

Guide for the Design and Construction of Concrete Parking Lots

Reported by ACI Committee 330



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Guide for the Design and Construction of Concrete Parking Lots

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Guide for the Design and Construction of Concrete Parking Lots

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Concrete parking lots serve many kinds of public facilities, commercial developments, businesses, and multifamily housing projects. They primarily accommodate parked vehicles, but may also provide maneuvering areas and access for delivery vehicles. The design and construction of concrete slabs for parking lots and outside storage areas share many similarities with the design and construction of streets and highways, but they also have some very distinct differences. A full appreciation of the differences and the modification of design and construction procedures to take these differences into account can result in economical concrete parking lots that will provide satisfactory service for many years with little maintenance.

This guide includes information on site investigation, thickness determination, design of joints and other details, durability considerations, paving operations, and quality-assurance procedures during construction. Maintenance and repair are also discussed.

Keywords: concrete pavement; curing; dowels; finishing; joints; load transfer; parking lot; subgrade; thickness; traffic loads.

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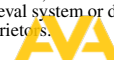
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CHAPTER 1—INTRODUCTION AND SCOPE

1.1—Introduction

Concrete parking lots have many similarities to other types of concrete pavement. On the other hand, parking lots differ from other pavements in that most of the area is intended for storage of vehicles and other goods rather than for movement of vehicles. The design of concrete parking lots should follow

generally accepted procedures for concrete pavements as outlined in this guide. Load-bearing capacity, drainage, crack control, life-cycle cost, constructibility, and maintainability are other characteristics that are important in the design and construction of concrete pavements, including parking lots.

Typically, concrete parking lots do not serve the same broad spectrum of traffic loading, from light vehicles to heavy trucks, as highways and arterial streets. Facilities designed to accommodate both light vehicles and heavier delivery trucks may employ traffic controls to separate and channel the heavier trucks away from areas designed for automobiles and light trucks. Facilities designed for heavier vehicles are likely those facilities where relatively accurate predictions of vehicle sizes and numbers are possible. Facilities intended to serve only light vehicles may have concrete parking lot slabs with thicknesses influenced by the practical limitations of the material and environmental effects rather than by the pavement stress created by vehicle loads. Durability-related distress is often the most critical maintenance concern for lightly loaded concrete parking lot pavements, which are subject to the effects of fuels and lubricants leaked from vehicles as well as environmental influences. Vehicles in parking areas usually travel at low speeds, diminishing the importance of smoothness tolerances. Because parking lots must also accommodate pedestrians, designs and geometrics should reflect pedestrian safety considerations including crosswalks, a slip-resistant surface texture, and nighttime illumination.

Concrete parking lots range in size from small, such as at corner convenience stores, to medium, such as at multi-unit housing projects, to large, such as those for shopping centers and office or commercial developments. Most parking areas include driveways, some of which need to accommodate relatively heavy loads. Special consideration may be needed if access to dumpsters is to be included. Accordingly, concrete parking lots are constructed with a wide variety of construction equipment, ranging from hand tools and vibratory screeds to large highway paving equipment or laser screeds.

Because of the relatively high stiffness of concrete pavements, loads are spread over larger areas of the subgrade compared with asphaltic pavements. As a result, thinner concrete pavements can be used for the same subgrade material. Additional benefits of using concrete to construct parking lots include the following:

- Concrete surfaces resist deformation from maneuvering vehicles;
- Concrete surfaces drain well with only minimal slopes;
- Concrete has relatively simple maintenance requirements;
- Traffic lane and parking stall markings can be incorporated into the jointing pattern;
- Concrete is minimally affected by leaking petroleum products;
- The light-reflective surface of concrete can be efficiently illuminated with minimal energy requirements; and
- Concrete parking lots reduce the impacts of the urban heat island effect relative to those of asphalt parking lots by producing lower surface temperatures, thus providing a cooler urban environment and reducing ozone production.

The sustainable construction benefits of concrete are considerable as compared with other pavement materials. Concrete parking lots typically have service lives of 30 years or more, requiring no additional use of aggregates and other nonrenewable materials resources through the period. In addition to opportunities for the use of sustainable concrete component materials such as recycled aggregates and supplementary cementitious materials derived from industrial by-products, concrete's light-colored surface helps reduce reflected solar radiation, and its higher reflectivity can reduce illumination requirements considerably. Lower resulting energy requirements are realized throughout the facility's life cycle. Pervious concrete may be useful in reducing storm water runoff from the site (ACI 522R). At the end of the service life, concrete can be recycled into aggregates and pavement subbase materials. These and other attributes of concrete can be useful in obtaining LEED Green Building certification for a project (Portland Cement Association 2005).

1.2—Scope

This guide is based on the current knowledge and practices for the design, construction, and maintenance of concrete parking lots. It emphasizes the aspects of concrete pavement technology that are different from procedures used to design and construct other types of slabs-on-ground, such as streets, highways, and floors. This guide is not a standard or a specification, and it is not intended to be included by reference in construction contract documents. ACI 330.1 can be used for these purposes.

