Thornton Tomasetti

HOW TO DESIGN PARKING LOTS THAT WORK

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1. Introduction

Parking as we know it today had its birth in the 1920s. Before that time, early forms of mass transit provided the means of delivering workers to their destinations and shoppers to retail destinations. But it was during the 1920s, when the downtown area (central business district or CBD) of all large cities was the major hub of activity that the concept of parking garage began to develop. The garage's primary purpose was to protect a vehicle's oil-paint finish from the elements. Getting vehicles off the roadway was not a major concern.

In addition, the notion of self-parking had not been conceived. Instead, attendants parked the vehicles of garage patrons. Chauffeurs were not uncommon. Attendant parking required a large drop-off area at the garage entrance, allowing customers to leave their vehicle until an attendant was available to park it. Early garages also sold gasoline and provided other services, such as lubrication, washing, and mechanical repair.

The early boom in parking garage construction flourished until the Great Depression and did not resume until after World War II. Land values decreased significantly as a result of these two events, leading to a proliferation of surface parking lots in the nation's CBDs. During the same period, technological advances saw the emergence of enamel as an automobile paint finish. No longer did vehicles have to be parked indoors to protect their finish.

Parking as we know it today evolved from 1945 to 1965. The economy was changing and large downtown developments became common. Street congestion underscored the need for more off-street parking facilities.

The mid-1950s brought an important change in the parking industry. A complete rethinking of design concepts and dimensional standards evolved, and innovation in parking design to meet the needs of self-parking brought many changes.

Another aspect of the self-park evolution was the development of head-in parking. In earlier decades, an attendant backed the vehicle into its parking space to facilitate its rapid retrieval. In contrast, head-in parking at angles ranging from 45 to 90 degrees better accommodates patrons who park their own vehicle.

Other concepts that evolved at this time for the benefit of the parking patron included a focus on lighting, signage, drainage, and safety.

From the beginning and up to the mid-1960s, parking garages were usually built by, owned by, or associated with large retail department stores and large office buildings. Today, parking facilities are constructed for a variety of user categories such as hospitals, colleges and universities, office buildings, hotels, municipalities, airports, sports stadiums, and even places of worship.

A major factor in the suburbanization of retailing in the 1950s and 1960s and of office space in the 1960s and 1970s was the proliferation of free parking for all users. Given that suburban land was inexpensive, developers did not pay careful attention to estimates of demand and efficient parking design. However as land become more and more expensive, developers started to pay attention to efficient design in the suburbs to avoid constructing parking garages.

Two other events had a significant impact on design of parking facilities. First, the 1970s saw an increase in the number of foreign-made vehicles sold in the United States. Second, the gasoline shortage of the early and late 1970s spurred demand for smaller cars. Designers were faced with the challenge of implementing smaller-width parking stalls; widths decreased from nine feet to eight feet to seven and one-half feet.

Designing specifically for small cars increased overall facility capacity by 15 to 20 percent. However, small-car use was not universal across the country; as a result, location and site-specific use trends became design factors. More important was how to control facilities that accommodate both large-and small-car parking stalls. The dilemma was how to ensure the drivers of small vehicles would not park in large-car spaces and vice versa, thus causing a potential loss of total available parking spaces in a given parking facility.

The impact of small cars on the parking industry was enormous. The 1980s saw almost 50 percent of all vehicles sold in the United States classified as small cars. One significant influence on small-car production was growing concern over clean air. Many West Coast cities reported as much as 75 percent increase in the small-car population.

In the late 1990s, and 2000s more attention is being paid to the ratio of large cars to small cars. An idea of uniform parking stalls is starting to creep into the parking industry.

The evolution of parking facilities from the 1920s to today has brought about significant changes in parking geometry, use of materials, safety and paying attention to environmental issues.

2. Property Acquisition

a. In order to procure a property for a facility such as a manufacturing, retail, office, and housing, a detailed study should be undertaken to determine the feasibility of the project. Every facility will require considerable amount of parking which in most cases occupies more land than the facility itself. Therefore a parking study is as important as a market study for the business enterprise.

In general a traditional parking feasibility study includes each of the following three components:

- Parking supply/demand analysis;
- Site alternatives analysis; and
- Financial feasibility analysis.

Some parking feasibility studies consist of only one of the above components; others include additional components, such as an analysis of traffic impacts or management/operations issues.

The menu of analysis that might form parts of a parking study includes following:

- *Parking supply/demand analysis.* Determine current and future parking supply and demand.
- *Market study.* Identifies how many users a facility will capture on a particular site given demand, competitive climate, and prevailing parking rates.
- *Shared parking.* Determines the need for parking in mixed-use/multiuse development areas in view of variations in individual-use needs by time of day, day of week, and season and the relationship needs among planned land uses.
- *Site alternatives*. Involves selection and comparison of sites for the parking improvements that will be required to resolve documented parking shortages.
- *Schematic design.* Involves developing the functional design for a proposed parking facility to a level of detail sufficient to obtain concurrence of the interested parties. Design documents normally constitute the first phase of a design contract, but they may be necessary during feasibility study phase to provide the background information needed to obtain consensus and proceed with design and funding.
- *Traffic impact analysis (TIA).* Applies standardized traffic engineering analysis to determine current and/or future traffic conditions and to recommend improvements. Although the TIA generally focuses on determining the effect of a proposed parking facility on traffic conditions, it sometimes needs to address existing traffic problems that should be considered simultaneously with parking needs.
- *Financial feasibility.* Involves an analysis of what and how much various parties should pay for the parking facility.
- *Preliminary Geotechnical study.*

b. Preliminary Geotechnical Study

Subsurface conditions are but one of the factors to be considered when evaluating the suitability of a particular site for a specific type of facility. Like other site evaluation factors, subsurface conditions can range from very favorable to strongly negative; so negative, in some cases, as to render the site unfeasible for the intended use.

The objective of the site selection process is to evaluate and quantify each of the suitability factors so as to provide a uniform evaluation of all sites, leading to the selection of the most favorable one. In the case of evaluation subsurface conditions, two primary elements should be considered: subsurface construction costs and foundation serviceability. The make-up of each of these elements is discussed below.

> _Subsurface construction cost:_ These are all costs associated with establishing a transition between the earthern site materials and the facility. Included would be such cost items as substructure and foundation units, initial cost of permanent groundwater control systems, excavations, excavation support systems, groundwater control during construction, work on adjacent structures necessitated by the new construction, etc. sometimes overlooked, but frequently significant, are the costs incurred outside the limits of the facility, such as site grading and the installation of underground service utilities.

> _Foundation Serviceability:_ Two factors should be considered, namely, the ultimate safety of the facility and the long-term cists are related to subsurface conditions. For the former, one must consider the margin of safety against loss of utilization of the facility resulting from such things as large-scale differential settlements or dynamic loadings induced by earthquakes. For the latter, one should consider such items as long-term costs of permanent groundwater control or corrective maintenance resulting from long-term settlements.

Obviously it is not feasible to make detailed study of each of a large number of sites during the site selection process. During the early phase of selection, the geotechnical engineer will have to rely on such general information as geological and engineering literature, current and historic topographical data, a reconnaissance of the site and surrounding area, discussions with local engineers and geologists, examinations of nearby structures, etc. in most parts of this country there are adequate sources of information relative to subsurface conditions that can be utilized to make realistic appraisal of the relative condition of potential sites.

Prior to actually purchasing any site, however, the owner should conduct a more detailed study of the site in order to determine the actual sub-surface conditions and make an assessment of the effects of these conditions on the proposed construction. This involves taking two or three borings in order to determine the subsurface conditions and its impact on the surface parking construction. For example, if there is a soft organic layer approximately 10’-0” below the surface and fill is added because of site grading design, considerable long term settlement maybe expected after a surface parking lot is constructed.

3. Types of Surface Parking Lots

a. Urban Lots

In general, the urban parking lot is comparatively small and may charge patrons for the use of its parking spaces. Such lots may meet the needs of the short-term (hourly) parker or the long-term parker- ether on an all-day basis or under the terms of a monthly contract, short- or long-term parking can be encouraged by varying a facility's rate structure. Facilities situated near retail and business establishments cater primarily to short-term parkers who generally are willing to pay a higher rate for the convenience of parking close to their destination; thus, short-term lots produce more revenue per parking space than do lots catering to long-term parkers. In the case of parking lots located progressively farther from the core of a community the facilities' function shifts increasingly from short-term high-turnover hourly parking to long-term and monthly contract parking.

