PDHonline Course G202 (3 PDH)

Parking Structures

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2020

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Introduction

The Building Codes recognize two types of parking structures; open and closed. The building codes do not require that open parking structures have forced air ventilation or automatic sprinkler systems. Closed parking structures must be provided with mechanical systems so they are more expensive to construct and maintain.

Typically an open parking garage is any structure of Type I or II construction (i.e., non combustible materials) which is open on two or more sides totaling not less than 40% of the building perimeter and is used exclusively for parking or storage of cars. For a side to be considered open, the total area of the distributed openings shall not be less than 50% of the exterior projected area at each level of the garage.

Although there are general guidelines for the design of a parking garage, the designer must realize that parking related dimensions (i.e. minimum parking space width and length, etc.) are often set by local ordinances.

Parking structures, because they are exposed to the elements, are easily affected by severe weather, climate changes and temperature extremes. In addition, in climates where de-icing salts are used to diminish the effects of snow and ice on the roadways, the de-icing salts will increase the likelihood of accelerated deterioration of the garage structure. Other than highway bridges, no other type of structure has to resist this kind of exposure to corrosive environments and deterioration. In addition, unlike most bridges where rain can wash away road salts, only the exposed roof of a parking structure is entirely open to the full effects of precipitation.

In most parking structures there are no architectural finishes that can be used to conceal mistakes in construction forming or finishing. Therefore, extra care must be taken, to construct parking garage structures.

Planning

Typically, suburban office buildings require 1 square foot (SF) of parking for every 1 SF of leaseable space. A typical shopping center requires as much as 1.5 SF of parking for every 1 SF of leaseable space. Parking structures are expensive to own and operate and can cost up to five or six times as much as on grade surface parking. In addition, revenue from paid parking rarely pays for the cost of a structured parking garage. At the same time, on grade surface parking usually does not provide the best and most efficient use of a piece of land. Parking structures on the other hand allow for denser development of a parcel of land.

Parking demand is the number of spaces that should be provided for a building or facility based on the peak accumulation of vehicles on a given day, including a small cushion of extra spaces over and above the expected need. Parking demand for specific land or building use can vary significantly from one location to another. A sensible approach to determining the parking demand for any garage is to start with a national standard that assumes a 100% need for automobiles and is then adjust it for local conditions.

An important concept in parking analysis is the selection of the appropriate design day and hour. It is not practical to design a parking garage for the peak accumulation of vehicles that might conceivably ever occur because this results in a substantial number of vacant parking for most of the time. At the same time it is not practical to design based on an average condition because this will result in an insufficient number of parking spaces for any given day.

Another important concept in determining the required number of spaces is the effective supply. A parking system operates at optimum efficiency at somewhat less than its actual capacity. For example, an individual who arrives to park when there is only one space left will experience significant frustration based on the perception that the available parking is not adequate. To avoid creating this type of environment it is necessary to provide a cushion of extra spaces in addition to the actual demand. Therefore, an effective supply factor of 5 to 10 percent should be applied to the anticipated design day or hour volume to arrive at the total number of parking spaces that should be provided.

A typical 60-feet clear span parking garage with adequate circulation throughout the structure should result in an average utilization rate of anywhere from 275 to 350 SF per parking space (i.e. total number of spaces/total SF of the structure). Short-span garages (where columns occur at both the ends and entrances of a space rather than just at edges of a clear span bay) will have efficiencies over 350 SF per space.

A common rule of thumb for sub-grade parking structures is that the first level underground will cost approximately 1½ times that of above grade parking with this same multiplier doubling for each additional level below grade. Therefore, the second level below grade can cost 3 times that of above grade parking, the third level below grade 4½ times that of above grade parking and, etc.

Design

Parking structures have some unique attributes that are different from that of a regular building. One of the most fundamental differences is that there must be a circulation system that provides access from one floor to the next because cars cannot use the elevators and stairs that provide circulation for the pedestrians. Vertical circulation in most garages is provided via sloped ramps. Many factors affect the selection of the best design for a particular parking facility and can include; types of users, pedestrian needs, site dimensions and peak-hour demand. See Figure 1 for common parking garage terms that will be used through out the following discussion.

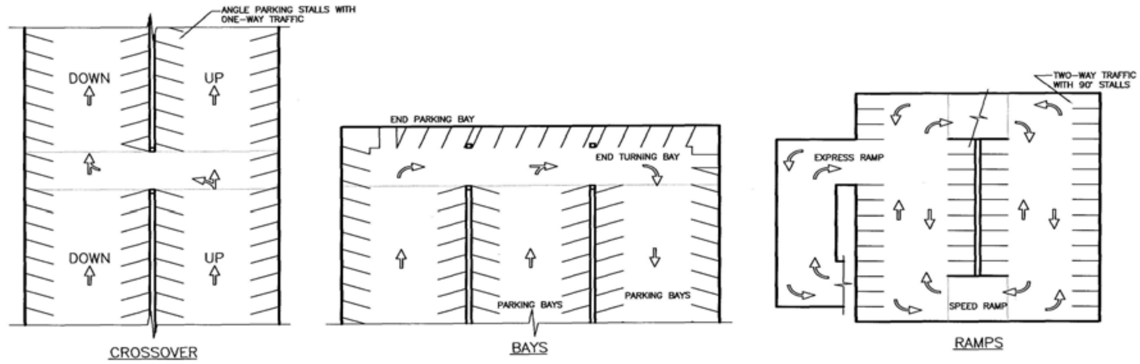


FIGURE 1

No one set of design standards is suitable for all situations. To provide guidance to designers traffic engineers have developed a system of classifying conditions based on the level of service (LOS) deemed appropriate for any given condition. The following table provides examples of the relationship between this service criterion and the needs and concerns of a typical parking garage user. The table indicates for example that an employee who uses the same garage everyday expects a LOS of A when it comes to how much waiting time is required at the entrances and exits of the garage. In contrast, an infrequent visitor to a garage is more likely to accept a longer waiting period since they do not have to deal with any related or perceived loss of time on a regular basis.

Design Consideration	**Factor**	**Acceptable Level of Service (LOS)**			
		Lowest	**to**		**Highest**
		D	**C**	**B**	**A**
Turning radius, ramp slopes, etc.	Maneuverability	Employee	→	→	Visitor
Travel distance, number of turns, etc.	Maneuverability	Visitor	→	→	Employee
Geometry	Maneuverability	Employee	→	→	Visitor
Entrance & Exits	Waiting Time	Visitor	→	→	Employee

A major factor in selecting the most appropriate LOS design criteria is the familiarity of the user. In other words, when arriving and departing activity is at high levels throughout most of the day, a better LOS should be provided than if there is only two, ½ hour rush periods during the day, one in the morning and the other in the afternoon. In addition, it should be realized that the more urban and congested the setting of the facility, the more tolerant users are of lower levels of service.

There are four basic approaches to designing the circulation system in a parking facility and include:

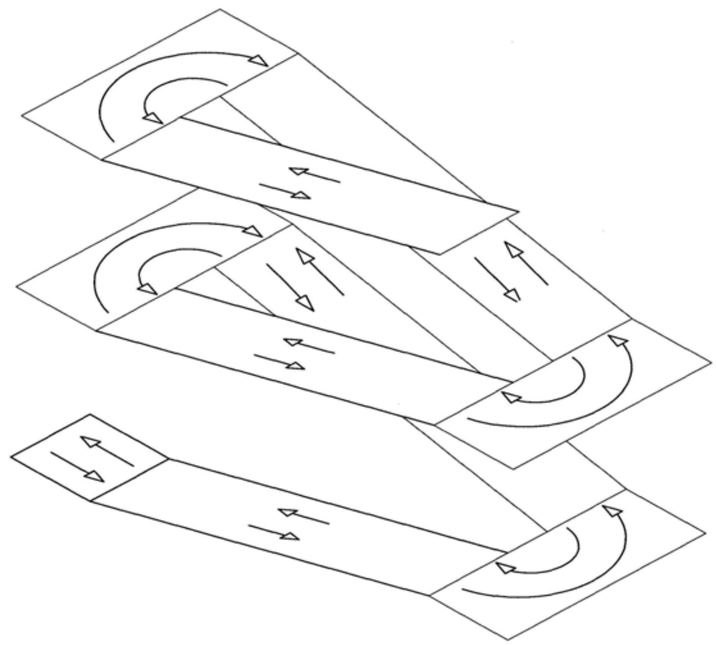
1. Level parking bays.
2. Level drive aisles without parking.
3. Sloped parking bays.
4. Sloped driving aisles without parking.