Parking lots have most loads imposed on interior slabs surrounded by other pavement, providing some edge support on all sides. Highway and street pavements carry heavy loads along and across free edges, and are subjected to greater deflections and stresses. Streets and pavements are usually designed to drain toward an edge where the water can be carried away from the pavement. Parking lots are usually designed so some of the water is collected internally and is conveyed away through underground systems. In urban areas where rainfall runoff from large impervious surfaces is regulated, parking lots often serve as detention basins (not addressed in this guide). This means that the pavement should store water for a period of time without incurring any damage due to loss of support from a saturated subgrade. Parking lots often accommodate appurtenances, such as lighting standards, drainage structures, traffic islands, and landscaped planting areas. Provisions for these appurtenances should be considered in the design of the jointing system and the layout for construction.

1.3—Background

Design methods for concrete parking lot pavements are somewhat empirical, and are based on the methods developed for the design of highway pavements such as the Portland Cement Association (1984a,b) method and the AASHTO (1993) design method. These methods are primarily concerned with limiting both the stresses in the slab and the reductions in serviceability caused by mixed traffic, including heavy trucks, whereas parking lots usually serve

fewer vehicles either parked or traveling at slow speeds. For many parking lots that will serve only light traffic loads, the need for an extensive design process may be less critical. For such projects, a designer can rely on personal experience to select conservative values for the design criteria of subgrade soil support and imposed vehicle loads. In these cases, a conservative selection of pavement thickness is prudent practice.

Determining and specifying practical thickness tolerances for pavements is critical. Reduction of the pavement thickness beyond recommendations can significantly increase pavement stresses, reduce pavement structural capacity, and potentially reduce pavement life. Although construction smoothness tolerances are not critical for parking areas for low-speed traffic, smoothness is important where concrete surfaces are expected to drain well and carry water long distances across pavements with minimal slope.

Aesthetic considerations of surface texture and crack control in parking lots can be important because of close scrutiny from pedestrians and the owner's desire to project a quality image. In large parking lots, it is important to direct traffic into designated driving lanes and deter heavy vehicles from crossing thin pavements. The future expansion of a parking lot and the facility it serves should also be considered during initial design so that light-vehicle pavements are not required to accommodate future heavy loads. Industries and shopping centers served by public transportation and schools served by buses are examples where expansion can transform auto parking areas into more robust truck or bus driveways.

CHAPTER 2—NOTATION AND DEFINITIONS

2.1—Notation

Notation used in the Appendixes are not listed herein, but are shown immediately after the corresponding figure or equation(s); some of these notations may have other meanings in the Appendix.

A	=	area of distributed steel reinforcement required per unit width of slab, in. ² /ft (mm ² /m) (Section 3.8.1)
ADTT	=	average daily truck traffic (Section 3.5)
CBR	=	California bearing ratio (Section 2.2, 3.4, 3.6, 8.1, B.2)
C_f	=	coefficient of subgrade resistance to slab movement (Section 3.8.1)
f_s	=	allowable tensile stress in distributed steel reinforcement, psi (MPa) (Section 3.8.1)
h	=	slab thickness, in. (mm) (Section 3.8.1)
k	=	modulus of subgrade reaction, psi/in. (MPa/mm) (Section 2.2, 3.4, 3.6, A.1, B.2, B.3)
L	=	distance between joints, ft (m) (Section 3.8.1)
MOR	=	modulus of rupture, psi (MPa) (Section 2.2, 3.5, 3.6, A.1)
PI	=	plasticity index (Section 2.2, B.2)
R	=	resistance value (Section 2.2, 3.4, 3.6)
SSV	=	soil support value (Section 2.2, 3.4)
w	=	density of concrete, lb/ft ³ (kg/m ³) (Section 3.8.1)

2.2—Definitions

California bearing ratio (CBR)—the load required to force a standard piston into a prepared sample of soil divided

by the load required to force the standard piston into a well-graded crushed stone in accordance with ASTM D1883 and D1429, usually expressed as 100 times the result. Note: Used in the design of pavements.

curling—out-of-plane deformation of the corners, edges, and surface of a pavement, slab, or wall panel from its original shape caused by a normally-occurring combination of differences in moisture content and temperature between the two surfaces of the panel; taken independently, temperature differentials result in curling and moisture differentials result in warping. (See also **warping**.)

distributed steel reinforcement—welded wire fabric or bar mats placed in concrete pavements or slabs-on-ground to restrict the width of cracks that form between joints.

dowels—hardware—usually smooth, parallel steel bars—placed across a joint to transfer vertical load while allowing the joint to open and close.

faulting—the differential vertical displacement of slabs adjacent to a joint or crack.

frost-susceptible soil—subgrade or subbase material in which segregated ice will form, causing frost heave, under the required conditions of moisture supply and temperature.

modulus of rupture (MOR)—the calculated apparent tensile stress in the extreme tension fiber of a plain concrete beam test specimen at the load that produces rupture when tested in accordance with ASTM C78.

modulus of subgrade reaction k —ratio of the load per unit area of soil to the corresponding settlement of the soil, typically evaluated in place per ASTM D1196.

panel—an individual concrete pavement slab bordered by joints or slab edges.

plain pavement—unreinforced concrete pavement.

plasticity index (PI)—the range of water content in which a soil remains plastic, evaluated as the numerical difference between liquid limit and plastic limit, as calculated according to ASTM D4318. (Also referred to as **plasticity**.)

raveling—the tendency for aggregate to dislodge and break away from the concrete along the joint that is being sawed.