A facility can be operated as a valet-parking system, self-park system, or honor-park system. With the increasing cost of labor, self-park and honor-park systems continue to predominate. Valet parking operations are somewhat restricted to smaller facilities that can be staffed by a few employees. Honor-parking systems are generally used in facilities that are on the fringe of the central business district (CBD) and cater primarily to all-day and monthly parkers are a relatively low charge. They do not produce sufficient revenue to warrant employment of full-time personnel. All honor systems require periodic enforcement to ensure effectiveness.

b. Suburban Lots

The past several decades have witnessed an explosion in business and commercial development in the suburbs of most major metropolitan areas. The shift in office building and shopping center development from urban to suburban locations is the result of lower land costs, development of the federal interstate highway system, the desire to conduct business near major single-family residential areas, and the convenience afforded by the automobile. Public transportation satisfies little of the demand currently generated by suburban commercial and business developments, thereby placing the onus on developers to provide parking for their tenants and tenant visitors.

The parking lot at a suburban shopping center functions in accordance with a completely different set of principles than those guiding an urban parking facility. For example, shopping center lots tend to be large; they vary from hundreds to thousands of spaces depending on the size of the shopping center. Moreover, the more generous parking space geometrics commonly found in suburban lots have now become the norm expected by the public.

Suburban office building parking lots also tend to be considerably larger than their urban counterparts. Suburban zoning regulations, lack of public transportation, and inadequate on-street parking create the need for a greater number of parking spaces per 1,000 square feet of net rentable office area. In addition, the ratio of visitor to employee spaces varies with the function of the office building. A medical office building might require only 10 to 15 percent of total spaces to be reserved for visitors.

Most suburban shopping center parking lots do not charge a direct fee for the use of their facilities. Likewise, suburban office building complexes usually do not charge a fee for use of their facilities. However, the cost of developing maintaining, and controlling suburban shopping center parking areas is factored into rents and ultimately into the costs of merchandise, services, and public use of the areas.

c. Employee Facilities

The largest individual segment of parking in the United States is provided by employers responding to the needs of their employees. In most instances, such parking is provided at no cost to employees. Free parking for employees has even been written into major labor agreements as an employee fringe benefit.

The design of long-term employee parking can differ somewhat from the design of short-term customer parking. Employees, who are familiar with the work facility and may enter and exit from the facility only once or twice a day, do no necessarily require the same degree of user convenience as medical center patients or retail/service customers. Employees can be expected to walk farther and use facilities with narrower aisles and reduced parking space widths.

d. Special Use Facilities

Special-use parking facilities are distinguished from other parking facility types by their design requirements. That is, they must be designed to meet the brief peak parking demand generated by sports complexes, convention and meeting facilities, theaters, coliseums, and similar activity centers. However, other special uses such as hospitals, airports, and hotels generate parking demand 24 hours a day 365 days a year and thus exhibit still different peak parking needs. While certain design considerations are common to most special-use parking lots, proper evaluations of these facilities requires subdivision of the special-use category into special-use generators that operate 24 hours a day and special-use generators that operate only periodically.

Hospitals, airports, and hotels are excellent examples of special-use generators that create parking demand over a 24 hour day. They must accommodate parking demand associated with large numbers of employees and visitors as well as demand occasioned by daily periods of peak public parking. If an economical and efficient parking facility is to be developed for the special-use generators, facility design must permit the operation of parking services with minimum manpower during periods of low demand while still providing sufficient entry/exit lanes to handle periods of peak in/out activity. Airports, in particular offer public parking lots that are divided in long- and short-term parking areas. Furthermore, optimum revenue control can be achieved by segregating employee parking from paid parking, including separate entry/exit control points.

Uses that generate periodic parking demand, such as sports facilities, present a completely different set of parking problems that require different design considerations. Generally, the major design consideration is maximum entrance and exit capabilities to handle peak parking demand during a relatively short period of time. In addition, for special-event parking, fees are usually collected upon entry to rather than exit from the parking facility, with selection of a parking space rigidly controlled.

4. Surface Parking Lot Design

a. Relationship between Design and Operation

The operation of a parking facility is greatly influenced by its design. The design elements and their associated operational features may be identified in successive steps as follows:

1. Vehicular access from the street system (entry driveway);
2. Search for a parking stall (circulation and/or access aisle);
3. Maneuver space to enter the stall (access aisle);
4. Sufficient stall size to accommodate the vehicles length and width plus space to open car doors wide enough to enter and exit vehicle;
5. Pedestrian access to and from the facility boundary (usually via the aisles);
6. Maneuver space to exit from the parking stall (access aisles);
7. Routing to leave the facility (access and circulation aisles); and
8. Vehicular egress to the street system (exit driveway).

In general parking lots should be designed in such a way as to facilitate easy access and fast maneuver into a parking space. This should apply when leaving a parking lot.

b. Stall and Aisle Dimensions—Large Cars

In developing the design of a parking facility, it is customary to work with stalls, aisles, and combinations called “modules”.

A complete module is one access aisle servicing a row of parking on each side of the aisle, (Fig. 1). In some cases, partial modules are used where the aisle serves only a single one-side row of parking. This arrangement is inefficient and should be avoided.

The minimum practical stall width varies principally with turnover (frequency of stall use), experience of the parker, and vehicle size. Commercial parking attendants can park large cars in stalls less than 8.0 feet wide. With self-parking, stall widths that will accommodate most passenger cars and light trucks range between 8.3 feet and 8.8 feet, depending on anticipated parking activity. Site specific circumstances will influence determinations of the most appropriate stall width dimension.

For example, a generous stall width is suggested by conditions of high parking turnover or limited module width in which to develop the access aisle. Where parking turnover is expected to be low, as for all-day employee parking, narrower stall widths are usually acceptable.

Other use considerations may also influence stall width selection. In order to allow for shopping cart movement between parked vehicles, food supermarket parking is often designed with a wider stall dimension than used for other types of parking having similar turnover characteristics. Generous parking stalls also may be appropriate for special events where parking maneuvers must be performed as rapidly as possible.

One approach to the range of stall width needs is to consider a stall class. This might be roughly equated to the level of service concept, whereby parking delay and ease of access and egress varies with expected activity and type of user. Table 1 identifies typical stall widths associated with turnover/user characteristics.

Table 2 lists suggested basic design guidelines for large-size cars for typical parking angles, stall widths, and modules that will also adequately accommodate a mixture of large and small cars. In practice, a faster parking operation will be achieved if the dimensions are increased. Aisle widths are based on the stall depths listed in Table 2. if an agency has set a longer depth, then the total module dimension is the one to be considered (a 61 foot module would have a 21-foot aisle, if stall depths are marked at 20 feet, for example).

Narrowed stall width in each class for parking angles of less than 90 degrees is not desirable. There is a relation between stall width and aisle width, as shown in Table 2, but the stall width needs are basically determined by door-opening clearances. Only at very flat angles of less than 35 degrees will doors open ahead or behind the cars in adjacent stalls, and even then there can be little reduction in basic stall width.

Table 1. Stall Width Classification

		Typical Turnover			
Class	***Width (ft)***[a]	***Low***	***Medium***	***High***	***Typical Uses***
A	9.00			X	Retail Customers, banks, fast foods, other very high turnover
B	8.75		X	X	Retail customers, visitors
C	8.50	X	X		Visitors, office employees, residential, airport, hospitals
D	8.25	X			Industrial, commuter, university

Table 2. Large-Size Parking Layout Dimension Guidelines[a]

Parking Class	SW Basic Stall Width (ft)	WP Stall Width Parallel to Aisle (ft)	VPW Stall Depth to Wall (ft)	VP1 Stall Depth to Interlock (ft)	AW Aisle Width (ft)	Modules W2 Wall to Wall (ft)	Modules W4 Interlock to Interlock (ft)
Two-Way Aisle- 90 Degrees							
A	9.00	9.00	17.5	17.5	26.0	61.0	61.0
B	8.75	8.75					
C	8.50	8.50					
D	8.25	8.25					
Two-Way Aisle- 60 Degrees							
A	9.00	10.4	18.0	16.5	26.0	62.0	59.0
B	8.75	10.1					
C	8.50	9.8					
D	8.25	9.5					
Two-Way Aisle- 75 Degrees							
A	9.00	9.3	18.5	17.5	22.0	59.0	57.0
B	8.75	9.0					
C	8.50	8.8					
D	8.25	8.5					
Two-Way Aisle- 60 Degrees							
A	9.00	10.4	18.0	16.5	18.0	54.0	51.0
B	8.75	10.1					
C	8.50	9.8					
D	8.25	9.5					
Two-Way Aisle- 45 Degrees							
A	9.00	12.7	16.5	14.5	15.0	48.0	44.0
B	8.75	12.4					
C	8.50	12.0					
D	8.25	11.7					

(Source: Institute of Transportation Engineer)

c. Small-Car Dimensions

Special dimensions for small-car parking have increased applications in North America. The percentage of such cars varies by year and also somewhat by geographical location. It is currently about 40 to 50 percent in the United States.