Sloped driving aisles without parking are sometimes referred to as ramps. There are three types of ramps to consider when designing a parking garage and include:

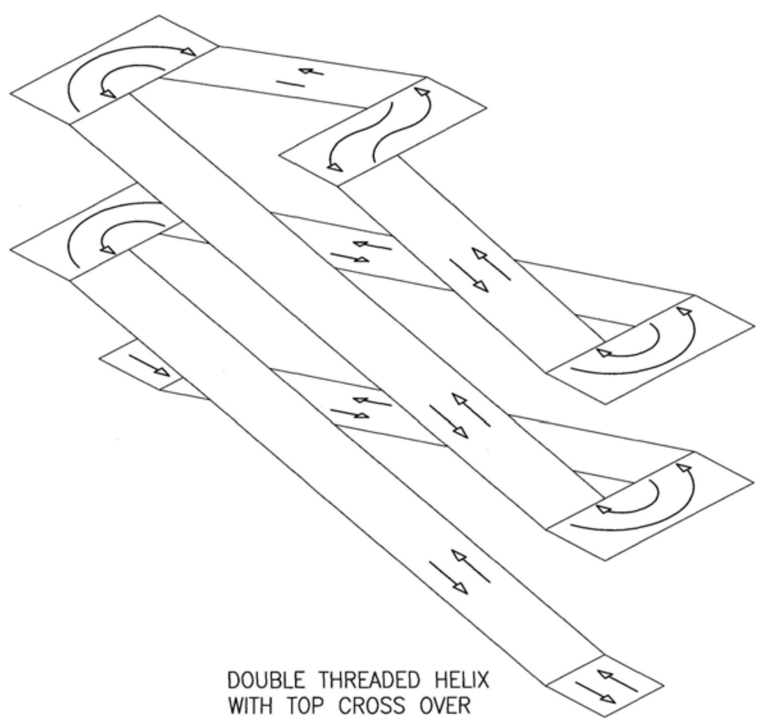
1. Circular (or Helix).
2. Express.
3. Speed (short ramps that connect floors with no more than a full story of separation).

Helical ramps can include single helix (rises 1 story for every 360º of turning revolution) and double helix (rises 2 stories for every 360º of turning revolution). Two double helixes are typically intertwined on the same footprint. See Figure 2 for examples of helical ramps. A single helix (i.e. sloped two-way garage) is the simplest and cheapest configuration of all of the different types of circulations options.

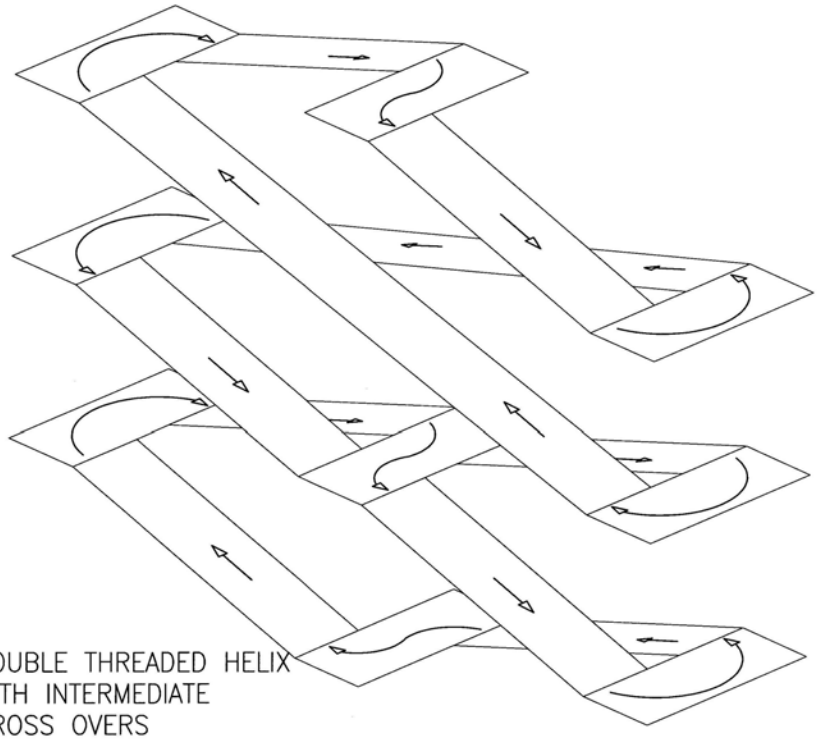
The maximum slope recommended for speed ramps is 12% because the maximum pedestrian ramp slope allowed per most building codes is 1/8-inch per foot. Some local ordinances limit the slope of speed ramps to 10%. Speed ramps can be as steep as 16% if pedestrian traffic is restricted from the ramp area.



SINGLE THREADED HELIX
FIGURE 2A



DOUBLE THREADED HELIX
WITH TOP CROSS OVER
FIGURE 2B



DOUBLE THREADED HELIX
WITH INTERMEDIATE
CROSS OVERS
FIGURE 2C

Wayfinding is the ability of a user to understand where they are in a garage and where they want to go in the facility, and then to find the path of travel to get there. In parking facilities wayfinding is necessary for both drivers and pedestrians. Typically wayfinding in a garage is provided via signage.

The AASHTO design criteria for passenger cars, which has been set at 7-feet by 19-feet for more than thirty years, is generally not adjusted for different vehicle sizes that may be using a typical parking garage. This standard AASHTO vehicle size is larger than the majority of most cars that are used in the United States. The minimum turning radius of the outside front tire of the standard AASHTO vehicle at speeds less than 10 MPH is 24-feet. Typically parking garages are designed to this same turning radius criteria in express ramps and other major aisleways. However, less restrictive and more realistic criteria are typically used for the design of parking spaces and adjacent access aisles.

In addition, the turning radius used for non-parking ramps at higher levels of services is typically greater than that used for parking areas. This difference reflects the speeds of the vehicles and the distractions that can occur in parking areas due to parking and departing vehicles as opposed to non-parking ramps.

Another important design consideration for both parking and express ramps is the need to provide adequate transitions to avoid the underside of the car from coming in contact with the driving surface. In addition, contact between the top of a vehicle and the underside of the structure above should also be avoided at both ramp transitions and driving aisles. For this later condition it is recommended that the height of vehicles entering a parking facility be limited to two to four inches less than the actual overhead clearance because the vehicular clearance can be impacted by sloping floors and differential camber between adjacent driving surfaces.

When there is a difference in slope of 10% or more between two adjacent sections of ramp or aisleway, a transition slope is required to prevent the vehicle from “bottoming out” as described above. This condition can occur in express ramps and some speed ramps. In general, the transition area should have one half of the difference in slope between the two adjacent driving surfaces (see Figure 3). The recommended length of the transition slope varies depending on the LOS and can range from 10-feet (LOS D) to 13-feet (LOS A).

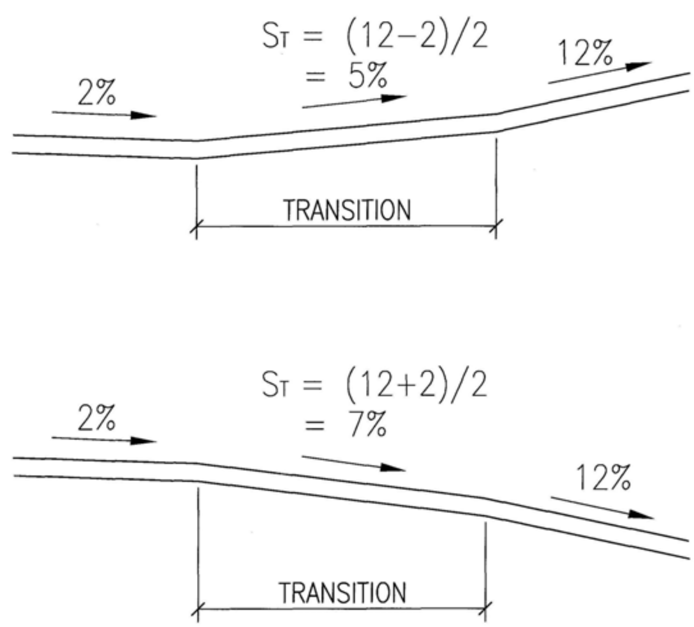


FIGURE 3

The minimum floor-to-floor height in a typical cast-in-place, post-tensioned concrete parking structure is 10-feet, which provides an overhead clearances of anywhere from 7-feet to 7’-4”, depending on the structural depth of the system. A facility with only 7’-0” clearance (as required to meet the Building Code) should therefore include signage that restricts the maximum vehicle height to between 6’-8” to 6’-l0”. Vehicular clearance should also include allowances for light fixtures, signs and piping.