resistance value R —the stability of a soil determined in accordance with ASTM D2844 using the Hveem Stabilometer, which measures the horizontal pressure resulting from a vertical load. (The stability represents the shearing resistance to plastic deformation of a saturated soil at a given density.)

soil support value (SSV)—an index characterizing the relative ability of a soil or aggregate mixture to support traffic loads imposed through a flexible pavement structure.

subbase—a layer in the pavement system between the subgrade and the concrete pavement.

subgrade—the soil prepared and compacted to support a structure or a pavement system.

sympathy crack—an uncontrolled crack influenced by mismatched joints, resulting from tensile stresses that develop in the uncracked section due to normal movement across the unmatched joint and friction between the two sections along the joint that separates them.

warping—out-of-plane deformation of the corners, edges, and surface of a pavement, slab, or wall panel from its original

shape, caused by a normally-occurring combination of differences in moisture content and temperature between the two surfaces of the panel; taken independently, temperature differentials result in curling and moisture differentials result in warping. (See also **curling**.)

CHAPTER 3—PAVEMENT DESIGN

3.1—Introduction

The design of a concrete parking lot pavement entails selecting dimensions and other details to provide a slab that will adequately carry the anticipated traffic on the subgrade, provide the correct types of joints in the proper locations, channel and segregate traffic where needed, incorporate required drainage features and lighting, and allow for efficient and economical construction. The most important aspect of the structural design for pavement is selecting the appropriate thickness. Excessive thickness can result in unjustifiable construction cost. Inadequate thickness will result in unsatisfactory performance and expense, premature maintenance, or replacement. Selection of the appropriate thickness requires careful evaluation of soil conditions and traffic, as well as the selection of appropriate concrete properties and design life.

Selecting the proper pavement thickness will result in a slab that supports the heaviest anticipated loads by distributing the loads over the subgrade soil without inducing excessive stress in the slab. Joints or cracks between joints produce discontinuities in the slab. Loads crossing these discontinuities cause increased deflections and stresses in the slab and in the subgrade below. Repeated deflections of a slab edge or joint and the resulting displacement of the subgrade can eventually cause fatigue cracking in the slab and faulting at the joint. Proper thickness provides adequate stiffness to minimize fatigue and joint faulting during the design life of the pavement. Faulted joints or occasional cracks are probably not as objectionable in a parking lot as on a street or highway because parking lot traffic moves slowly.

Another inherent characteristic of concrete slabs that affects stresses is the differential volume changes of upper and lower surfaces due to differences in moisture content and temperature. Differential shrinkage or expansion can cause slab corners and edges to deflect up or down relative to the slab center. The tendency for this warping or curling is decreased by reducing the size of individual slabs or by increasing slab thickness. As a practical matter, there is no benefit in building slabs less than 4 in. (100 mm) thick. Thinner slabs do not significantly reduce construction costs, and because of their tendency to warp and curl, are extremely vulnerable to inadvertent overloads and variations in subgrade support. The detrimental effects of concrete thickness variations that result from typical surface irregularities of the prepared subgrade are also magnified.

Methods used to select an appropriate concrete pavement thickness relate concrete stresses and fatigue characteristics to the nature of the underlying subgrade, the strength of the concrete, and the magnitude and location of pavement loadings. They have been developed and refined using experimental and performance data as well as theoretical models. Such methods

have generally been intended for the design of street and highway pavements, but are also useful for parking lot design.

Appendix A contains additional information on the methods of concrete pavement analysis and design.

3.2—Pavement stresses

Thickness design of pavement is intended to limit slab tensile stresses produced by vehicular loading. Model studies, as well as full-scale accelerated traffic tests, have shown that maximum tensile stresses in concrete pavement occur when vehicle wheels are close to a free or unsupported edge of the pavement. Stresses resulting from wheel loadings applied near interior joints are generally less severe due to load transfer across the joints. The critical stress condition occurs when a wheel load is applied near the intersection of a joint and the pavement edge. Because parking areas have relatively little area adjacent to free edges and vehicle loads are applied mostly to interior slabs, pavements should be designed assuming supported edges. At the outside edges or at entrances, integral curbs or thickened edge sections can be used to decrease stresses. Thermal expansion and contraction of the pavement and warping or curling caused by moisture and temperature differentials within the pavement cause other stresses that are not addressed directly in thickness design. Proper jointing reduces these stresses.

3.3—Traffic loads

A pavement will be subjected to varying, but predictable, vehicular loads throughout its lifetime. To determine the pavement thickness, the designer needs to know the types of vehicles that will use the pavement (such as passenger cars, light trucks, heavy trucks, and school or commuter buses), the number of trips for each vehicle type, vehicular loads, and the daily volume or total volume anticipated for the facility over the design life. The owner's projections of the type of traffic expected to use a facility, supplemented by traffic studies or counts for similar facilities, should provide adequate design traffic estimates.

3.4—Subgrade support

The subgrade is the underlying surface of soil or existing pavement on which the parking lot pavement is constructed. The ability of the subgrade soil to uniformly support the loads applied to it through the pavement is extremely important and affects both the required pavement thickness and the performance of the pavement. Uniform subgrade support is the goal of site preparation. For example, a designer can require grading operations to blend soil types to improve uniformity. Information on the engineering properties of the soil on a particular project can be obtained from foundation investigations for buildings constructed at the site, the U.S. Department of Agriculture Soil Survey, or geotechnical investigations conducted for adjacent roads or buildings. It is recommended, however, that actual soil conditions and subgrade properties be determined by appropriate soils testing on the area to be paved.

