 5 to 6 percent. The relative flat slope permits comfortable parking on

1.



Single straight ramp with two-way traffic

2.



Two parallel straight ramps, each with one-way traffic both sides of the driving aisle "ramps" and does not require the use of additional building site area to be used for inter-floor travel. This economy, together with proven acceptance, makes it an extremely popular design solution. Aisle widths are typical 24 to 25 ft with 90º parking. Each ramp climbs only half the height of the tier.

4. Double sloping floor ramps for one-way traffic (double helix)

Ideal for longer sites, where it is possible to achieve one-way traffic aisles with parking along the aisles on every level. The sloping parking stalls allow easier vehicle access and narrower parking bays. In this configuration, exit flow must travel the full circulation route to exit the structure unless parking spaces are eliminated to allow for occasional cross-over openings where opposing ramps intersect each other. Bay widths can vary from 40 to 60 ft. Structure lengths required typically exceed 200 ft. Ramp slopes should be designed at 5 percent and not exceed 6 percent. Each ramp climbs the full height of the tier.

5. Double sloping floor ramps with crossover (end-to-end helix)

Two double sloping floor structure units are, in effect, laid out end to end, and in the level center section, where the two units meet, traffic can cross over. This crossover allows exiting traffic to avoid circulating through the entire structure. Bay widths can vary from 40 to 60 ft. Typical structure lengths required would be in the range of 400 ft. Each ramp climbs the full height of the tier.

6. Staggered double sloping floor ramps (double-threaded helix)

Two double sloping floor units are intertwined allowing for cross-over traffic at every other floor level. Angled parking is achieved, one-way traffic and the need to travel through the entire structure is avoided while being practical in structure lengths of less than 250 ft. Bay widths can vary from 40 to 60 ft. A very popular arrangement where site dimensions allow. Each ramp climbs the full height of the tier.

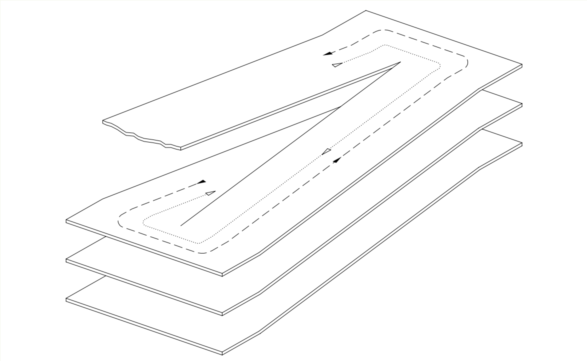
7. Staggered ramps (split level)

Split-level floor construction requires the length of ramp travel to be about one-half the usual inter-floor distance. This was one of the most common designs for years. Split-level floors can overlap as much as five to six feet at the split, which increases space efficiency and makes a narrow site workable. Typically, two ramps are utilized supporting either one- or two-way traffic. Parking and walking does not take place on the ramps. Ramps can be sloped as greatly as 16 percent, but any slopes over 14 percent will require transitions. Each ramp climbs half the height of the tier.

8. Circular or spiral ramps

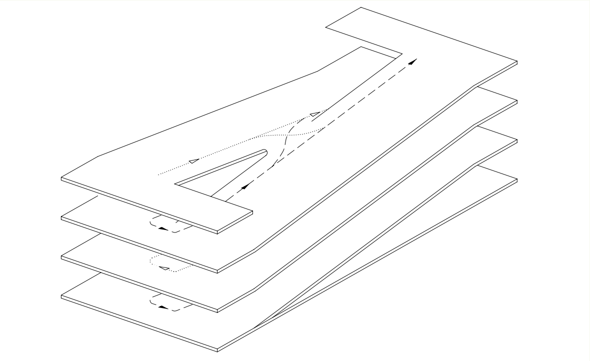
Typically used in larger parking structures located on sites with additional available space, these are flat surfaced (except for drainage slopes) parking structures similar to a conventional building with one-way spiral ramps leading to and from the parking levels. Such a ramp provides for travel without interference except at the intersections with parking floors. A single-lane spiral has a typical in-

3.



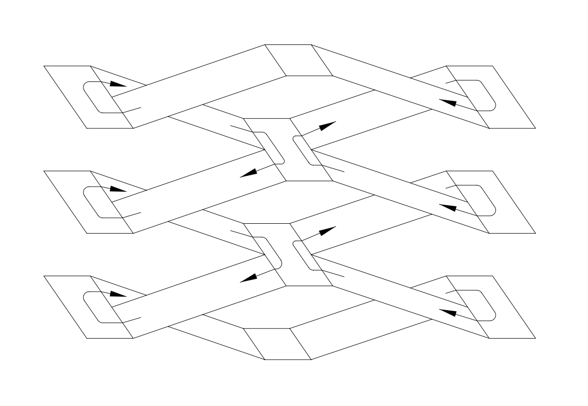
Continuous sloping floor ramp with two-way traffic (single helix)

4.