The American with Disabilities Act (ADA) requires that 8’-2” vertical clearance be provided in the path of travel to and from van accessible spaces. This generally requires increasing the floor-to-floor height from 11'-2" to 11'-4". However, the Author has designed precast concrete structures with 30-inch deep, pre-topped concrete double tees with coped stems at the supporting 30-inch deep inverted tee beams for a 10'-8" floor-to-floor elevation.

In addition, for parking garages that are predominately below grade and are accessed via an open top area at the street level, it is recommended that "goal posts" be installed across the entrance in order to restrict vehicles other than cars from accessing the structure. The "goal posts" (which restrict the maximum height of any vehicle that can enter the garage) can prevent large trucks and other similar vehicles that could potentially exceed the load carrying capacity of the structure from accessing the framed areas of the facility. The Author witnessed a structural failure in Nashville Tennessee in the early 1980's in which a truck crane was driven on to the top deck of a garage at the street level. The crane collapsed the upper framing of the 2-story structure. Fortunately the accident happened over the weekend when no cars or pedestrians were in the sub-grade parking level below.

In a garage with a significant amount of turnover traffic, any two-way turning bays should be large enough to allow for two vehicles to pass each other in the same area. Turning bay widths for two-way traffic can vary from 26'-6" (LOS D) to 31'-0" (LOS A). However, when turnover traffic is low and it is less likely that two vehicles will have to pass each other in the turn, these standard dimensions can be reduced by as much as 3-feet. See Figure 4 for a typical end turning bay.

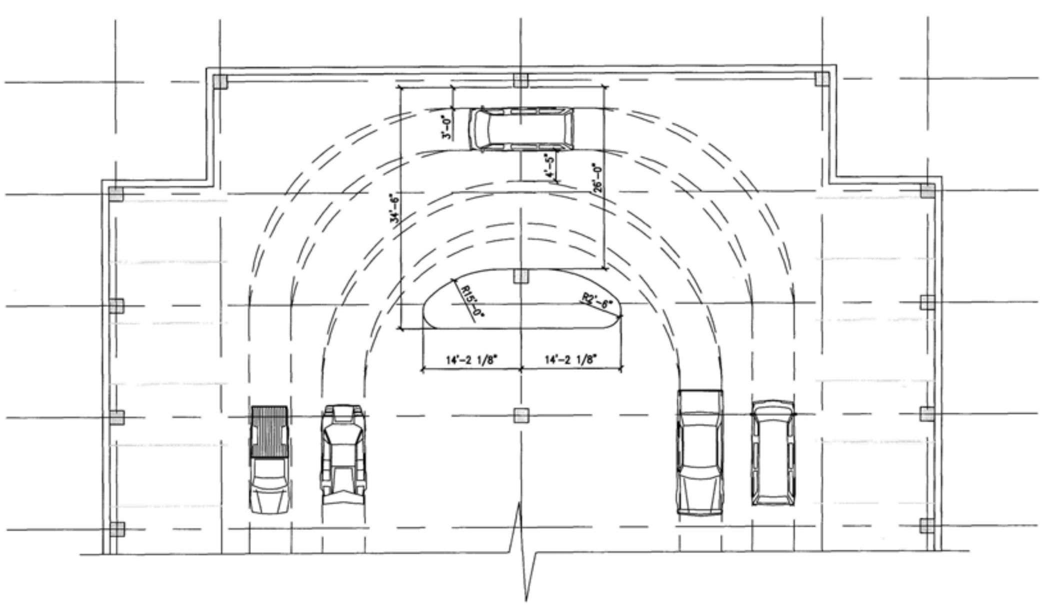


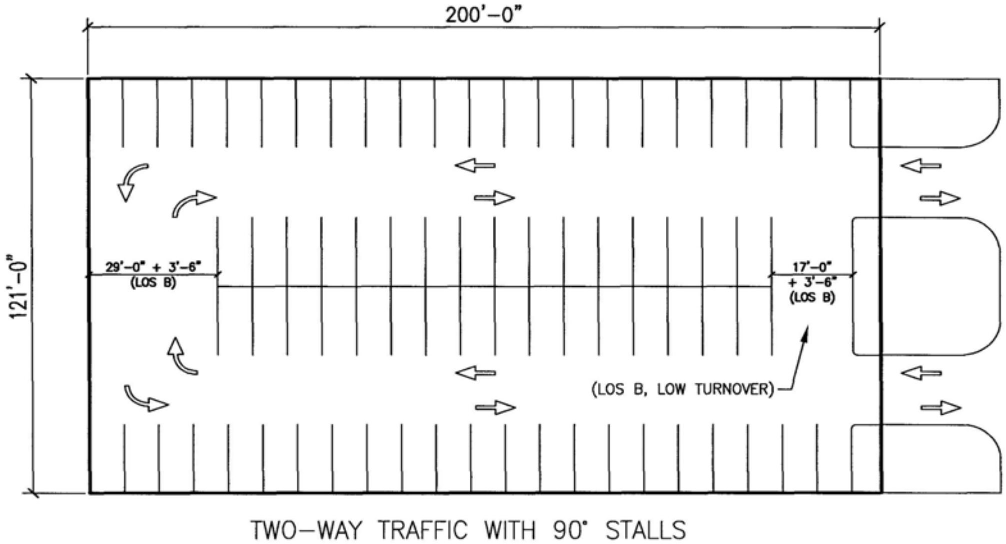
FIGURE 4

Minimizing the number of turns (in terms of 360º of turning revolutions) in the path of travel should be a priority for parking designers. This is because there is a tendency for drivers to become disoriented and even dizzy when there are too many turns in the path of travel. Therefore the maximum practical height of a parking garage is about 10 stories.

The size of the project site greatly impacts the type of circulation system that can be used in any garage. Speed ramps are typically used when the site is short and the length of the garage does not allow for enough vertical climb without exceeding the recommended slope in a parking/driving aisle. The width of the site also impacts the selection of the structural and circulation system as it determines the number of typical 60-feet clear span parking bays that can be placed on the site.

One of the chief factors influencing the width of a parking garage structure is whether one-way or two-way traffic flow is required. Among the chief advantages of two-way traffic flow is wider driving aisles which provide better angles 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. Wider aisles are also safer for pedestrians. In addition two-way traffic flow avoids the situation in which a driver is going the wrong way on a one-way aisle. The minimum bay width for two-way traffic is 60-feet while the minimum bay width for one-way traffic is 40-feet. Both of these dimensions assume 2 rows of parking spaces separated by a driving aisle.

It is not true however that two-way traffic with 90º parking always provides greater efficiency than one-way traffic with angle parking spaces. In fact for a garage with a large unrestricted footprint with the same overall width, five bays of 75º angled parking will provide more spaces than four bays of 90-degree spaces. See Figure 5 for a comparison between a one-way and two-way garage.