The extent of the geotechnical investigation will be determined by the magnitude of the project. A geotechnical

investigation should include the identification and the properties of in-place soils and their suitability for use as a subgrade. The soil should generally be classified according to one of the standardized systems such as the Unified or AASHTO systems (refer to Appendix B.2). Soil properties, such as liquid and plastic limits, moisture-density relationships, expansion characteristics, susceptibility to pumping, and susceptibility to frost action should be determined by standard ASTM or AASHTO tests. The relative bearing capacity expressed in terms of modulus of subgrade reaction k , CBR, resistance value R , or SSV should be determined. For projects designed for light traffic loads only or where extensive soil testing is impractical or economically unjustified considering the project scope, the selected value can be estimated. Conservatism is advised in making such estimates. Table 3.1 shows ranges of values for several types of soil (Portland Cement Association 1984a,b; American Concrete Pavement Association 1982). The value used will be for the subgrade compacted to the specified density. Fine-grained soils, such as clays or silts, are usually compacted to 95% of maximum dry density using standard effort as determined by ASTM D698. A higher density may sometimes be specified for heavier traffic pavements or for materials that are more easily compacted and, alternatively, a maximum dry density using modified effort as determined by ASTM D1557 may be specified, resulting in a higher soil unit weight.

It probably is not economical to use imported subbase material or to chemically treat the subgrade for the sole purpose of increasing k values, though such measures are sometimes used to improve the contractor's working platform or to reduce subgrade susceptibility to pumping and erosion. If a subbase or treated subgrade is used, the increased support it provides should be considered in the thickness design. Table 3.2 is indicative of the effects of subbases on k values (Portland Cement Association 1984a,b; Federal Aviation Administration 1978). Note that increases in subbase thickness do not result in proportional k value improvement. For example, for a subgrade having a k value of 100 psi/in. (27 MPa/m), tripling the thickness of a 4 in. (100 mm) granular subbase to 12 in. (300 mm) results in an increase of k value from 130 psi/in. (35 MPa/m) to only 190 psi/in. (51 MPa/m).

Additional detailed information on subgrade investigation, subbases, and special subgrade problems can be found in Appendix B.

3.5—Concrete properties

Concrete mixtures for paving should be designed to produce the required flexural strength, provide adequate durability, and have appropriate workability considering the placement and finishing equipment to be used. Loads applied to concrete pavement produce both compressive and flexural stresses in the slab; however, flexural stresses are more critical because heavy loads will induce flexural stresses that may be a significant percentage of the concrete flexural strength, whereas compressive stresses remain small in relation to the compressive strength of the concrete. Consequently, flexural strength or modulus of rupture

Table 3.1—Subgrade soil types and approximate support values (Portland Cement Association 1984a,b; American Concrete Pavement Association 1982)

Type of soil	Support	k , psi/in.	CBR	R	SSV
Fine-grained soils in which silt and clay-size particles predominate	Low	75 to 120	2.5 to 3.5	10 to 22	2.3 to 3.1
Sands and sand-gravel mixtures with moderate amounts of silt and clay	Medium	130 to 170	4.5 to 7.5	29 to 41	3.5 to 4.9
Sand and sand-gravel mixtures relatively free of plastic fines	High	180 to 220	8.5 to 12	45 to 52	5.3 to 6.1

Notes: CBR = California bearing ratio; R = resistance value; and SSV = soil support value. 1 psi = 0.0069 MPa, and 1 psi/in. = 0.27 MPa/m.

Table 3.2—Modulus of subgrade reaction k^*

Subgrade k value, psi/in.	Sub-base thickness			
	4 in.	6 in.	9 in.	12 in.
Granular aggregate subbase				
50	65	75	85	110
100	130	140	160	190
200	220	230	270	320
300	320	330	370	430
Cement-treated subbase				
50	170	230	310	390
100	280	400	520	640
200	470	640	830	—
Other treated subbase				
50	85	115	170	215
100	175	210	270	325
200	280	315	360	400
300	350	385	420	490

*For subbase applied over different subgrades, psi/in. (Portland Cement Association 1984a,b; Federal Aviation Administration 1978).

Note: 1 in. = 25.4 mm, and 1 psi/in. = 0.27 MPa/m.

(MOR) of the concrete is used in pavement design to determine the required thickness.

Flexural strength is determined by the MOR test in accordance with ASTM C78. The 28-day strength is normally selected as the design strength for pavements, but this is conservative because concrete usually continues to gain strength, and the pavement may not be placed in service until after 28 days. While design of pavements is generally based on flexural strength of concrete, compressive strength testing is typically used for quality control in the field, and is preferred because it is less costly, with less testing-induced variability. The correlation between compressive strength and flexural strength for a given concrete mixture is consistent and should be understood. On projects designed for heavy traffic that are large enough to economically benefit from refinement of the MOR value used in thickness design, a correlation between flexural strength and compressive strength should be developed from laboratory tests on the specific concrete mixture to be used. On other projects, especially those that will accommodate little truck traffic or where the mixture of traffic loads may not be well known, it may be more practical to assume an approximate, but conservative, relationship between compressive strength f'_c and flexural strength MOR (refer to Eq. (3-1) and (3-2)).