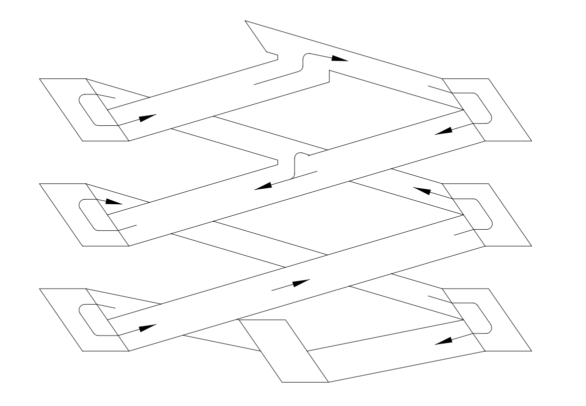
Double sloping floor ramps for one-way traffic (double helix)

5.



Double sloping floor ramps with crossover (end-to-end helix)

6.



Staggered double sloping floor ramps (double-threaded helix)

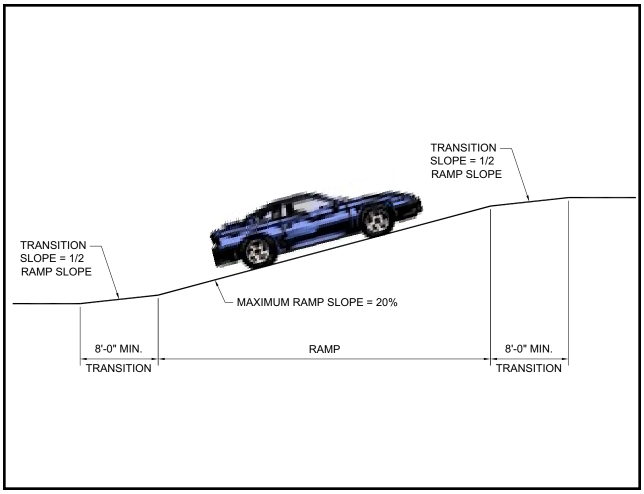
TABLE B-2 — Ramp Length for Straight Ramps							
Floor-to-Floor Height						**Half height split-level**	
Slope	8 ft	9 ft	10 ft	11 ft	12 ft	4 ft	5 ft
5%	160 ft	180	200	220	240	80	100
6%	114	128	143	157	172	57	77
7%	67	75	83	92	100	34	42
8%	57	64	72	79	86	29	36

side curb radius of approximately 30 ft and an outside radius of 41 to 44 ft.

Suggested ramp slopes under ADA requirements are in the range of 5 percent to 6 percent. Non-parking ramps should not exceed 16 percent but preferably not more than 10 percent. If the ramp is greater than 14 percent, a breakover transition will be required.

B.8 Stall Configuration

Parking stall and aisle dimensions are critical to the layout of the parking deck. Standard stalls range from 7.5 ft in width and 15 ft in length for compact cars to 8.5 ft in width and 18 ft in length for full sized cars. The width of the aisle between opposing parking stalls varies based upon the angle of the parking and whether the deck is designed for one- or two-way traffic. The standard aisle



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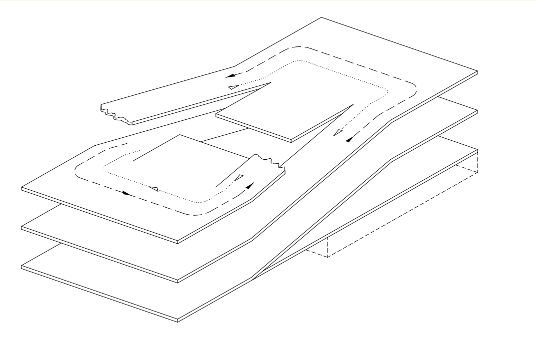
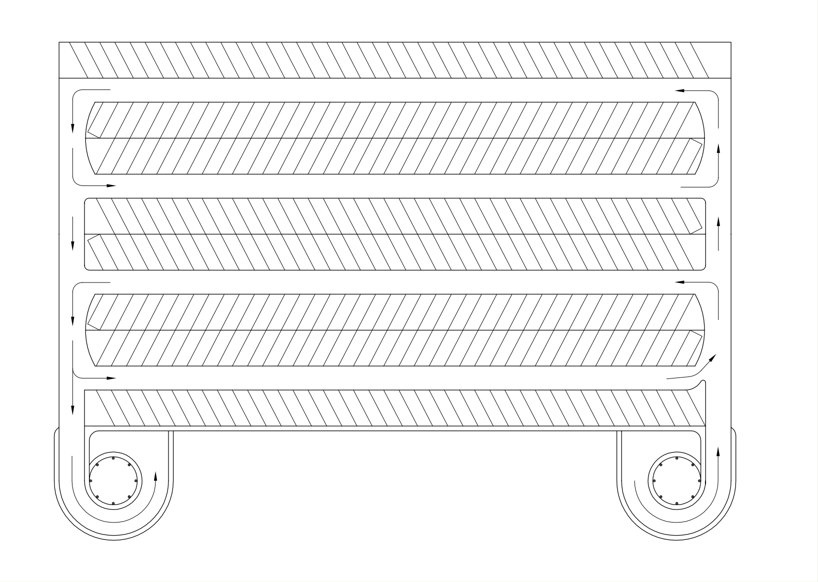