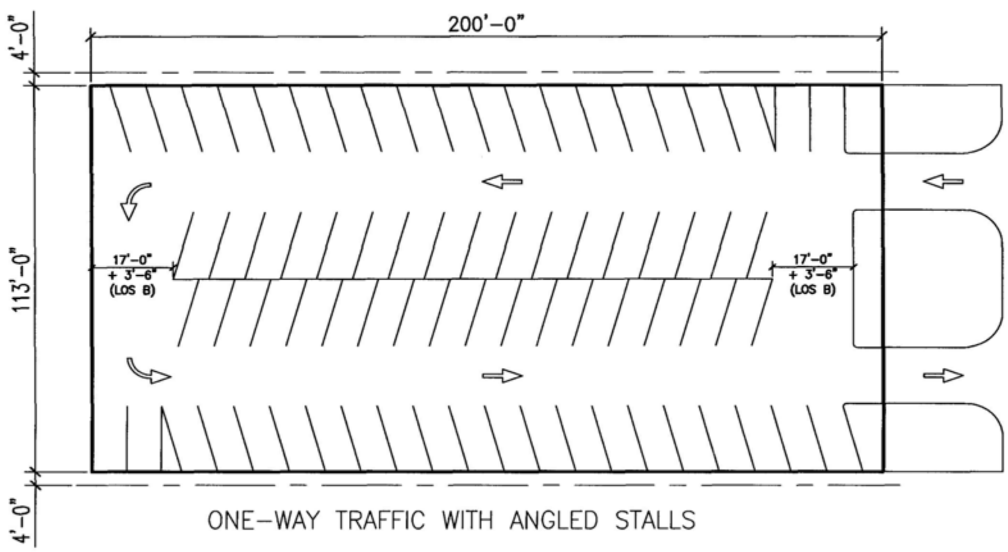


FIGURE 5

One-way traffic with angled parking also makes it easier for drivers to enter and exit the parking spaces. In particular, when a vehicle is backing out, angled parking provides better visibility. In addition, conflicts between two vehicles approaching an open space from opposite direction do not occur with one-way traffic as it can with two-way aisles. One-way traffic also allows the angle of the parking spaces to be altered to accommodate changes in car sizes. If the size of the space needs to get smaller the angle of the slot can be increased closer to 90º; if the space needs to get bigger the angle can be increased to make it more obtuse.

One-way traffic, in a multi-level parking garage with peak-hour volumes of 1000 spaces or more, also has distinct advantages over two-way traffic flow patterns. It is recommended that angled parking spaces always be used with one-way traffic as the orientation of the spaces self-enforces the one-way traffic flow thus eliminating the danger of wrong way traffic. Therefore if 90º parking is required, the circulation should always be designed to accommodate two-way traffic.

In addition to one and two-way traffic flow, parking garages can also include a number of different overall circulation systems which can include single and double threaded helixes, side by side configurations, split level layouts and single threaded systems with express or speed ramps. In general, the use of single-threaded schemes for facilities that that serve large numbers of infrequent users is recommended when user comfort, visibility and ease of wayfinding orientation are the most important considerations. In contrast, sloping parking bays with double-threaded patterns are generally preferred for office parking and other situations which involve predominately every day users.

Most parking designers consider the dimension of the parking space to be more important than the aisle width. The first major concern in the determination of the space size is the vehicle door opening dimension. For long-term parking (3 hours or more), studies have shown that a door opening clearance of 20 inches between parked vehicles is acceptable. For high turnover parking, a door opening clearance of 24 inches provides a better level of convenience for the more frequent turnover. The second major concern is vehicle movement into the stall. As the angle of parking is rotated from 90º toward 45º, as measured perpendicular to the direction of traffic in the driving aisle, the parking module may be reduced while providing similar maneuverability. In general parking space width can vary from 8'-6" (LOS C) to 9'-0" (LOA A). Parking space length can vary from 17'-5" (45º) to 17'-9" (90º).

The most critical variable in determining the adequacy of any circulation system is the volume of vehicles expected to arrive and or depart in the peak hour. Peak hour volumes can vary from 40 to 70 cars per hour at an office facility, 90 to 100 in a short term airport parking garage to 80 to 150 cars per hour at a retail center. For large facilities it is recommended that a study be performed to accurately determine the peak hour volume for the particular project. In general, as previously indicated, one-way angled parking flow capacity is greater than that of a two-way 90º system. The most difficult parking garages to design are those intended for intermodal use, therefore special expertise is required when designing garages intended for use in conjunction with bus and or train terminals.

The number of entrance and exit lanes also needs to be determined as a part of the parking design. The number of recommended lanes can be estimated by dividing the volume of vehicles expected in the peak hour by a peak utilization factor (PUF) times the service rate (SF):

$$\text{Number of Lanes} = V/(PUF \times SF)$$

For parking garages that require daily payment the PUF is .5, .65, .75 and .8 for 1, 2, 3 and 4 or more lanes, respectively. For automatic prepaid parking the PUF is ..8, .9, .925 and .95 for 1, 2, 3 and 4 or more lanes, respectively. The SF for parking garages can range from approximately 6.0 to 18.0 for entrances and from approximately 10.0 to 45 for exits.

The use of reversible entrance and exit lanes, which alternate between peak uses, can be result in more space efficient use as opposed to one-way lanes. It is also important to understand that per ADA, every cashier booth must be accessible to and through the door. This basically means that the booth must be recessed in the island. It is also recommended, but not required by ADA, that at least one of the cashier booths be designed for wheelchair accessible. A common error in entrance and exit layout is providing inadequate space for the driver to turn into the lane and get aligned with the ticket dispenser or card reader.

In addition to the need to properly design garage for the peak parking volumes it is also just as important to include pedestrian considerations into the parking design. This includes the need to understand the vertical circulation of the pedestrian users. Therefore it should be noted that the acceptable waiting time for an elevator for most user is approximately 30 seconds. However, a waiting time of 60 seconds is assumed acceptable for elevators during a special event.

Building Codes

Life Safety Issues

The NFPA 101 (Life Safety Code) doesn't require sprinklers in open parking structures, however, it does have some provisions that are more restrictive than the other Building Codes. For example, stairs in open parking structures must be enclosed. There is a provision however that allows the stairs to be open if the walking distance within the stair is included in the path of travel to the exit, but complying with this provision usually results in having to provide additional stairs. At the same time the NFPA also has some less restrictive requirements including the provision that if an open parking facility is at least 50% open on all four sides the travel distance may be increased from 300-feet to 400-feet. This increase in travel distance can allow open stairs to be used in many structures with three or four supported levels, without penalty under NFPA.

The UBC has had a long standing long provision that open parking structures cannot be part of a mixed-use building, 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 automatically defaults to an enclosed structure. NFPA, BOCA and the IBC allow open parking structures to be a part of mixed-use buildings, if separated appropriately.

Sections 1002 and 1010 of the IBC contain a provision that may appear at first to limit parking ramp slopes to 1 in 20 (5%) even though slopes up to about 1 in 15 (6.7%) have been used on a regular basis in parking structures across the country with no apparent problems. This is because there is an exception in the IBC which states that vehicular ramps in parking garages for pedestrian exit access shall not be required to comply with Sections 1010 when they are not an ADA accessible route serving accessible spaces or means of egress. A further discussion of this issue follows under the means of egress section.

The history of parking structure fires indicates that the risk to life safety from a fire in a parking structure, whether open or enclosed is very low. In fact, there is no record of a loss of life resulting solely from a fire that began in a parked vehicle. The building codes have for a long time recognized the low risk of fire in relationship to the higher risk of crime in parking garages by allowing open stairs. The biggest problem that most designers face however is when a local building official requires that open parking structures be provided with sprinklers even though all of the national building codes clearly do not require sprinklers.

It has been shown that sprinklers spraying water on the roof of a vehicle will not extinguish a fire that has occurred either inside or beneath the automobile. In addition, it has been demonstrated that water from sprinklers will actually facilitate the spread of fire from one car to another by allowing any gasoline that has leaked out of the vehicle via the sprinkler water runoff to flow to another adjacent car.

Open and Enclosed Garages

Buses and commercial trucks are prohibited from parking in open parking garages under the provisions of all of the building codes except NFPA 101. Under IBC and UBC, motor homes and RV's are considered to be private passenger vehicles and are therefore allowed in open structures even though they may be closer to buses than passenger cars in terms of size and potential fire hazard. Conversely, taxis and limousines (which are usually converted cars or vans and typically have the same fire risk as cars) cannot be parked in open parking structures under IBC and UBC. If taxis and limos are to be parked in a structure, it automatically must be considered an enclosed structure under IBC and UBC.

Most local building officials consider a garage storing rental cars to be an open parking structure based on the fact that the fire risks are basically identical to a parking garage serving private vehicles. BOCA limits parking structures, both open and enclosed, to vehicles that carry nine or fewer passengers.

Both NFPA 101 and 88A (Standard for Parking Structures) allow motor vehicles (including vehicles powered by propane or other natural gases) to be parked in both open and enclosed parking structures. All of the building codes except NFPA 88A prohibit the dispensing of fuels or the repair of vehicles in either an open or enclosed parking structure. NFPA 88A allows repairing and fueling in either open or enclosed structures without separation but does impose certain special requirements for these same conditions.