It is a generally accepted principle in concrete mixture proportioning that the coarse aggregate type has a greater influence on the flexural strength than on the compressive strength, and that rough-surfaced and angular-shaped coarse aggregates generally provide increased margins of flexural

strengths as compared with smooth-textured and round-shaped coarse aggregates. Goldbeck (1988) noted that the reason for higher margins of flexural strength associated with rough-surfaced and angular-shaped aggregates is the enhanced mechanical bond between the cementitious paste and the aggregates.

For concrete made with most smooth-textured, round-shaped aggregates, an approximate relationship between specified compressive strength f'_c and MOR can be expressed using Eq. (3-1)

$$\begin{aligned} \text{MOR (psi)} &= 8\sqrt{f'_c} \quad (\text{in.-lb units}) \\ \text{MOR (MPa)} &= 0.7\sqrt{f'_c} \quad (\text{SI units}) \end{aligned} \quad (3-1)$$

An approximate relationship between compressive strength f'_c and MOR for concrete made with some rough-textured, angular-shaped (typically crushed) aggregates can be expressed using Eq. (3-2)

$$\begin{aligned} \text{MOR (psi)} &= 10\sqrt{f'_c} \quad (\text{in.-lb units}) \\ \text{MOR (MPa)} &= 0.8\sqrt{f'_c} \quad (\text{SI units}) \end{aligned} \quad (3-2)$$

If no information is available to the designer about coarse aggregates to be used in project concrete, the lower MOR assumptions are recommended as more conservative. Higher MOR values (as produced by Eq. (3-2)) may be used if there is documentation or field experience showing that these higher MOR values can be anticipated with the aggregates to be used, and the resulting pavement section may be slightly thinner. Additional discussion of approximations of MOR appears in various pavement design resources (Goeb 1989).

3.6—Thickness design

3.6.1 Basis for design—Thickness designs for concrete pavements are based on laboratory studies, road tests, and surveys of pavement performance. Commonly used procedures include the AASHTO method, which was developed from data obtained at the AASHTO Road Test (Highway Research Board 1962), and methods based on calculated stresses and fatigue resistance such as the Portland Cement Association Design Procedure (Portland Cement Association 1984a,b). Other methods have been used, such as the Brokaw Method (Brokaw 1973), which is based on surveys of the performance of plain concrete pavements in use throughout the country. While most of these design methods were developed for analyzing and designing pavements for strength and rigidity, the research behind them has included thin pavements.

and they can be used for parking lot design. The different design procedures generally give similar thicknesses. Huang (2004), however, noted that the AASHTO method values are unconservative for lightly-trafficked pavements, and produce less reasonable results than Portland Cement Association methods. For thickness design of parking lot pavements, Tables 3.3 and 3.4 have been developed as the preferred approach. More complete explanations of these design procedures can be found in Appendix A.

Concrete pavements can be classified as plain or reinforced, depending on whether or not the concrete contains distributed steel reinforcement. Plain pavements can be divided into those with or without load-transfer devices at the joints. Those with load-transfer devices are usually referred to as plain-doweled pavements. The aforementioned design methods can be used for plain or reinforced pavements because the presence or lack of distributed steel reinforcement has no useful effect on the load-carrying capacity or thickness. Joint design, however, is affected by the presence of distrib-

uted reinforcement. The use of load-transfer devices may sometimes enable pavement thickness to be reduced, but the devices are costly and not normally used in light-duty pavements. The differences between reinforced and plain pavements, with and without load-transfer devices, are discussed in Sections 3.7 and 3.8.

Tables 3.3 and 3.4 have been prepared to facilitate the selection of an appropriate pavement thickness for the types of traffic and soil conditions most frequently encountered in parking lots. Table 3.3 lists four different traffic categories that range from passenger cars and light trucks to heavy trucks. Table 3.4 gives recommended pavement thicknesses for large and small numbers of trucks per day in four different traffic categories and six different categories of subgrade support, ranging from very high to low. The high values of subgrade support can apply to treated subbases or existing flexible pavement. The levels of subgrade support can be related to Table 3.1, which lists the estimated support values for the most commonly occurring subgrade soil types. The thicknesses shown are based on flexural strengths ranging from 500 to 650 psi (3.5 to 4.5 MPa) at 28 days, which correspond to compressive strengths between approximately 3500 and 5000 psi (24 and 34 MPa) based on approximations for relating compressive and flexural strength such as those in Eq. (3-1) and (3-2). Approximate cost comparisons indicate that the lower-strength concrete can sometimes be justified in areas where freezing-and-thawing resistance is not important. Changes in modulus of rupture, however, affect the required concrete thickness and the capacity. A designer should determine whether it is more cost effective to increase strength or thickness, taking into account the other

Table 3.3—Traffic categories*

1. Car parking areas and access lanes—Category A		
2. Shopping center entrance and service lanes—Category B		
3. Bus parking areas, city and school buses		
Parking area and interior lanes—Category B		
Entrance and exterior lanes—Category C		
4. Truck parking areas—Category B, C, or D		
Truck type	Parking areas and interior lanes	Entrance and exterior lanes
Single units (bobtailed trucks)	Category B	Category C
Multiple units (tractor trailer units with one or more trailers)	Category C	Category D

*Select A, B, C, or D for use with Table 3.4.