A suitable stall length for small cars is 15 feet. Stall widths of 8.0 feet for higher turnover conditions. These dimensions are based on a small-sized design vehicle about 5 feet wide and 14 to 15 feet long. Table 3 gives several layout dimensions for small-size vehicles.

Table 3. Small-Size Parking Layout Dimension Guidelines[a]

Parking Class	SW Basic Stall Width (ft)	WP Stall Width Parallel to Aisle (ft)	VPW Stall Depth to Wall (ft)	VP1 Stall Depth to Interlock (ft)	AW Aisle Width (ft)	Modules: W2 Wall to Wall (ft)	Modules: W4 Interlock to Interlock (ft)
Two – Way Aisle-90 Degrees							
A/B	8.0	8.0	15.0	15.0	21.0	51.0	51.0
C/D	7.5	7.5					
Two – Way Aisle-60 Degrees							
A/B	8.0	9.3	15.4	14.0	21.0	52.0	50.0
C/D	7.5	8.7					
Two – Way Aisle-75 Degrees							
A/B	8.0	8.3	16.0	15.1	17.0	49.0	47.0
C/D	7.5	7.8					
Two – Way Aisle-60 Degrees							
A/B	8.0	9.3	15.4	14.0	15.0	46.0	43.0
C/D	7.5	8.7					
Two – Way Aisle-45 Degrees							
A/B	8.0	11.3	14.2	12.3	13.0	42.0	38.0
C/D	7.5	10.6					

(Source: Institute of Transportation Engineer)

d. Composite Parking Dimensions

Greater use of small cars in North America and pressure to make parking more space-efficient have resulted in a variety of parking arrangements to take advantage of smaller car sizes. The objective of each layout is to maximize the number of stalls in a given area. These designs involve either the provision of some spaces designed for the exclusive use of small cars, plus other spaces for large cars, or a downsizing of all "full-size" parking stall dimension It would, of course, be highly desirable to utilize one "standardized" set of parking dimensions. However, problems exist in separation of small- and large-sized cars. The smaller parking facilities probably do not warrant any consideration of separate dimensions for different-size vehicles. In some developments, it will be impractical to provide separate size layouts. An "ideal" composite size would utilize the values in Table 2. However, some engineers think that this will result in more area utilized per average car space than necessary. For this reason, some agencies may wish to utilize composite dimensions that represent a compromise between those dimensions necessary to adequately accommodate large-size vehicles, versus those dimensions needed for small-size vehicles. Proposals have been advanced for rationalizing dimensions based upon the expected proportions (weighted averages) of large- versus small-size vehicles. The 'one-size-fits-all' (OSFA) concept is favored by some engineers. The following listing is intended to present advantages and disadvantages of OSFA reduced sizes, relative to sole use of large-size dimensions (Table 2) or to mixed use of large and small-sized dimensions (Table 3).

Advantages of OSFA:

1. Simple for drivers to understand. No driver confusion regarding what size the vehicle is and which space they should park in.
2. No enforcing is required
3. Easier to load (route arriving vehicles to nearest vacant stall)
4. May have greatest flexibility in fitting variable modules to a given site.
5. No special signing required
6. Reduced cost of land, construction and maintenance, as compared only to sole use of large-size dimensions, if using composite stalls smaller than in Table 2.

Disadvantages of OSFA:

1. Large car drivers will often be unable to enter a stall when other cars are parked on both sides, in a single pass-especially at higher parking angles.
2. If large-size cars are parked in an adjacent stall, a pull-in parking maneuver may be physically impractical, and the driver is forced to search for a more accessible stall or to back in.
3. Increased delay to other motorists in access aisle due to increased parking rime of large-size vehicles.
4. Large cars will protrude a significant amount.

e. Handicap Spaces (figure 2)

The Americans with Disabilities Act of 1990, known as ADA, was signed into law on July 26, 1990. It differs from previous civil rights legislation in that it requires changes in the way some facilities are designed and constructed.

In 1991, as required by the ADA, the Department of Justice development regulations implementing subtitle A of Title II of the Act, which are applicable to state and local government services. These were published in the July 26, 1991 *Federal Register* (28 CFR Part 35). As design standards, these regulations referenced the *Americans with Disabilities Act Accessibility Guidelines* (ADAAG), which were developed mainly by the Architectural and Transportation Barriers Compliance Board in accordance with the ADA. These were published with the 28 CFR Part 36. The current provisions are listed in Table 4.

Table 4. Accessibility Standards

Total Parking Spaces	Required Minimum Number Of Accessible Spaces
1 to 25	1
26 to 50	2
51 to 75	3
76 to 100	4
101 to 150	5
151 to 200	6
201 to 300	7
301 to 400	8
401 to 500	9
501 to 1000	2%
Over 1000	20 plus 1 for each 100 over 1000
Source: Uniform Federal Accessibility Standard	

- ***Accessibility Standards of Handicap Spaces Location and Size***

Proper location and design of HC parking spaces is of critical importance. They should be located close to elevators, ramps, walkways, and building entrances. They should also be located so that persons in wheelchairs can access the building.

Curb cuts have to be constructed in accordance with the ADAAG. Such cuts should slope up at a rate of no more than 1 foot in 12 feet. Both ADAAG and UFAS allow for a maximum slope of 1 foot in 8 feet in some cases where the 1:12 slope is not possible. The ramps should be at least 3 feet wide in order to accommodate a wheelchair.

The HC parking space must be sufficient to accommodate the needs of a person who must use a wheelchair. A 13-foot wide area (8-foot parking space and 5-foot access aisle) is the minimum to provide adequate space to park a vehicle and yet allow the driver or passenger a wide enough area for a wheelchair to operate between parked vehicles (figure 2). For van accessible spaces, an 8-foot wide access aisle is needed.

When placing two HC spaces together, it is possible to utilize one access aisle for both spaces. As shown in Figure 2, each parking space is 8 feet wide, and the 5-foot access aisle (or 8-foot access aisle for van accessible spaces). This allows use of a single curb cut. The amount of pavement required for each HC parking space is reduced which reduces the construction cost of each space. Another advantage is that it is very difficult for three small vehicles to illegally use these two spaces.

Each HC parking space should be marked with a sign. The sign, which should be a minimum of 18 inches by 24 inches, should be mounted at a height of at least 4 feet from the pavement or sidewalk to the bottom of the sign, and should be positioned so as to be easily seen by drivers who are attempting to park. The sign should have the wheelchair symbol in white on a blue background. Additional wording that indicates that the space is reserved for disabled parkers is also useful.

Painting the wheelchair symbol on the pavement is another means of identification that is used. The symbol should be large enough (3feet by 3 feet) to be visible to drivers approaching vehicles. In some locations, blue stall markings are used to distinguish an HC parking space from a standard white parking stall. However, blue paint has a poor contrast with darker parking surfaces. A useful technique to discourage illegal use is to mark the access path of lane to be used by wheelchairs with diagonal striping. This provides a better defined parking location and is especially important where a curb cut is used, to keep the parker from blocking the curb cut with his vehicle.

5. Ingress and Egress

Usually, the larger a parking area, the more latitude there is in planning for street entrances and exits. One driveway opening per entrance or exit is often adequate for a small parking facility. In fact, local ordinances and codes frequently restrict the number of entrances and exits. Generally, though, the number of required driveway openings is related to lot size, turnover rate, the method of lot control, the lot's relationship with adjoining streets, and the type of clientele served. The determination of site access is an iterative process that results in the development of a site access plan.