There also is a distinction that should be made between mechanical-access open parking structures (which use parking machines, lifts, elevators, etc) and ramp-access open parking structures. UBC and IBC only define and address mechanical access structures if they qualify as open. Most of the latest mechanical structures are often designed to be totally automated and sometimes unattended by staff. Basically, a mechanical access structure can be treated as an open parking structure if it meets the same openness criteria and an enclosed structure if not. BOCA has a few exceptions pertaining to mechanical parking structures. NFPA 101 requirements for open and enclosed structures do not apply to mechanical structures or exclusively attendant-type structures, but does not indicate if any of its other sections apply to these facilities.

The clear height of a parking tier or level shall not be less than 7-feet under IBC, BOCA and

UBC. It is interesting to note that these same codes require a 7'-6" clear height for offices and other similar occupied spaces. The clear height is generally interpreted as the vertical clearance. A parking facility with this clearance will typically be signed with 6'-8" to 6'-l0" vehicular clearance to allow for vehicle break-over as previously described. NFPA 101, however, requires that 7'-6" clearance be provided throughout a means of egress system, which includes parking areas and ramps. However, under NFPA 101, structures, both open and enclosed, need only provide 6'-8" clearance to any projecting elements. These same facilities should be signed with as little as 6'-6" for similar reasons to that described above.

IBC defines openings in the walls of garages as follows;

The exterior side of the structure shall have uniformly distributed openings on two or more sides. The area of such openings…on each tier must be at least 20% 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% of the perimeter of the tier. Interior walls shall be at least 20% open with uniformly distributed openings. Openings are not required to be distributed over 40% of the building perimeter when the required openings are uniformly distributed over two opposing sides of the building.

The UBC does not have an exception allowing openings over less than 40% of the perimeter. When all 4 sides of a garage have openings the required height of the openings should still provide at least 20% openness along each wall of the garage tier, or story. With precast concrete structures, this requirement requires greater attention to the design of the up and or down turned portion of the spandrel panel by supplanting a portion of the panel with an open guardrail or handrail.

Uses and Occupancies

Mixed-use provisions of the building codes do not apply to two specific types of uses, incidental and accessory. Incidental use includes spaces such as mechanical rooms and storage rooms. Incidental use classification is tabulated in Section 302.1.1 of the IBC. There are provisions in IBC that allow a parking structure to be an incidental use in other buildings if the parking area is separated by a 2-hour fire barrier.

The most common accessory use in a parking garage is the management or parking operations office. Retail and coffee shops, even if they occupy less than 10% of the floor area, are not considered accessory uses in parking garages under the building codes if they are oriented for use by the general public. IBC 406.3.4 specifically limits parking management offices in open parking structures to no more than 1,000 square feet.

Parking garages, whether open or enclosed are typically classified as storage uses of low hazard. Under all of the codes except NFPA 101 (including NFPA 88A), both open and enclosed parking structures must be built of non-combustible materials (i.e. concrete and/or steel meeting the required fire ratings). IBC 406.2.6 also allows an exception for asphalt paving on grade. It is important to note that in addition to the limitations on construction material type, any building with an occupied floor above 75-feet in height may trigger high-rise fire protection code requirements.

Under IBC Section 403, a building that has an occupied floor more than 75-feet above the lowest level that a fire department vehicle can access shall meet the code provisions for high rise buildings. Open parking structures are specifically exempted from this requirement (Exception 3 of the IBC). However, when other building uses are located over an open or enclosed parking structure, and the high rise provision indicated above is triggered, the entire building including the parking garage, shall be treated as a high rise. NFPA 101 does not impose any high rise requirements on parking structures, either open or enclosed.

Building spaces that have a floor level used for human occupancy more than 30-feet below the lowest level of exit are considered underground buildings per the IBC. Where there is only one or two basement parking levels, this section is typically not triggered. In addition, parking structures otherwise qualifying under this provision are exempted from the related code requirements if they have approved automatic sprinklers.

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 while a "basement" structure is one with other uses (retail, office, residential, etc.) above. In addition, an underground structure might qualify as open for ventilation purposes, but would still have to be sprinklered under NFPA 88A. Under NFPA 101, an underground structure is any portion of a building with a floor level below the level of exit discharge.

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 the adjoining grade and if the openings are no more than 44-inches above the inside floor elevation.

A structure is not considered windowless under NFPA if it meets either of the following conditions:

1. It is a one story structure or a first story of a multi-story building where there are grade level doors or emergency access openings on two sides of the building that are spaced no more than 125-feet apart.
2. The structure is above the first story and has emergency access openings on two sides of the building spaced no more than 30-feet apart.

Because floors at or above grade in a parking garage that qualify as open would be provided with openings on at least two sides, windowless structure requirements typically do not apply to very many structures. However, it is important to check with the local authorities to confirm if there is adequate access provided to the openings.

In summary, 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 depending on how the local building official chooses to interpret the code.

Fire Separation Considerations

The location of a building relative to the property line and or adjacent structures affects the required fire rating of the exterior walls. Fire walls are required between two separate buildings. Fire barriers are required to separate occupancies within the same building. A fire wall must provide a complete barrier from the foundation to or sometimes through that roof and must continue to remain standing should either of the adjacent buildings be structurally compromised due to a fire or other similar disaster. Fire barriers that separate occupancies in the same building only have to extend to the underside of the floor or roof framing above. The required rating of a fire barrier is based on the usage of the spaces being separated. An additional discussion of fire walls can be found in Courses G125 (Understanding Fire Wall Basics) and G130 (MFL Fire Walls).

Fire walls in open and enclosed parking structures under IBC and BOCA are required to be 2-hour rated. The fire resistance rating of structural members and assemblies shall comply with the requirements for the type of construction used in the building. The only requirement regarding structural members in parking garages that is pertinent to this type of facility is IBC Section 713.4. This section requires that impact protection of the fire resistive covering of any structural member that is exposed to impact damage from moving vehicles be provided. This provision can have a significant cost impact on the use of steel framing in parking structures required to have fire-rated structural members. Under IBC and the IFC (International Fire Code) an automatic sprinkler system shall be provided throughout all facilities classified as enclosed parking structures, except enclosed structures classified as Group R-3.

Standpipes consist of pipes with connections and valves that allow a fire hose to be attached to deliver water to fight fires. Standpipes reduce the need for firemen to hand-lay hoses all the way back to the fire truck pumps in order to fight a fire. Automatic dry systems are typically used where an automatic supply of water is required, but freezing could damage a wet system, such as is the case in an unheated, enclosed parking garage.

IBC requires that the size and distribution of portable fire extinguishers comply with the IFC. The IFC states that occupancies involving flammable or combustible liquids of low hazard should have a maximum travel distance to a fire extinguisher of 30-feet.

Approved fire alarm systems and automatic smoke detection systems are not required in parking structures, either open or enclosed, per IBC 907.2 except as follows;

1. Where high rise requirements are triggered; fire alarms shall then be provided in accordance with IBC 907.2.12.
2. Where the lowest level of the structure is more than 60 ft. below the lowest level of exit discharge.

Means of Egress

Typically, both open and enclosed parking structures are required to have at least two means of egress (MOE) from every floor. Vehicular ramps cannot be considered a MOE, unless "pedestrian facilities" are provided. Although "pedestrian facilities" is not further defined in the codes, it is generally interpreted to mean a raised, curb high, sidewalk or a designated walkway delineated by bollards or other similar means. The only exception to the prohibition of using vehicular ramps as a MOE exit is NFPA 101 which allows an automobile ramp to serve as the second exit for an open parking structure if it discharges directly to the street.

Where no persons other than parking attendants are permitted, there shall not be less than two 3-feet wide stairs provided in a garage. Elevators, escalators and moving side walks are not permitted to be part of the MOE. The minimum width of an exit stair is 44-inches (IBC 1003.3.3.1). This width is a nominal dimension because handrails may project 3½-inches and stringers may project 1½-inches into this width. Under NFPA and BOCA, a stair serving an occupancy of less than 50 people can be 36-inches wide.

In order for wheel chairs to be able to evacuate a garage, the minimum width of the accessible means of egress is 48-inches clear between the handrails. This means that as much as 55-inches of nominal width should be used for calculating the required width of the accessible MOE.