Table 3.4—Twenty-year design thickness recommendations, in. (no dowels)

MOR, psi:		$k = 500$ psi/in. (CBR = 50; $R = 86$)				$k = 400$ psi/in. (CBR = 38; $R = 80$)				$k = 300$ psi/in. (CBR = 26; $R = 67$)			
		650	600	550	500	650	600	550	500	650	600	550	500
Traffic category*	A (ADTT = 1)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.5
	A (ADTT = 10)	4.0	4.0	4.0	4.5	4.0	4.0	4.5	4.5	4.0	4.5	4.5	4.5
	B (ADTT = 25)	4.0	4.5	4.5	5.0	4.5	4.5	5.0	5.5	4.5	4.5	5.0	5.5
	B (ADTT = 300)	5.0	5.0	5.5	5.5	5.0	5.0	5.5	5.5	5.0	5.5	5.5	6.0
	C (ADTT = 100)	5.0	5.0	5.5	5.5	5.0	5.5	5.5	6.0	5.5	5.5	6.0	6.0
	C (ADTT = 300)	5.0	5.5	5.5	6.0	5.5	5.5	6.0	6.0	5.5	6.0	6.0	6.5
	C (ADTT = 700)	5.5	5.5	6.0	6.0	5.5	5.5	6.0	6.5	5.5	6.0	6.5	6.5
	D (ADTT = 700) [†]	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
MOR, psi:		$k = 200$ psi/in. (CBR = 10; $R = 48$)				$k = 100$ psi/in. (CBR = 3; $R = 18$)				$k = 50$ psi/in. (CBR = 2; $R = 5$)			
		650	600	550	500	650	600	550	500	650	600	550	500
Traffic category*	A (ADTT = 1)	4.0	4.0	4.0	4.5	4.0	4.5	4.5	5.0	4.5	5.0	5.0	5.5
	A (ADTT = 10)	4.5	4.5	5.0	5.0	4.5	5.0	5.0	5.5	5.0	5.5	5.5	6.0
	B (ADTT = 25)	5.0	5.0	5.5	6.0	5.5	5.5	6.0	6.0	6.0	6.0	6.5	7.0
	B (ADTT = 300)	5.5	5.5	6.0	6.5	6.0	6.0	6.5	7.0	6.5	7.0	7.0	7.5
	C (ADTT = 100)	5.5	6.0	6.0	6.5	6.0	6.5	6.5	7.0	6.5	7.0	7.5	7.5
	C (ADTT = 300)	6.0	6.0	6.5	6.5	6.5	6.5	7.0	7.5	7.0	7.5	7.5	8.0
	C (ADTT = 700)	6.0	6.5	6.5	7.0	6.5	7.0	7.0	7.5	7.0	7.5	8.0	8.5
	D (ADTT = 700) [†]	7.0	7.0	7.0	7.0	8.0	8.0	8.0	8.0	9.0	9.0	9.0	9.0

*ADTT = average daily truck traffic. Trucks are defined as vehicles with at least six wheels; excludes panel trucks, pickup trucks, and other four-wheel vehicles. Refer to Appendix A. k = modulus of subgrade reaction; CBR = California bearing ratio; R = resistance value; and MOR = modulus of rupture.

[†]Thickness of Category D (only) can be reduced by 1.0 in. (25 mm) if dowels are used at all transverse joints (that is, joints located perpendicular to direction of traffic).

Note: 1 in. = 25.4 mm; 1 psi = 0.0069 MPa; and 1 psi/in. = 0.27 MPa/m.

benefits of high strength such as improved durability. Table 3.4 can be used to assist the designer in this determination.

3.7—Jointing

Joints are placed in concrete pavement to minimize random cracking and facilitate construction. The three types of joints that are commonly used in concrete pavement are contraction joints, construction joints, and isolation joints. To effectively control cracking due to tensile stresses created by restrained shrinkage and warping or curling caused by moisture or temperature differentials, it is important to have the joints properly spaced (Table 3.5). This spacing depends on the thickness of the pavement, the strength of the concrete, the type of aggregates, climatic conditions, and whether distributed steel reinforcement is used. Distributed steel reinforcement helps minimize the width of intermediate temperature and drying shrinkage cracks that can occur between joints. Experience is often the best guide for determining the optimum joint spacing to control temperature and drying shrinkage effects. Closer joint spacings can result in smaller joint openings that provide increased load transfer between panels in the form of aggregate interlock. Spreading the joints farther apart can result in wider openings and diminished aggregate interlock. Joints in the pavement slabs should be carried through adjacent curbs or curb and gutter sections to prevent symphaty cracks.

3.7.1 Contraction joints—A contraction joint predetermines the location of cracks caused by restrained shrinkage of the concrete and by the effects of loads and warping or curling. Hardened concrete will shrink almost 1/16 in. (2 mm) for every 10 ft (3 m) of length while drying. If this shrinkage is restrained, tensile stresses develop that can reach the tensile strength of the concrete, and the concrete cracks.