Staggered ramps (split level)

8.



Circular or spiral ramps

TABLE B-3 — Level of Service - B								
	Park Angle							
	Interlocked				Non-Interlocked			
	45°	60°	70°	90°	45°	60°	70°	90°
Curb length – ft	12.33	10.10	9.33	8.75	12.33	10.10	9.33	8.75
Depth of stall - ft	13.60	16.60	17.50	17.75	17.50	18.75	19.00	17.75
Aisle width - ft	13.67	15.50	17.50	25.00	13.67	15.50	17.50	25.00
Bay width	40.87	48.70	52.50	60.50	48.67	53.00	55.50	60.50

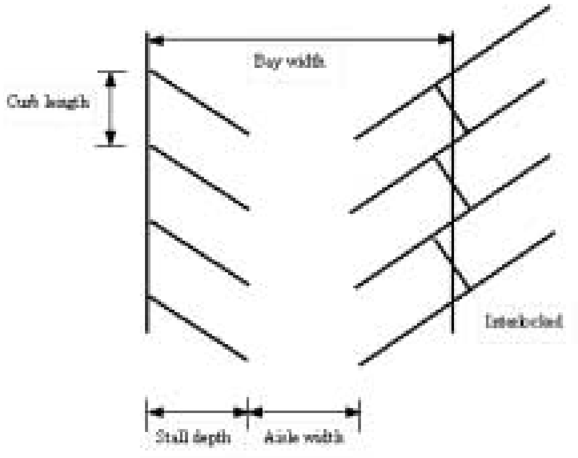
width for 90º parking supported by two-way traffic flow is 24 ft. When combined with the 18 ft stall depths, this results in a parking bay width of 60 ft. Ideally, the structural bay size will match this parking bay size so that structural columns can be located on the perimeter of the parking area. Stall and aisle dimensions change based on the type of service anticipated for the parking structure. Typically, stalls and aisles in retail structures utilized by occasional visitors need to be larger than stalls in a facility frequented by a regular occupants. Stall depths and bay widths can be reduced by allowing for interlock between cars parked in opposing rows (allowing the right front corners of vehicles to intrude into the open left corner of the opposing parking space). In general, 90º parking allows the greatest number of vehicles to be parked in a given size structure. If site dimensions require a structure with a footprint that cannot easily support 60 foot bays, angled parking may become a more efficient solution.

Table B-3 provides basic dimensions for an average level of service (B) condition.

Under ADA provisions, a certain number of spaces must be set aside as handicapped spaces. These spaces must be adjacent to open areas to ease access to the vehicle. Typically, these expanded stalls require at least 5 ft of set-aside space next to the handicapped space. Significant variation exists within local codes specifying the dimensions of handicapped spaces and these local codes should be consulted when laying out a parking deck. Passenger-accessible spaces should be located near exits on the entry floor and near to elevators on elevated floors.

The number of handicapped spaces required is:

TABLE B-4	
Total Parking Spaces	Required Handicapped
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+	20 plus 1 for each 100 over 1000



Additional spaces must be set aside at the grade level of the parking structure to allow for handicapped van access. This requires a minimum clearance of 8-ft-2-in. and an expanded set-aside area 8 ft in width next to the allocated space.

Typical parking structures range from 275 sq ft per space to 350 sq ft per space. For the purpose of planning, 300 to 325 sq ft per parking space should be used.