The maximum permissible width of an exit stair is 60-inhces between handrails, or about 67-inches nominal. In addition, within this same dimensional width an intermediate handrail is required. (IBC 1003.3.3.11.2). The maximum nominal width under UBC is 88-inches.

The minimum clear width of a door when fully open, when in the path of the MOE, is 32-inches (IBC 1003.3.1.1). For openings greater than 48-inches, two door leaves are required under all of the codes except BOCA and NFPA. The minimum width of a ramp under IBC 1003.3.4.4.1 is the same as that for corridors, 44-inches. Both corridors and ramps require 36-inches clear between the handrails.

One of the key determinants of the MOE is the occupant load. Both open and enclosed parking facilities have an occupant load of one person for every two hundred gross square feet under all of the building codes.

The required exit width is calculated as 0.3-inches of width per person for stairs, and 0.2-inches of width for other components if the building (as is the case with an open parking structure) is not sprinklered. If the building is sprinklered, the required exit width of stairs is calculated as 0.2-inch per occupant and the required width of other egress components is calculated as .15-inch per occupant.

Where an exit space also provides egress for multiple spaces, the combination of the number of occupants for both spaces is required. In addition, 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.

Where exits serve multiple floors, only the occupant load of each individual floor shall be considered in computing the required capacity of exits at that floor, provided that the exit capacity is not decreased by the floor level in question. In other words, where floors have different footprints, the occupant load shall be based on the largest floor.

A good rule of thumb for conceptual design is to calculate the required exit width per 100 parking spaces per floor. An open parking structure will typically require 45-inches to 52-inches of stair width for each 100 parking spaces per floor. The required aisle width is 30 to 39-inches per 100 parking spaces. As the minimum nominal width of exit stairs is 44-inches to 55-inches 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.

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 total occupant load.

IBC uses the ADA definition of a "ramp" as any floor surface with a slope over 1 to 20. Therefore parking consultants need to be aware that an exception to this IBC requirement for parking floors sloping between 5.0% and 6.7% will need to be obtained in order to exempt the ramps from the normal handrails and landing requirements of the Code if ,as was previously indicated, the route is considered an ADA accessible route.

At least two 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. In IBC, the maximum travel distances to an exit for both open and enclosed parking facilities are 300-feet in non-sprinklered facilities and 400-feet if the facility is equipped with an automatic sprinkler system throughout.

In smaller structures, up to approximately 55,000 square feet 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 the minimum width at each. In this situation, 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. In mega-structures with more than about 150,000 square feet per floor, occupant load will begin to play more of a factor.

It is important that a stair enclosure not reduce the driving aisle to narrower than required for the turning radius required into the stalls opposite the stair. Stair treads shall be 11-inches wide minimum and risers shall be no less than 4-inches and no more than 7-inches high. A flight of stairs shall not have a vertical rise greater than 12-feet. Stairs greater than 12-feet in height require an intermediate landing to be used.

Enclosure of an exit stairs is not required in open parking structures under IBC, UBC and BOCA. In enclosed structures, most stairs are required to be enclosed. An exception would be an exterior exit stairway where the stair is exterior to and separated from the building. For security reasons, it is recommended that the last flight to grade is closed off because it may afford a hiding place for criminal activity and/or sleeping areas for the homeless.

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 an automatic sprinkler system.

Therefore, all parking structures (whether open or enclosed) with four or more stories will have at least one elevator with the required emergency power/operation/signaling provisions. Although neither accessibility nor a means of egress requirement, it should be noted that the IBC and the UBC require that buildings with four or more stories must have at least one elevator sized to accommodate a 24-inch by 76-inch stretcher in the horizontal, open position.

When a stair is part of an accessible means of egress, it must be enclosed and have a clear width of 48-inches between handrails and have an area of refuge or connect to a horizontal exit. Under IBC and ADA, stairways in open parking structures or buildings equipped throughout with an automatic sprinkler system as defined by the code, are exempt from both of these same requirements.

Therefore, as parking structures have one occupant for every 200 square feet there must be one area of refuge for every 40,000 square feet of parking floor where NFPA or other local requirements insist on areas of refuge. Each area of refuge must connect to a stair, elevator or horizontal exit meeting the requirements for an MOE.

When an elevator lobby is used as the area of refuge, the shaft and lobby shall be smoke proof enclosures, unless it also has a horizontal exit or smoke barrier. Where an area of refuge is required, it must have a 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.

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 that does not require a stair. Pedestrian bridges connecting a parking structure to an adjacent building can be horizontal exits from either.

Where a ramp is part of a means of egress, it shall have a running slope not greater than 1 to 12 (8.33%). Maximum cross slope is 1 to 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 to 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 to 20, or 5.0%. Parking ramps with floor slopes exceeding 5% are allowed to be part of the path of travel to an exit. However, if the travel path is ADA accessible the need for landings for each 30-inches of rise is then required. The real problem, however, is that the handrail requirements under IBC that stipulate intermediate handrails must be provided at 60-inch spacing. It then basically becomes impossible to use an accessible ramp for vehicular travel. One way to accommodate this requirement is to use a 5.0 % maximum ramp slope for the main parking slopes and make up any shortfall with speed ramps at the ends.

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:

1. The path of travel is free and unobstructed and readily apparent.
2. 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.

<u>MEP</u>

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 square feet of floor area. Any automatic operations shall not reduce the ventilation rate below 5 cfm per person. With the occupant factor of 200 square feet per person, the low setting is 5 cfm per 200 square feet or about 0.025 cfm per square feet, which is 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-feet above the roof. Exhaust air may not be directed onto walkways.

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 of which most parking facilities would qualify. Given the occupant load of one per 200 square feet the water closet and lavatory requirements correspond to one pair (toilet and sink) of fixtures for each 20,000 square feet 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, when they are provided for employees only, customer facilities are not required for storage occupancies. In either case, as will be discussed on the topic of security, it is strongly recommended that customer restrooms not be provided in parking structures, but should instead be provided at the destination served.

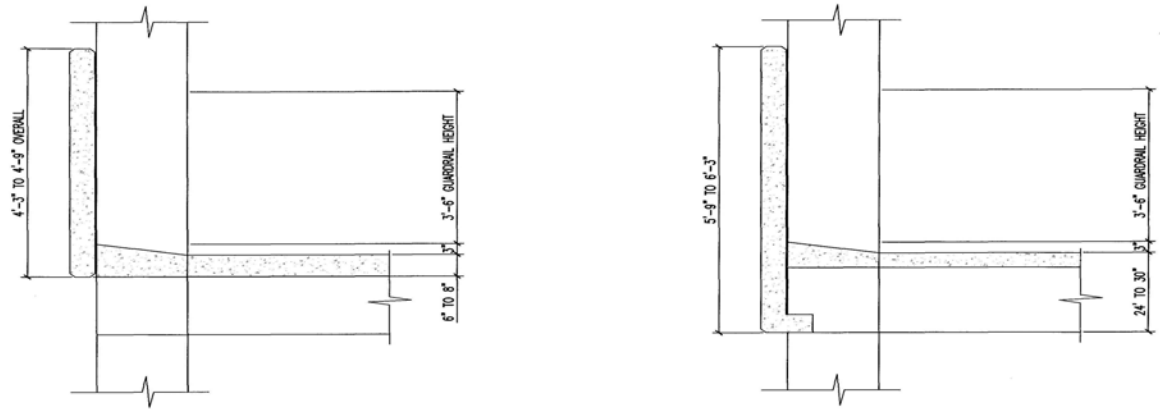
Vehicular and Pedestrian Barriers

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.

Guardrails in parking structures shall be at least 42-inches in height under all of the codes. Guardrails for most occupancies are required to prevent a 4-inch diameter sphere from passing through any openings up to a height 34-inches above the floor and an 8-inch sphere for the height from 34-inches to 42-inches.

Technically, IBC, as well as NFPA, has an exception that allows storage uses (which would include open and enclosed parking structures) to employ a 21-inch sphere rather than a 4-inch or 8-inch sphere. However, this exemption may simply be an oversight, given the more likely presence of children in public parking facilities as compared to other storage uses, therefore it is strongly recommended that the design standard for other uses be followed.