Contraction joints create planes of weakness that subsequently produce cracks as the concrete shrinks. The planes of weakness can be created while the concrete is still plastic by using a grooving tool or by inserting a premolded filler strip. Concrete can also be cut with saws after it has hardened enough to support the saws and avoid raveling. The depth of the joint should be at least 1/4 of the slab thickness when using a conventional saw, or 1 in. (25 mm) when using early-entry saws on slabs 9 in. (230 mm) or less in thickness (refer to Section 5.7.1). The width of a cut depends on whether the joint is to be sealed. A narrow joint width, generally 1/10 to 1/8 in. (2.5 to 3 mm) wide, is common for unsealed joints. Cuts at least 1/4 in. (6.5 mm) wide are required for sealed joints, and a 3/8 in. (9.5 mm) wide cut is commonly recommended. Joint sealant manufacturers’ recommendations should be followed for the depth and width of joints that are to be sealed.

Contraction joints are normally called transverse joints or longitudinal joints in streets. In parking areas, longitudinal joints refer to those parallel to the direction of paving. Transverse joints divide the paving lanes into panels. Contraction joint patterns should divide pavements into approximately square panels. The length of a panel should not be more than 25% greater than its width. Joint patterns across lanes should be continuous. In unreinforced parking lot pavements, maximum spacing should be about 30 times

Table 3.5—Spacing between joints

Pavement thickness, in. (mm)	Maximum spacing, ft (m)
4, 4.5 (100, 113)	10 (3.0)
5, 5.5 (125, 140)	12.5 (3.8)
6 or greater (150 or greater)	15 (4.5)

the thickness of the slab up to a maximum of 15 ft (4.5 m) (Table 3.5). In many instances, jointing patterns can be used to delineate driving lanes and parking stalls.

3.7.2 Construction joints—Construction joints provide the interface between areas of concrete placed at different times during the course of the project. A common use is the longitudinal joints along placement lanes. Butt-type joints without special load-transfer features are usually recommended for parking lots serving light vehicles, but the need for load transfer should be considered for heavier traffic loads. Keyways of half-round or trapezoidal shape have, at times in the past, been used as a load-transfer design feature across construction joints, but this practice is no longer recommended for pavement designs within the scope of this document due to poor performance histories of this type of detail. Steel leave-in-place forms with keyed shapes should not be used. Refer to Section 3.8.2 for information on the use of dowels for load transfer.

Transverse construction joints are designed for interruptions in paving operations, such as those that occur at the end of a day or when placing is stopped for other reasons, such as weather or equipment breakdown. Whenever work is interrupted, a construction joint should be used.

When transverse construction joints are needed, they should be installed at contraction joint locations, if possible. If the slab thickness was established based on the assumption of load transfer by aggregate interlock at transverse joints, slab edges at any butt-type joints should be thickened approximately 20%. In emergency situations, such as lack of materials, sudden changes in weather, or equipment breakdown, it may not be possible to place the joint where planned. A construction joint can be made in the middle third of a panel if deformed tie bars are used across the joint to prevent joint movement.

Longitudinal construction joints between paving lanes deserve the same considerations concerning load transfer. Longitudinal construction joints along the periphery of a parking area can be tied with deformed bars if joint tightness is critical where heavy vehicles are expected. It is usually sufficient to tie only the first joint inward from the exterior edge. Tying additional joints will restrict movement and can cause undesirable cracks. Refer to Section 3.8.3.

Designers should recognize that when new concrete, with an inherent tendency to shrink, is tied to older concrete, which has already gone through the shrinkage process, stresses will develop that can cause cracking. Measures should be taken to prevent or minimize such cracking.

Where slabs of different thicknesses come together at construction joints, such as between automobile parking and truck lanes, the subgrades under the thinner pavements

should be shaped to provide gradual thickness transition over a distance of 4 ft (1.2 m) or more.

3.7.3 Isolation (expansion) joints—Concrete slabs should be separated from other structures or fixed objects within or abutting the paved area to offset the effects of expected differential horizontal and vertical movements. Isolation joints are used to isolate the pavement from these structures, such as light standard foundations, drop inlets, and buildings. They are full-thickness, vertical joints usually filled with a compressible material. While sometimes referred to as expansion joints, they are rarely needed to accommodate concrete expansion. When they must be located in areas that encounter wheel and other loads, the pavement edges at the joint should be thickened by 20% or 2 in. (50 mm), whichever is greater (refer to Fig. C.4 in Appendix C). Isolation joints are not recommended along the face of curb and gutter abutting a pavement, but pavement joints of any type that intersect this junction should extend through the curb and gutter.

Premolded joint fillers prevent the new slab from bonding to other structures during and after concreting operations. The joint filler should extend through the slab thickness to the subgrade and be recessed below the pavement surface or used with void caps so that the joint can be properly sealed with closed-cell backer rod and joint-sealant materials. The types of joint filler materials available include bituminous mastic, bituminous impregnated cellulose or cork, sponge rubber, recycled tire rubber, and resin-bound cork. Joint-filler materials should be installed in accordance with the manufacturer's recommendations.

Isolation joints are not recommended for routine use as regularly spaced joints. They are difficult to construct and maintain, provide no load transfer, and can be a source of pavement distress, distortion, and premature failure.

Isolation joints are not needed to accommodate expansion when contraction joints are properly spaced; their use should be limited to the role of isolating other structures or fixed objects. Designers are cautioned that wheel loads at isolation joints cause distresses similar to those at pavement free edges unless additional support is provided by features such as thickened pavement edges along the joint.