Site access plans should consider the following factors:

- number and location of the site driveways serving the facility (for example, it is important to locate a new site driveway away from an adjacent intersection or other driveway);
- number of inbound and outbound lanes at each site drive;
- opportunities for reversible lanes and adequate turning radii;
- appropriate vehicle storage areas for each inbound and outbound lane;
- landscaping and sight distance requirements;
- traffic control at the site driveways;
- pedestrian and bicycle access;
- accommodation for special vehicles such as buses and trucks; and
- Appropriate signage and pavement markings and other controls to facilitate safe, convenient, and efficient access into and out of the parking facility.

One overall design objective should be to minimize the number of access points while ensuring safe and expeditious movement to and from the street system. Shared or joint-access driveways with other land uses may be advisable but may require legal agreements that create joint-access easements and define maintenance responsibilities.

A variety of traffic, non-traffic-related, and land use factors may influence the site access plan. Therefore, a set of acceptable site access plan alternatives may need to be developed for consideration. A matrix system that compares measures of effectiveness for each alternative should be prepared and evaluated to permit reasonable election of the preferred site access plan.

In any event, adequate reservoir space should be provided at lot entrances to avoid hazardous queues on public roadways. To prevent friction with street traffic, driveway openings should not be located near street intersections.

Typically the most efficient entrance and exit design can be achieved by favoring the traffic entering a facility, even at the expense of complicating the exit. Favoring entering traffic expedites the rapid movement of traffic from the street to the facility and avoids vehicle queues on public roadways. Moreover, given that traffic exiting from a parking facility tends to move slowly, drivers can comfortably negotiate the turns required to reach the exits. Driveways should minimize interruptions to the traffic flow within the facility itself.

6. Site Grading

A concept of design grading is essential in developing the physical vertical form of parking lots. Positive drainage, an important concept in grading, allows storm water run-off to flow away from structures, and activity areas. Positive drainage in parking lots, allows water to flow towards low points where areas of discharge are located.

In developing a site grading plan, it is important to balance cut and fill to avoid bringing in borrow material which is quite expensive.

Familiarity with underlying soil in a parking lot is also very important. It is important to know where the ground water elevation is located, and if the soils can be properly compacted. To obtain sub-surface information, it is very important to commission a comprehensive geotechnical report. Geotechnical reports should be bases on borings and laboratory testing of materials. The report should supply information on methods of compaction, and methods of dealing with ground water. When sub-surface information is not obtained, quite often this omission leads to costly change orders when difficulties are encountered with soil compactions.

In cut areas the original subgrade should be proofrolled with a ten ton roller using 7 to 10 passes. In fill areas, suitable borrow or suitable excavated soil should be compacted in 12 inch layers to 95 percent at optimum moisture content in accordance with ASTM 1557D. The rate of compaction is usually measures in the field with a nuclear device or a sand cone, and then compared with a compaction test performed in a laboratory commonly referred to as a Modified Proctor Test.

Earthwork for parking lots consist of cut and fill work, rough grading, and fine grading. During the stage of rough and fine grading, elevations shown on site plans are met allowing for the thickness of pavement section which usually varies from 9 to 12 inches.

7. Pavement Design

The durability and serviceability of a surface parking lot largely depend on the quality and type of the lot's surface material. The most important consideration in the structural design of pavement is proper preparation of the subgrade material and selection of the appropriate pavement type and thickness. Excessive thickness results in unjustifiable construction costs; insufficient thickness results in unsatisfactory performance and expense, premature failure, and/or excessive maintenance. Proper subgrade preparation is mandatory and in many cases must be accomplished under the supervision of a geotechnical engineer. Concurrent with the subgrade work, the site must be sloped to ensure positive drainage, which often requires installation of surface drains and drain lines. Surface lots are typically paved with bituminous, concrete, gravel, or porous surface materials.

a. Asphalt Concrete Pavement (figure 4)

Asphalt concrete pavement consists of a bituminous surface course placed on a binder course and in turn based on a base course. Asphalt concrete must be placed on a well compacted subgrade.

The function of the bituminous surface course is to prevent the penetrations of surface water to the binder course, provide smooth, well binded surface, and resist sheering stresses produced by car and truck wheels. The bituminous surface course is composed of a well graded aggregate mix (1/8" - 1/4"), and bituminous binders (6% - 8% content) to produce a uniform surface possessing stability and durability qualities. The surface course ranges in thickness from 1 ½" – 3".

The binder course and the base course are the principle structural components of the asphalt pavement. Their function is to distribute the imposed wheel load pressure to the subgrade. The binder course and base course must be of such quality and thickness to prevent failure of the subgrade.

The binder course is composed of the mixture of a well graded aggregate ranging from 3/4" to 8 % passing to #200 sieve. In this case the aggregate is much larger than in the surface course to provide more structural strength. The bituminous content in a binder course ranges from 4.5% to 6.5%. The binder course thickness varies from 0" – 5".

The base course is usually a well graded stone varying in thickness from 4" – 9". The base course is a main structural element of the pavement and it should be designed in such a way that it distributes the load to the subgrade and prevents frost formations and heave. Design curves have been developed for design of concrete pavements. The design curves are based on California Bearing Ratio (CBR) method of design. The CBR design method is basically an empirical method: however, a great deal of research has been done with the method. The curves are usually based on 20 year pavement life and its parameters are CBR, weight of a single axle, and classifications of traffic. These curves can be found in the Asphalt Institute handbook.

b. Concrete Pavement (figure 5)

Concrete pavements for parking lots are composed of a concrete surface layer placed upon well-graded aggregate or sand base course that rests upon a compacted subgrade. Concrete surface layer provides an acceptable non-skid surface, prevents the infiltration of surface water and provides structural support for vehicle wheel loads. The purpose of the base course on the concrete pavement is to provide uniform, stable support for the concrete slab. Sometimes the base course can be omitted when the subgrade consists of well-graded aggregates or well-graded sand.

The subgrade for the concrete pavements consists of virgin soil or fill material. Subgrades should be properly proof rolled or well-compacted. Subgrades should be compacted to 95% maximum density in accordance with ASTM D1557 for non-cohesive soils and 92% for cohesive soils.

Concrete pavements are designed by using well established nomographs or computer programs developed by Portland Cement Association (PCA). The parameters of the nomographs consist of subgrade reaction “K”, effective wheel contact area, wheel spacing and stress per 1,000 lbs. axle load. Concrete pavements are generally designed as unreinforced slab-on-grade elements. The flexural strength of concrete resists load imposed stresses. Flexural strength of concrete generally ranges from 500 psi to 750 psi. Subgrade reaction “K” is usually derived from a 30 inch diameter plate bearing test procedure, specified in AASHTO T-222.

In order to prevent cracking, the concrete slabs should contain control joints which are generally spaced 2½ times to 3 times the thickness of the concrete slab in feet. A more accurate spacing can be derived form an empirical formula, $S=6.1 \times (t)^{1/2}$ where t represents the thickness of the concrete slab (figure 6, 6A). Construction joints are created at termination of a concrete pour. Construction joints should contain dowels to transfer shear forces between slab sections. Control joints (7, 7A), usually do not contain dowels, however, if parking lots are subjected to heavy truck traffic dowels should be provided in control joints. Expansion joints are also an important part of concrete pavement design. They’re generally located at concrete pour termination or at locations to prevent cracking due to temperature forces.

c. Other Pavements

Pervious concrete pavements are quite often used where there is no room for large detention ponds. Pervious concrete is a mix of course aggregate cement, water and little to no sand. The mix creates an open structure allowing rainwater to filter through to underlying soils by modeling natural ground cover. Pervious concrete is an excellent choice for storm water management.

Other surfaces for parking lots are open grass pavers. Open grass pavers are used only for light loads where a grass surface is desired from a design point of view.

Composite pavements consisting of concrete base and asphalt concrete surface course is also used when very heavy traffic in parking lots is expected.

8. Drainage Systems

Proper drainage systems are vital to ensure that rainwater will be carried away from the site. A surface parking lot should be sloped a minimum 1.5 percent to 2 percent toward drain inlets, catch basins, or curb inlets. Designers should consult local ordinances and control standards to ensure compliance.