B.9 Barriers, Curbs and Bumpers

Barrier rails are required around the perimeter of a parking structure to provide an adequate amount of restraint that will prevent a vehicle from breaking through the barrier and dropping to the ground surface below. The National Parking Association recommends using a point load of 10,000 pounds applied on a one square foot area at a distance of 18 in. above the riding surface, located at any point along the length of the riding surface. Curbs and vehicle bumpers are to be generally avoided as they present a tripping hazard for patrons.

B.10 Pedestrian Safety and Security

All travel paths to exits need to be well illuminated, striped and signed. These paths should be free from all obstructions. ADA requirements do not allow for pedestrian travel on any surface with a slope greater than 5 percent. It is wise to ensure that pedestrian walkways are located in open areas at a distance from any location where an assailant could hide. The goal of providing passive security features that enhance the pedestrian's sense of security in the structure, can be accomplished by eliminating large obstructions including shear walls and promoting openness. Steel-framed structures are particularly well adapted as a result of their small column sizes and lack of reliance on shear walls to provide lateral stability. Stair and elevator shafts should be located for the convenience of the patron, not the designer and should incorporate the same sense of openness through open shafts and glass walls. All areas must be well lit.

Active security features may include video monitoring, emergency call boxes and periodic, but random visits from security officers.

B.11 Stairs and Elevators

Every parking structure is required to have a minimum of two means of egress (stairs) which are separated from each other. These stairwells should be located based upon the requirements of local safety codes. One of the stairwells is normally located adjacent to the elevator locations. If the parking structure supports a high peak flow, extra wide stairs may be necessary. The minimum clear width for the stairway is 36 in. Stairwells on the perimeter of the structure are often left open or glass enclosed to create a sense of security within the structure.

TABLE B-5
Maximum Number of Spaces Above Grade per Elevator

	Special Event	Retail	Office	Airport
2 tiers	236	358	697	955
4 tiers	191	286	565	764
6 tiers	158	246	468	657
8 tiers	138	216	387	849

The number and locations of stairs is determined by the maximum travel distance or the distance the patron must travel along a normal path from any point in the structure to the closest stair. In open structures the controlling distance is 300 ft.

The number of elevators required to service the parking structure varies by the usage of the structure. Elevators should be located along the natural direction of travel for a patron exiting the structure. Some parking designers take into account elevator locations in specifying the traffic flow through the facility. In doing so, all incoming traffic is routed past the elevators as a means of orienting the patron to the structure layout.

B.12 Fire Protection Systems

Local fire codes will specify the number and location of fire extinguishers and standpipes in the parking structure. Standpipes are best located in areas sheltered by columns or protected by bollards to avoid vehicle damage. Sprinkler systems are typically not required in steel-framed, open-deck parking structures. As fire extinguishers are often the target of theft and vandalism, the requirement for them may be waived by some localities if a standpipe system is provided. Fire alarms and smoke detectors are generally not required in open-deck parking structures.

B.13 Drainage

Drainage is of primary concern in any parking structure. Ponding of water on parking decks and around columns is a major cause of deck and structural system deterioration. This is true for all types of deck and framing systems. It is critical to design a positive drainage flow for each level taking into account the effects of deck cambering. A slope no less than 1 percent, preferably 1.5 percent, should be maintained for positive flow and drains should be recessed at least 0.5 in. from the deck surface. Roof level drains and downspouts should be sized to handle the minimum of a typical 20-year storm event. Drains should be located away from columns to avoid ponding around the columns. When possible, redundant drains should be installed to minimize the impact of clogged drains. Drain lines and downspouts should be protected from vehicle impact by positioning them near columns and/or protecting them with bollards. Drainage outflows should be directed to approved municipal storm sewers or directed to a location distant from the parking structure in order to avoid standing water around the perimeter of the structure.

B.14 Signage

Signage is critical in directing traffic through the parking structure in a clear, understandable manner. All entrances and exits should be clearly designated and marked with minimum clearance indicators. Wayfinding signs should be clear, minimizing directional decisions and reinforcing the typical travel path. Signs should be centered along the typical travel path and placed as low as possible for visibility, but still at a height above the maximum allowable vehicle height.

Pedestrian signage should be easily distinguished from vehicle signage, and should direct the patron from the end of the drive lane to the closest elevator or ground-level exit. Level and aisle signs should be large and memorable to aid the patron in remembering the location of the vehicle.

B.15 Lighting

All areas of the structure should be well lit and bright for creating a sense of security in the patron. Lighting requirements, based on IES recommendations, are shown in Table B-6.

TABLE B-6

	Day	Night	
Area	Average footcandles on pavement	Average footcandles on pavement	Uniformity Ratio
General Parking and Pedestrian Areas	5	5	4:1
Ramps and Corners	10	5	4:1
Entrance Areas	50	5	4:1
Stairways	20	20	