In recent years, there has been controversy over BOCA's adoption of language prohibiting a ladder effect in guardrail design. This provision is not present in the UBC, IBC or NFPA 101. The purpose of this requirement is to discourage children from attempting to climb a handrail or guardrail and accidentally falling over it. The problem is that the interpretations of ladder effect have varied widely. In either case, if cable railing of any type is used in a garage, it is recommended that cyclone fencing be installed above the top cable to prevent the users from climbing over the top of the railing. Figure 6 *provides* examples of ways to avoid creating a ledge by changing the required height of a guardrail.



POST–TENSIONED CONCRETE

PRE–CAST CONCRETE

FIGURE 6

The loads on pedestrian guardrails are the same as those for any personnel handrail which includes a concentrated load of 200 pounds at any point and in any direction along the top and a horizontal load of 200 pounds over an area of 1 square feet anywhere on the railing.

Traffic barrier should be designed to resist a load of 6000 pounds applied horizontally in any direction to the barrier system and shall have anchorages or attachments capable of transmitting this load to the main structure. The load should be assumed to act a minimum of l'-6" above the floor over an area of 1 square feet. BOCA requires vehicular barriers to meet Section 4.4 of ASCE 7. Barriers in structures accommodating trucks and busses should be designed in accordance with an approved AASHTO method for the design of traffic railings. Additional sources of traffic barrier design criteria is provided in the structure section of this course.

Most parking consultants avoid using wheel guards because of the trip and fall hazard. In addition, 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.

Accessible Design

Perhaps the most important thing to remember about ADA (Americans with Disabilities Act) is that it is a civil rights law and not a building code**.** As such these guidelines for building and facility design are therefore subject to state or local approval and variances. The Department of Justice is charged with enforcing the act, and individuals who feel they have been discriminated against can sue the property owner.

It is also important to note that Titles I, II, and III have different requirements, especially in regards to existing buildings. Title I states that existing areas of buildings that are used only by employees only have to be modified when an employee with a disability needs such modifications.

In addition, as a part of a building renovation program, whatever is taken out as a part of an alteration, must be put back accessible unless it is technically infeasible. An example of putting something back accessible would be if a nonconforming curb at an elevator tower were removed during a renovation or repair. ADA requires that the new curb that is put back must meet the required accessible requirements of the law.

Basically ADA requires that at least 1 accessible parking space be provided for every 25 spaces in a parking lot or garage. For large garages (500 to 1000), 2% of the total number of spaces shall be accessible. 1 van accessible space shall be provided for every 8 accessible spaces required.

ADA also has special requirements for the number of accessible spaces at certain medical facilities. For outpatient facilities 10% of the total number of parking shall be accessible. For facilities that specialize in treatment or services for persons with mobility impairments 20% of the total number of parking spaces shall be accessible.

As indicated above ADA requires that some of the accessible spaces be specially designed for the use of persons using vans for transportation. One in every eight accessible spaces, but not less than one, shall be served by an access aisle 96-inches wide and shall be designated "van accessible". The vertical clearance at van accessible spaces shall be 8'-2". All van accessible spaces may be grouped on one level of a parking structure.

Accessible parking spaces serving a particular building shall be located on the shortest accessible route of travel from the adjacent parking to the 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.

Accessible parking spaces shall be at least 96-inches wide. Parking access aisles shall be part of an accessible route to the building or facility entrance. Two accessible parking spaces may share a common access aisle. Parking spaces and access aisles shall be level with surface slopes not exceeding 1 to 50 (2%) in all directions. Except as provided in above, access aisles adjacent to accessible spaces shall be 60-inches wide. An example of an accessible parking space layout is provided in Figure 7.

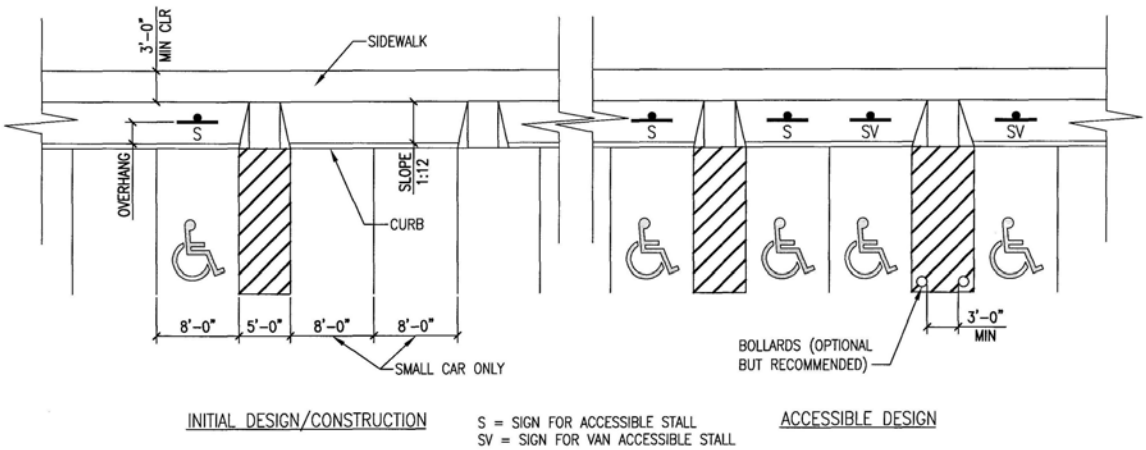


FIGURE 7

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 the ADA. For example, all doors, hardware and elevators must meet ADA. This requirement is based on the premise that persons needing some of the ADA design features may not qualify for a disabled parking permit.

Security

Security design in parking facilities deals with minimizing the risk of incidents that threaten the safety of the users and the parking attendants. Psychology plays a big role in security design. In other words, a good design uses visual clues to influence people's perception. In addition, the courts often hold owners and operators liable for injuries suffered in criminal attacks when the defendant did not take adequate steps to reduce foreseeable risks. The courts will generally not find an owner or operator liable when security considerations have been thoroughly assessed and appropriate measures have been taken.

Parking facilities are subject to a somewhat higher risk of crime than most other types of uses. In the early 1990's parking facilities were the third most frequent place for a violent crime to occur. There is one other type of crime that includes special concerns for the design of certain types of parking facilities and that is terrorism The most common terrorist attack mode, even in the U.S, has been a truck or car bomb. Another type of special risk facility is courthouses, which have a higher risk for various types of violent crime. One approach in designing courthouses includes providing secured, segregated areas away from the public for employees and judges.

Why do parking facilities pose a higher risk than other facilities? Because parking facilities include a relatively large volume of space with relatively low activity levels. Other features that are inherent to parking facilities that make security (both perceived and real) difficult include:

1. Parked cars provide hiding places and impede distribution of lighting.
2. Sloping ramps impede visibility across the facility.
3. Parking facilities are open to the public.
4. There is an "ideal" mode of escape for the perpetrator, a car.

The selection of the appropriate security system for any parking garage depends on the history of the surrounding area. The process of evaluation the risk is called a security audit. The first step in a security audit is an analysis of the risk of the different types of crimes. This requires that an incident history and profile be developed for the area by contacting the local police. Using this information, the facility should be classified as one of the following;

Low-Risk: Facilities that involve only minor vandalism and juvenile theft problems and no personal injury incidents or professional theft activity.

Moderate-Risk: Facilities where there may be an occasional suspicious person or vehicle theft in off-hours, but there is no reason to anticipate personal injury attacks.

High-Risk: Facilities where previous incidents of personal injury or a pattern of thefts that might escalate to personal injury.

Special-Risk: Facilities that are more likely to be targets of terrorism or special concerns such as courthouses.

The second step is an evaluation of the design features that may impact security, either positively or negatively. There are two types of security measures typically used at a parking garage, passive and active. Passive security measures are a physical part of the facility, such as lighting and glass-walled elevators and stair. Active security measures include active responses by the management and/or employees of the facility. Examples of active measures include on going and continuous security patrols and monitored closed circuit television systems. Active systems are generally not necessary in low-risk facilities, but may be used to provide a positive perception and level of comfort by the users. Active patrols are the best type of security to have in any garage.

The structural system should be evaluated for security aspects also. Long, clear open span construction and high ceilings create an effect of openness and make it easier to properly light the facility. Lighting is considered to be the most important security feature in a parking facility. Shear walls should be avoided, especially near turning bays and pedestrian travel paths and should be provided with large openings to improve visibility if absolutely required from a structural stand point. When visual obstructions are unavoidable, mirrors should be used to allow the users to see around corners where potential attackers may be hiding.