To prevent the ponding of water, a parking lot must be appropriately sloped and incorporate a properly designed drainage system. The pitch of paved surfaces to drains, the location and size of drains, the slope of drainage lines, and the careful selection of piping materials must work together to remove standing water from parking lots.

The recommended slope of a parking lot to drain is a minimum 1.0 percent, with a 1.5 to 2.0 percent recommended minimum in all directions. Advantageous points must be chosen for placement of catch basins, and their connection to existing drainage channels in the area or to an existing storm drainage line must be considered. One catch basin should cover a maximum of 20,000 sq feet with 10,000 sq feet recommended.

Surface drain lines are called storm sewers and are constructed with tight or closed joints. Surface drainage can be provided by adjusting ground slopes to allow for runoff of storm water and it’s inter ception at various intervals in catch basins.

a. Run-off Calculations

The design of a drainage system is based on the amount of rainfall to be carried away at a given time. Runoff is that portion of precipitation that finds its way into natural or artificial channels either as surface flow during the storm period or as subsurface flow after the storm has subsided. Runoff is determined by calculating the volume of water discharged from a given watershed area and is measured in cubic feet of discharge per second.

To calculate runoff, we use the rational formula:

$$Q = CIA$$

Where:

Q = storm water runoff from an area (ft^3/sec)

C = coefficient of runoff (percentage of rainfall that runs off depending on the characteristics of the drainage area)

I = average intensity of rainfall (in./hr) for a duration equal to the time of concentration for a selected location and rainfall frequency

A = area (acres)

The rational method makes two assumptions:

1. Time of concentration (TOC) is based on average rainfall rate during the time required for water runoff to flow into the nearest inlet from the most remote point (inlet time), plus the time of flow in the storm line from the furthest inlet to the outlet point.
2. The peak rate of rainfall occurs during the time of concentration.

The rational method can be used for drainage areas less than ½ square mile.

In urban areas the frequency of rainfall generally designed for is the 10-year storm. These maps are not used for TOC method calculations where durations shorter than 1 hr are needed. Rainfall maps are available for every region in the United States. In residential areas this may be reduced to a 2- or 5-year storm. Inlet times of 5 to 15 min are generally used. To determine the design storm to be used, various communities have established design criteria that must be followed. Rainfall intensity duration curves in inches per hour are available from the weather bureau or city engineering office. These curves have 2-, 5-, 10-, 25-, 50-, and 100-year storms.

b. Catch Basins and Drop Inlets

Catch basins intercept storm water and sediment is retained before water enters the outlet line. The catch basins must be cleaned periodically to prevent clogging.

Drop inlets do not have sediment traps below the outlet line and must be designed with self-cleaning velocities to function properly. Drop inlets are often used in low-maintenance areas where sediment would clog improperly maintained catch basins.

Both these structures use cast-iron grates to allow water to enter the structure. Grate openings must be large enough to permit water to enter, but in areas where pedestrian or bicycles use its predominant, grate openings should be a minimum size for safety.

Catch basins or drop inlets are generally placed 100 to 200 ft apart.

c. Manholes

Manholes are used as a means of inspecting and cleaning sewer lines. They are placed at these points:

1. Changes of direction of pipe lines
2. Changes in pipe sizes
3. Change in pipe slope
4. Intersection of two or more pipe lines
5. Intervals not greater than 300 to 500 ft

d. *Drywells*

In areas where there are no municipal storm sewer systems, drywells are used. Drywells are simply large manholes with openings in the walls to allow water to exfiltrate into the soil. Drywells usually consists of precast rings 4’-0’’ high and ranging in diameter from 8’-0’’ to 12’-0’’. The rings are stacked one on top of each other with a cone section at the very top of the drywell. The cone section has a frame and grate to collect the storm runoff. The drywalls are usually connected to each other at the top or at the bottom with a pipe. When the drywells are connected at the top, then they will fill up consecutively. If the drywells are connected at the bottom, they are filled simultaneously. The volume of the drywells, are designed to hold the run-off discharged from a parking lot minus the amount of water which percolates into the ground.

e. Run-off Storage

Many municipalities have a moratorium on how much run-off water can be discharged into the storm sewer system. In this case, run-off discharge must be stored in underground tanks. The tanks quite often consist of large diameter pipes or concrete storage chambers. The stored storm run-off is then slowly discharged into a municipal storm sewer system. The rate of discharge depends on the municipal moratorium requirements. The rate of discharge can be controlled by varying the diameter and the slopes of the outflow pipe.

9. Curbs and Sidewalks (Figure 3)

The parking lot perimeter should incorporate curbs and gutters of cast-in-place concrete or extruded concrete curbs or similar materials. Concrete is strong enough to withstand wheel impact and outlasts other types of curbs such as asphalt. Sidewalks should be provided for pedestrian circulation. To prevent the soil from washing out from under the sidewalk, edges should be more than four inches thick and turned down into the ground approximately six inches. An aggregate base course should be provided under all sidewalks. The sidewalk surface should be sloped for drainage and should have a light broom finish for safety. Control joints should be placed at a maximum of five feet.

10. Lighting

Large lots are usually illuminated with light standards located between parking stalls. The standards should be positioned along the centerline of a double row of vehicle stalls as well as along the stall line between vehicles.

Common fixture types include high-pressure sodium and metal halide. Fixture type, the number and height of fixtures per standard, and the desired illumination level all determine the spacing of standards. The type fixture covering should be consistent with neighboring uses; for example, cut-off fixtures should shield residential areas from direct lighting. When security is a concern, lighting levels should be increased to a level that reasonably satisfies economic, security, and community concerns.

Illuminating Engineering Society developed standards for the level of illumination in parking lots. Table 5 outlines Recommended Maintained luminance values for parking lots.

All writing should be placed in buried conduits before completion of the paving operation. Photoelectric lighting controls can be located in a central area on poles or a nearby building and connected to a timing device.

Table 5. Recommended Maintained Illuminance Values for Parking Lots

	Unit	Basic	Enhanced Security
Minimum horizontal illuminance on the pavement	Lux	2	5
	FC	0.2	0.5
Uniformity ratio, maximum to minimum		20:1	15:1
Minimum vertical illuminance at five feet above pavement	Lux	1	2.5
	FC	0.1	0.25

Source: The Dimensions of Parking, Urban Land Institute

11. Signage and Pavement Markings

The main purpose of signage and pavement markings in a parking lot is to guide patrons safely from the roadway system to a parking place near their destination and then back to the roadway system. Signage systems must be designed with the objective of providing a concise and informative series of verbal and nonverbal messages that are understandable by the patron of a parking lot.

A well designed signage system helps patrons efficiently to find a parking space, walk to their destination, retrieve their vehicle and then return to the roadway systems. Signs must be readable and legible. Legibility is the case with which information can be seen and perceived by the senses. Information is not legible because it is obstructed, poorly located, too small or too busy to be perceived.

Readability is the ease with which the information can be understood. For example, a universal stop sign is a very readable sign. A small sign which reads “Caution Speed Bump” is not a legible sign. Pavement markings are painted signs on the pavement which usually indicate directions by arrow or lane markings by a broken line. Pavement markings should be durable and legible. Thermoplastic paint is a long lasting paint and should be used for pavement markings. Thermoplastic paints are used on municipal streets because they last a very long time and have excellent adhering properties.

12. Landscaping

Properly designed plantings can help soften the visual impact of surface parking lots by screening circulating and parked vehicles. Many communities have enacted ordinances and requirements that govern landscaping for surface parking facilities.

Ideally, landscaping should be located in unusable parking or circulation areas, with the proper clearance from parked vehicles carefully maintained. To allow for vehicle overhangs, plantings should not be located within three feet off the curb unless low-lying groundcover is used. All planting areas should be mounded to promote drainage and salt runoff but should not be used for snow storage. Planter areas and tree wells should be installed in accordance with he planned lot dimensions and the needs of specific plant materials, thus avoiding any adverse impacts on parking functions due to improper locations and/or design of landscaping features. A five-foot or greater turning radius is recommended for islands to accommodate sufficient vehicle maneuvering during circulation and to avoid breakdown of curbed areas and damage to plant materials.

If the parking layout is designed to accommodate future expansion, the landscaping plan should consider such expansion in order to maximize the efficiency of the initial landscaping.

The distance between interior parking lot islands and parked automobiles should never be less than the distance between two adjacent parked vehicles. Landscaping materials located within large parking areas should be sufficiently scaled so that the heat reflected from the pavement does not damage the vegetation. Underground sprinkler systems should be considered to ensure the long-term viability of plantings.

Other landscape design considerations are vehicle sight lines, particularly at points of ingress and egress and pedestrian routes that prevent cut-through traffic in planted areas. Bushy growth and leaves between three and eight feet above grade will severely reduce the sight line of drivers at critical ingress and egress locations. Low ground cover and tall trees without low branches are preferred. Final landscaping plans should be reviewed in conjunction with the Americans with Disabilities Act to ensure barrier-free design.

13. Maintenance

Surface parking lots require continual maintenance to increase its service life. A comprehensive maintenance program will produce a cleaner safer and more user friendly atmosphere which promotes repeat business and discourages littering and loitering. A well manufactured parking lot also reflects a positive image the facility it serves. The owner of a parking lot must establish a comprehensive maintenance program which is an important phase in the operation of the entire facility the parking lot is serving.

a. Specific Maintenance Programs should include the following

1. Establishment of a maintenance budget

2. Assignment of personnel to implement the program.

3. A schedule of cleaning inspection, painting, sealing and other maintenance activities.

4. Recording procedure to log maintenance activity,

5. A management control system to oversee and administer the program

Table 6 *outlines a recommended maintenance program and a checklist of activities:*

Table 6	Daily	Weekly	Monthly	Quarterly	Semi-Annually	Annually
1. CLEANING						
▪ Sweeping – localized	x					
▪ Sweeping – all areas (including curbs)		x				
▪ Pavement Expansion joints		x				
▪ Wash down				x		
2. ELECTRICAL SYSTEM						
▪ Check light fixtures and exposed conduit			x			
▪ Relamp fixtures		x				
▪ Distribution Panels					x	
3. LANDSCAPING						
▪ Remove Trash	x					
▪ Gardening – mow, trim, weed		x				

	Daily	Weekly	Monthly	Quarterly	Semi-Annually	Annually
4. PAINTING						
▪ Check for rust spots --Metal				x		
▪ Check for appearance --Striping --Signs --Walls --Curbs --Touch-up paint			 x x x x	 x		
5. PLUMBING/DRAINAGE SYSTEMS						
▪ Check for proper operation --Irrigation --Floor drains --Sump pump --Hydrants		 x x x	 x			
▪ Drain water systems for winter						x
▪ Check for icy spots	x					
▪ Remove snow and ice	x					
6. SAFETY CHECKS						
▪ Tripping hazards	x					
7. SIGNS (GRAPHICS)						

▪ Check signs for:						
--In place		x				
--Clean				x		
--Legible				x		
▪ --Illuminated	x					
8. STRUCTURAL SYSTEMS						
▪ Check for:						
--Pavement deterioration				x		
--Sealing of asphalt pavement						x
--Cracking of concrete and asphalt				x		
▪ --Rusting of steel				x		
▪ Repair	*As per engineer's recommendations*					
▪ Sealing of concrete pavement						x

Source: NPA Parking Garage Maintenance Manual

APPENDIX

- θ PARKING ANGLE
- W_1 PARKING MODULE WIDTH (WALL TO WALL), SINGLE LOADED AISLE
- W_2 PARKING MODULE WIDTH (WALL TO WALL), DOUBLE LOADED AISLE
- W_3 PARKING MODULE WIDTH (WALL TO INTERLOCK), DOUBLE LOADED
- W_4 PARKING MODULE WIDTH (INTERLOCK TO INTERLOCK), DOUBLE LOADED AISLE
- AW AISLE WIDTH
- WP STALL WIDTH PARALLEL TO AISLE
- VP_1 PROJECTED VEHICLE LENGTH FROM INTERLOCK
- VP_W PROJECTED VEHICLE LENGTH FROM WALL MEASURED PERPENDICULAR TO AISLE
- S_L STALL LENGTH
- S_W STALL WIDTH

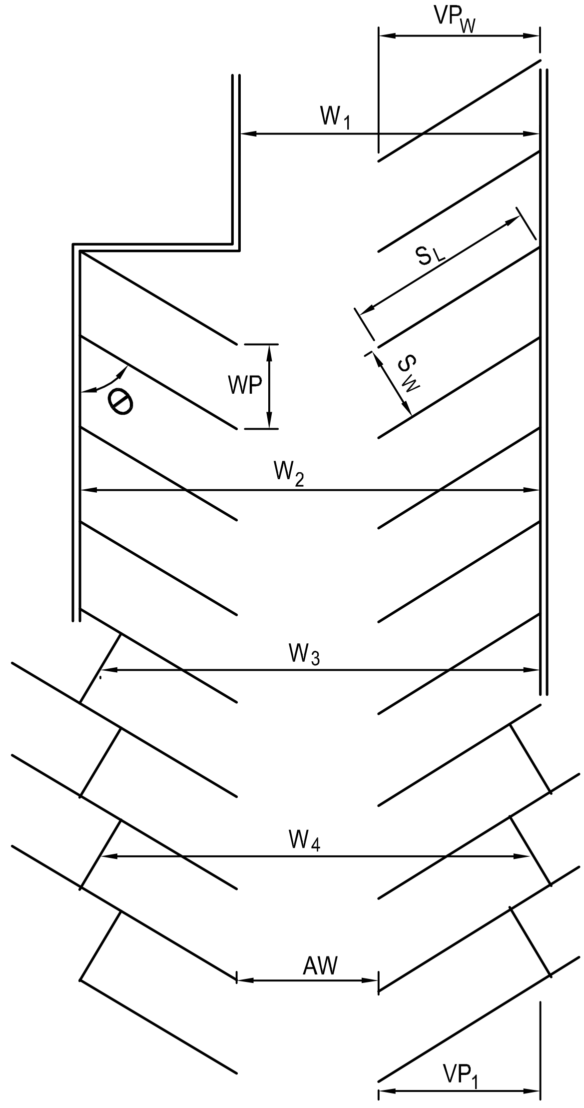
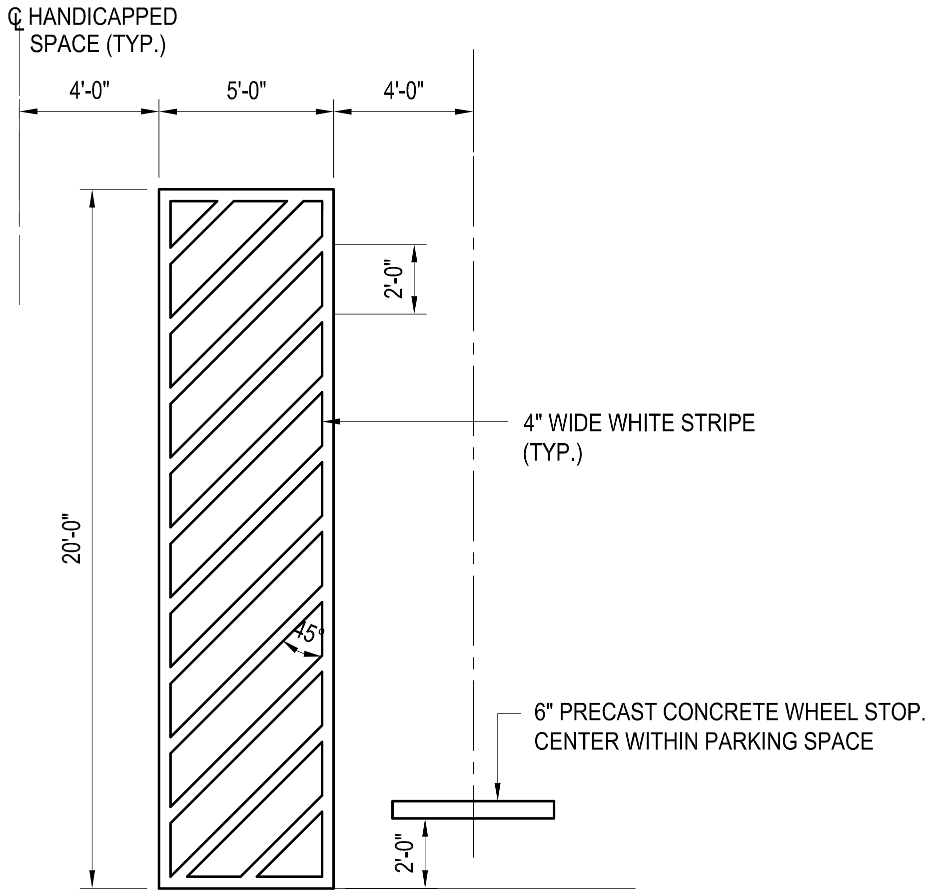