Stair towers and elevators lobbies should be designed as open as the code will allow. The ideal solution for a stair and or elevator lobby is to provide a totally visually open area exposed to both the interior of the garage and the exterior of the structure.

Parking owners, operators, and consultants all agree that public restrooms in a parking facility should be avoided to eliminate any security issues. Public restrooms should therefore be provided at the destination that the garage serves.

It is recommended that attended booths or offices be situated so that activity at pedestrian and vehicular entry points to the facility can be monitored. Landscaping should be designed to avoid hiding places. In addition, the design and placement of all signage should eliminate confusion and delays for the users. Other important systems that need to be considered as a part of the security design include;

1. The protection of cash.
2. Methods of emergency communication.
3. Closed circuit televisions

Structure

The structural design of a parking garage should satisfy the requirements for strength, flexibility, durability, ease of maintenance and minimum need for repair. Equally important are function, cost, appearance, and user comfort.

The effects of the ability of local contractors to provide or construct certain structural materials or components is an important consideration when designing a garage. Examples of specialty materials include silica fume concrete or high reactivity metakaolin concrete. Either material is stronger and less permeable than conventional concrete, but if it has never been used in a particular city, the bids will probably exceed the expectations of the designer. Another example would include pre-topped double tees. If there is not a precaster in the project city that has built a structure with pre-topped tees before, it is likely that none will be interested in bidding on the project.

Another similar constructability concern is that in some cities there may be few builders capable of producing quality cast-in-place concrete construction. In addition, trade union rules in some regions of the country require that all rebar bending be done on site. These two situations, will eliminate cast-in-place concrete construction as an option.

The cost of parking garages varies greatly from region to region. Currently the cost of a design build garage in the southeast without any architectural frills is in the neighborhood of $8,000 per space. A design bid parking garage in the Washington D.C. area costs about $12,000 per space. Garages in the northeast can cost as much as $20,000 per space.

The project budget may eliminate some systems from consideration. For 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. In addition, if 24-inch precast concrete double tees are the deepest available section this depth of member does not have the capacity to carry typical parking structure loads for 60-feet long-span conditions, therefore either short-span construction will be required or cast-in-place post-tensioned construction will be required.

Other factors that should be considered when evaluating different structural systems include; durability, speed of construction/erection, appearance and façade options. Other important considerations in selecting a structural system are availability, cost, expected quality of construction, expected service life, function, and appearance.

Most building codes require a uniform live load of 50 PSF and a 2000 pound concentrated wheel load distributed over a 20-in^2 area anywhere on a floor. Additional live load for snow on the top or roof level of the garage may also be required. Some building codes allow for the reduction of live loads for members supporting significant tributary slab areas.

ASCE 7 allows for only a 40 PSF live load in garages, however a 3,000 pound concentrated wheel load distributed over a 20-in^2 area anywhere on a floor must also be applied to the structure. This reduced uniform live load is based on statistical and dynamic studies which still results in a conservative magnitude of load as similar studies have shown that valet parking of cars (vehicles stacked side by side) result in a live load of no more than 30 PSF. IBC 2003 also allows for a 40 PSF live load in garages and a live load reduction (20% maximum) for columns and walls supporting 2 or more levels. The current IBC also allows for a reduction in the combined snow and uniform live load:

$$(1.2DL + 1.6LL + .5SL) \text{ or } (1.2DL + LL + 1.6SL)$$

When considering wind loading most designers consider it unrealistic to use anything less than the full building face area for the projected area. It is not necessary to subtract the open areas of the building face, instead consider the face as solid unless you are interested in developing a more rigorous analysis.

The Parking Consultants Council of the NPA recommends a factored concentrated lateral traffic barrier impact load (ultimate strength design load) of 10,000 pounds applied 18-inches above the driving surface. At least one code requires that this same load be applied 27-inches above the floor. These impact forces are based on a 5-mph impact speed. A typical 6-inch high curb or a precast wheel stop will not stop anything more than a slowly moving car, and should never be considered a barrier.

Perimeter guardrails composing of only cables or post-tensioned tendons are not recommended as traffic impact barriers 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.

When incorporating designated storage rooms into a parking garage it is important to label the room as dead storage on the contract documents. Otherwise, heat, mechanical ventilation, and sprinklers may be required.

In cold climates, a snow removal system may be required. This provision may involve design for special vehicle loading in addition to the snow live load. It is also sometimes necessary to consider provisions for snow-melting equipment and snow-disposal chutes or containment structures.

Proper drainage is essential to structural durability and serviceability. If water is allowed to stand or pond on the parking structure floors for long periods, deterioration will accelerate in the concrete beneath the ponded areas. No parking structure floor should ever be flat, even if rain cannot fall directly on the exposed surface, because rain can be blown into lower floors and cars will also carry water into lower floors. For drainage, the absolute minimum slope should be 1/8-inch per foot or about 1%. The preferred slope is 3/16-inch per foot or about 1.5%. When setting slopes on design drawings, be sure to take into consideration the anticipated camber and deflections of all members as either of these effects can reduce the design slopes if not recognized and accounted for.

Drain catch areas should not exceed about 4500 square feet of tributary area on floors that are nominally flat (i.e. sloped 1% or 1.5%). On floors that have more than minimum slope, drains should be spaced to drain more than the 4500 square feet. Drains should be located so that the runoff does not have to cross an expansion joint seal or turn a corner to reach the intended drain.

Drains should also have a sediment bucket that can be removed and emptied during regular maintenance. Drains at lower floors should include one way valves that can prevent flow from back ups in the main system from over flowing into the lower levels. 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.

There are many types of expansion joints systems available on the market for parking structures, however, even the best systems should be properly maintained following the manufacturer's guidelines. When an expansion joint system fails and allows water to drain through the joint, in lieu of going to the expensive of replacing the joint material, it is some times possible to install inexpensive sheet metal guttering systems beneath the joint to redirect the runoff away from vehicles below and towards adjacent floor drains.

Perceptible floor 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. In addition, what is acceptable is somewhat subjective as no building code requirements exist per say and the perceptions of users vary a great deal.

Volume change effects that have an impact on exposed parking garage structures include; elastic shortening (for prestressed and post-tensioned members), creep (for concrete structures) and changes in temperature.

There are two types of structural systems that are predominately used in parking facilities to resist lateral loads imposed from wind and earthquakes. These include; moment frame and shearwalls. Most shearwalls have openings that must be addressed as a part of the structural analysis. The size of the opening determines whether or not the shearwall be analyzed as a wall or a frame. Per the latest ACI Code, if the length of the pier on either side of an opening is greater than twice the wall thickness then the element can be analyzed as a wall. This is an important consideration when establishing the R factor for the structure as a part of a seismic analysis.

Durability and Maintenance

Parking structures deteriorate more rapidly than other building types primarily because they are more exposed to direct attack from weather including temperature changes, moisture and the combined effects of freeze-thaw cycles.

Two important facets of a garage, that if properly addressed, will help to offset the damaging effects of exterior exposure include proper drainage and durable concrete. In addition to the importance of providing properly designed, mixed and placed concrete it is also possible to include additives and admixtures to enhance the properties of concrete. These materials include air entrainment, water reducing admixtures, corrosion inhibitors, silica fume and highly reactive metakaolin. It is also sometimes necessary to use either epoxy coated reinforcing bars or galvanized rebar.

It is also sometimes advisable to provide protective coatings on the concrete surface. Surface treatments can include both sealants and sealers. 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. 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 will not stop deterioration, but will slow down the process of deterioration as well as reduce future maintenance costs. There are two types of sealers; film-forming and penetrating sealers. Film-forming sealers wear quickly in a parking structure so they are essentially of no value. 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.

Film-forming sealers that will not withstand abrasion include acrylics, epoxies, silicones, and stearates. Among the penetrating sealers, avoid silicates and siliconates. Siloxanes are less expensive than silanes.

Waterproof membrane systems (sometimes called toppings) for parking structure pavements are classified as two kinds; those applied over the pavement as a traffic-bearing surface and those which must be protected by a wearing course. Except for cast-in-place overlays on precast concrete, overlays are not often used in the construction of new parking structures. The use of toppings is more common in restoration work.

The purpose of parking facility maintenance is to assure proper and timely preventive actions to reduce premature deterioration of structural elements and equipment failures. A properly maintained open parking garage should have a maximum service life of approximately 60 years.