FIG. 1 SURFACE PARKING DESIGN

SOURCE: "GUIDELINE FOR PARKING FACILITY LOCATION AND DESIGN" BY INSTITUTE OF TRASPORTATION ENGINEERS



STRIPPING DETAIL BETWEEN HANDICAPPED SPACES

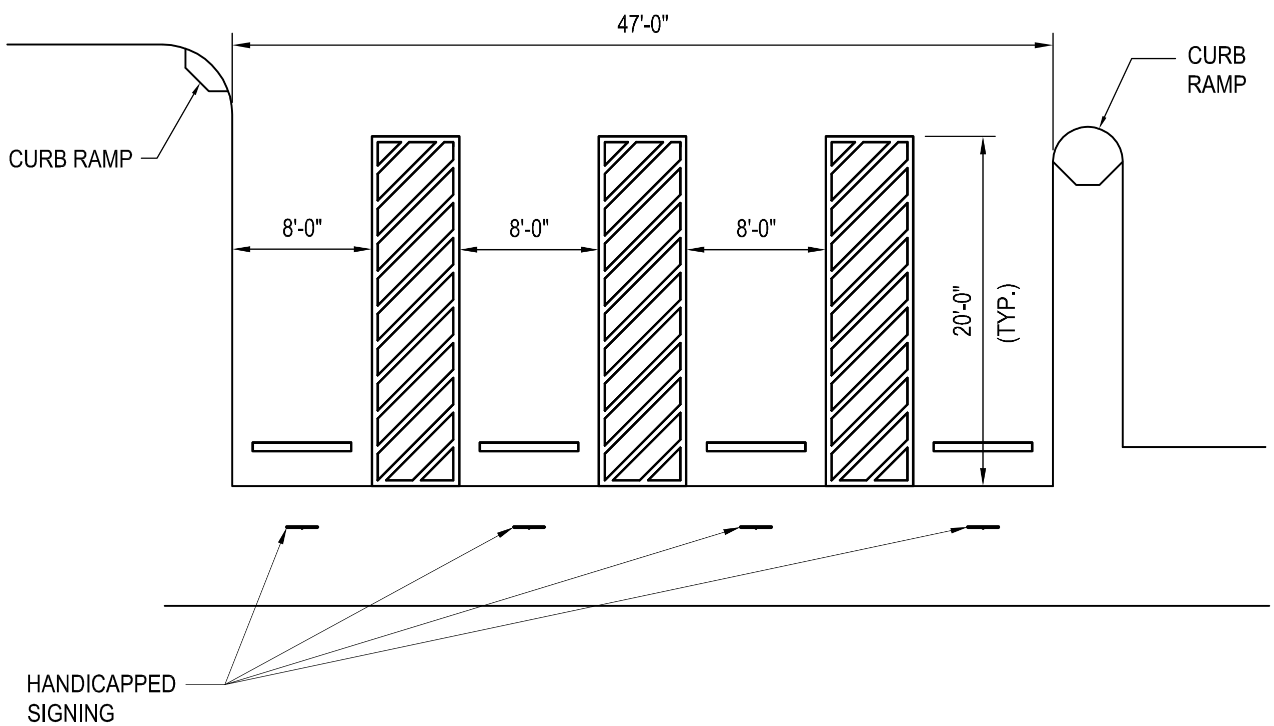
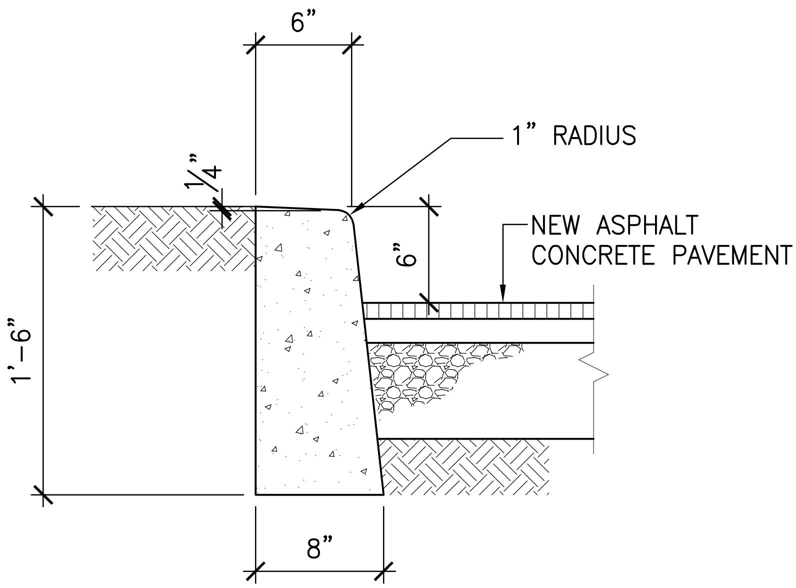


FIG. 2 STALL LAYOUT, HANDICAPPED PARKING

"GUIDE FOR THE DESIGN OF PARK-AND-RIDE FACILITIES"
BY AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS



NOTES:

1. CONCRETE TO TEST 3,500 PSI MINIMUM ON 28 DAY TEST. AIR ENTERTAINMENT 4% TO 7% SLUMP TO BE 3" MAXIMUM.
2. TRANSVERSE JOINTS 1/2" WIDE SHALL BE INSTALLED IN THE CURB 20'-0" APART AND SHALL BE FILLED WITH PERFORMED BITUMINOUS JOINT FILLER.
3. EXPOSED CONCRETE SURFACED IS TO BE RUBBED TO PROVIDE SMOOTH FINISHED SURFACE.

FIG. 3 6" CURB DETAIL

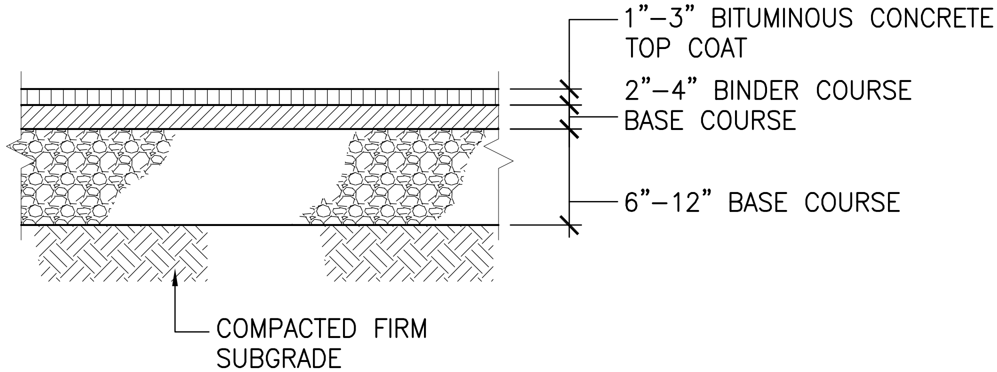


FIG. 4 ASPHALT CONCRETE PAVEMENT DETAIL

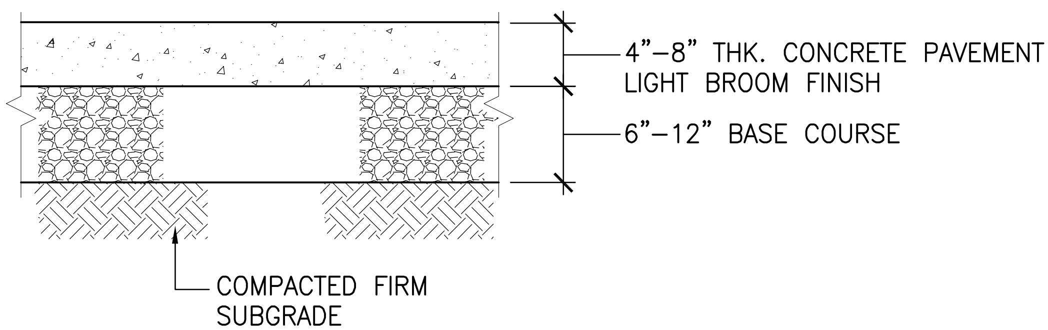
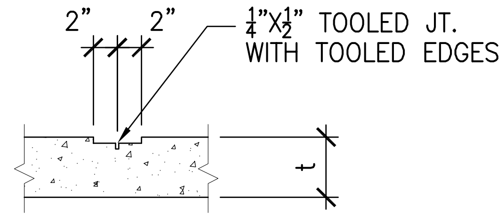


FIG. 5 CONCRETE PAVEMENT DETAIL



SECTION 6A

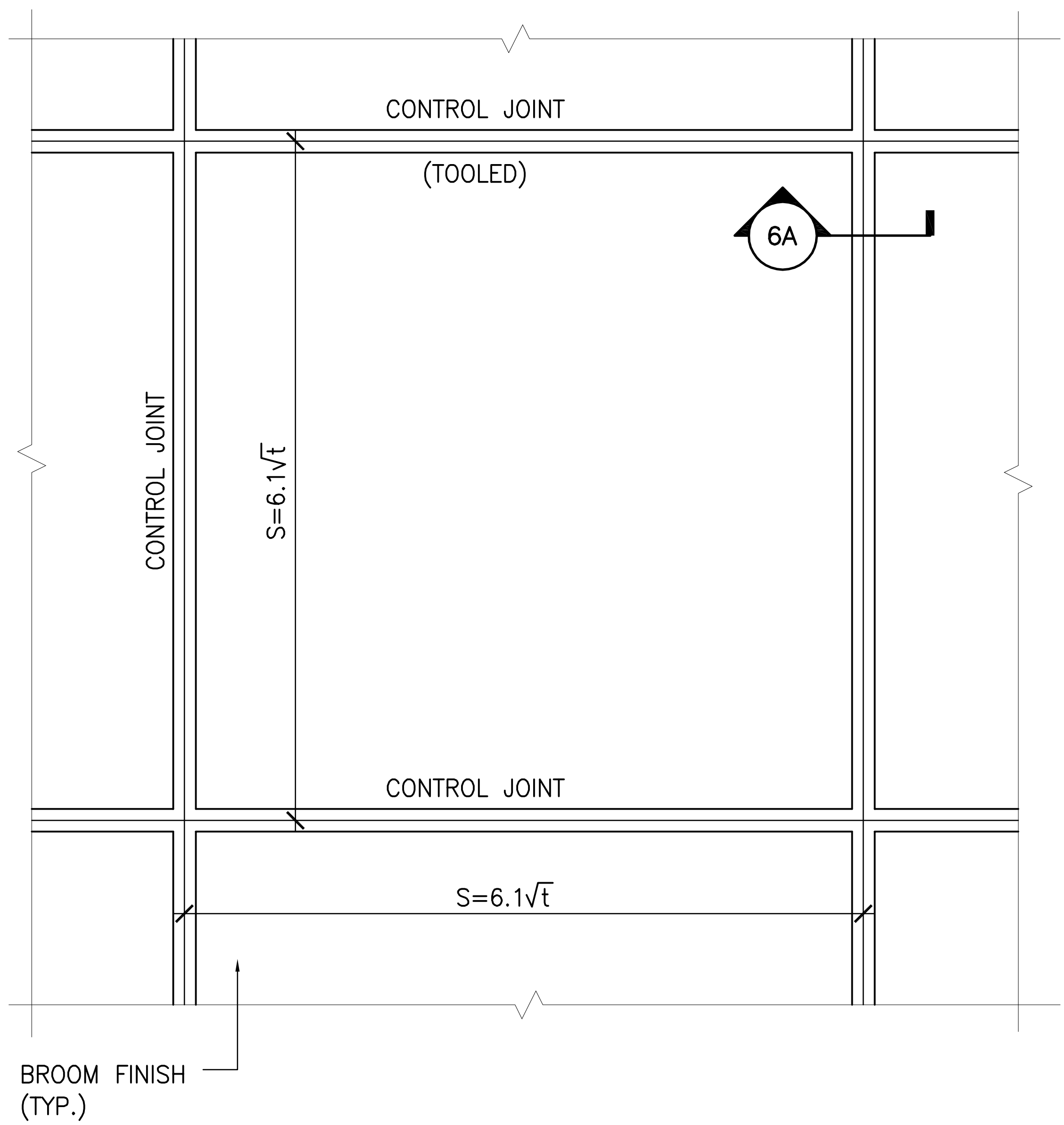
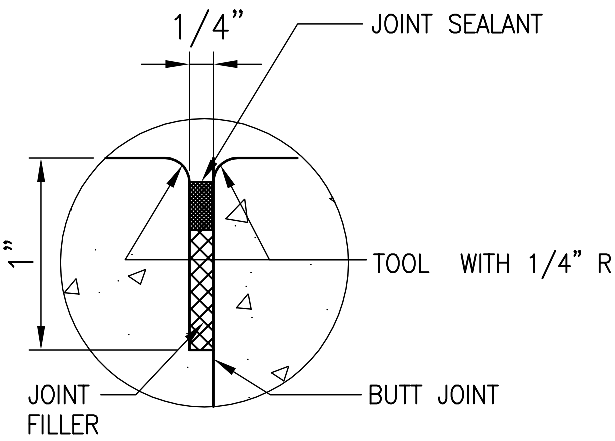


FIG. 6 CONCRETE PAVEMENT JOINTING (TYP.)



7A DETAIL
-
N.T.S.

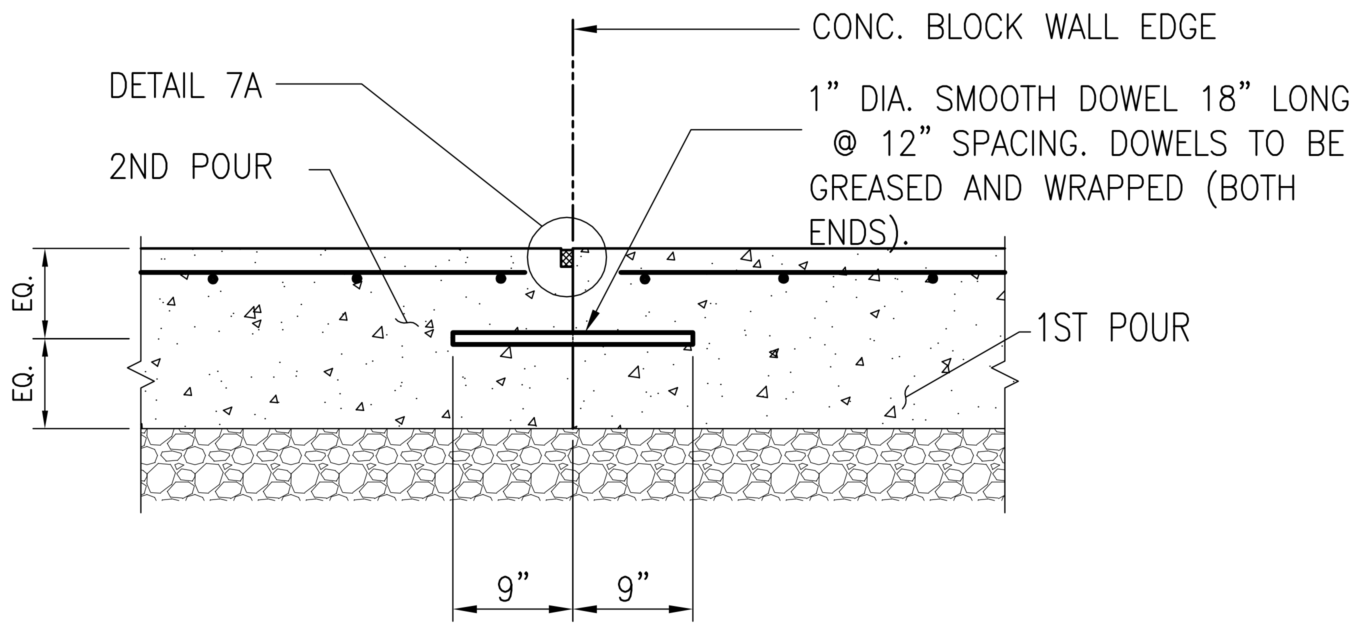


FIG. 7 TYP. CONSTRUCTION JOINT