3.8—Steel reinforcement in parking lot pavements

3.8.1 Distributed steel reinforcement—When pavement is jointed to form short panel lengths that will minimize intermediate cracking, distributed steel reinforcement is not necessary. The practice of adding distributed steel to increase panel lengths has largely been discredited, and generally leads to excessive joint movements and interior panel cracks that deteriorate over time. In areas where deicing salts and similar materials are used, distributed steel also presents a risk of corrosion. Shorter unreinforced panels are generally more economical and provide better performance. The use of distributed steel reinforcement will not add to the load-carrying capacity of the pavement and should not be used in anticipation of poor construction practices.

When joint spacings are in excess of those that will effectively control shrinkage cracking or when uncorrectable subgrade conditions are liable to provide nonuniform

support, distributed steel reinforcement can be used to control the opening of intermediate cracks between the joints. The sole function of the distributed steel reinforcement is to hold together the fracture faces if cracks form. The quantity of steel varies depending on joint spacing, slab thickness, the friction between the concrete and the subgrade expressed as the coefficient of subgrade resistance, and the allowable tensile stress of the steel. The area of steel required per unit width of slab is computed by the following drag formula (Portland Cement Association 1955)

$$\begin{aligned} A \text{ (in.}^2\text{/ft)} &= (LC_fwh)/24(f_s) \text{ (in.-lb units)} \\ A \text{ (mm}^2\text{/m)} &= (LC_fwh)/204(f_s) \text{ (SI units)} \end{aligned} \quad (3-3)$$

where

- A = area of distributed steel reinforcement required per unit width of slab, in.²/ft (mm²/m);
- L = distance between joints, ft (m);
- C_f = coefficient of subgrade resistance to slab movement (a value of 1.5 is most commonly used in design);
- w = density of concrete (145 lb/ft³) (2320 kg/m³);
- h = slab thickness, in. (mm); and
- f_s = allowable tensile stress in distributed steel reinforcement, psi (MPa) (a value of 2/3 yield strength is commonly used for example 40,000 psi (280 MPa) for Grade 60 steel).

Distributed steel reinforcement may be needed in pavements with transverse joints spaced more than 30 times the slab thickness. Because contraction joints should be free to open, distributed steel reinforcement is interrupted at the joints. Because increased spacing between joints will increase joint openings and reduce aggregate interlock load transfer, pavements designed for truck traffic that use such joint spacing typically require load-transfer dowels. Distributed steel reinforcement should be supported on chairs or precast concrete blocks to hold it in position, usually 2 in. (50 mm) below the top of the slab.

3.8.2 Dowels—Experience has shown that dowels or other load-transfer devices are not needed for most parking lot conditions. They may be economically justified where there are poor subgrade support conditions or heavy truck traffic if improved joint performance would allow a significant reduction in thickness.

Dowels across pavement joints can provide load transfer while permitting the joints to move. When dowels are used, their correct alignment and lubrication is essential for proper joint function. Dowel baskets (Fig. 3.1) should be used at contraction joints to maintain alignment, or dowel bar inserters can be used on slipformed placements. The dowels should be epoxy coated in areas where deicing salts are used. The dowel size should be in proportion to the pavement thickness. Table 3.6 gives recommended sizes of smooth, round dowel bars for different slab thicknesses (American Concrete Pavement Association 2007). Dowels should not be placed closer than 12 in. (300 mm) to a joint intersection to minimize the potential for corner cracking (ACI 308R, Schrader 1987, 1991). In thin pavements of 7 in. (180 mm)

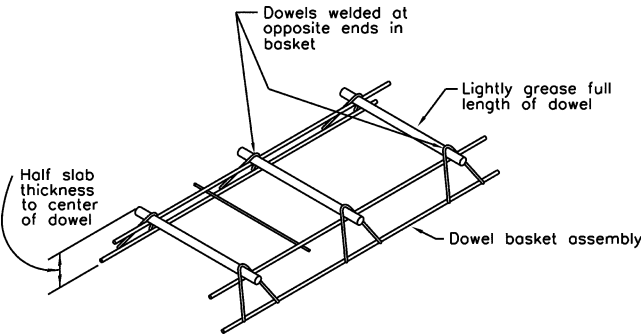


Fig. 3.1—Dowel basket assembly.

Table 3.6—Sizes of smooth, round dowels *

Slab thickness, in. (mm)	Dowel diameter, in. (mm)
7 (180)	1 (25)
8 (200)	1-1/4 (32)
9 (230)	1-1/4 (32)

* All dowels spaced at 12 in. (300 mm) centers, with minimum total length of 14 in. (360 mm) and minimum embedment length of 6 in. (150 mm) on each side of joint, with allowance made for joint openings and for minor errors in positioning dowels.

and less, round dowels can be impractical or counterproductive. Usually, it is more economical to keep joint spacing close, using aggregate interlock, and thicken the pavement slightly, if necessary, to reduce deflections.

The use of alternative dowel geometries and shapes has become common in the construction of industrial floor slabs, and some of these have been used successfully in parking and site pavements (Keith et al. 2006). These have most often been diamond- or trapezoid-shaped steel plate dowels, which may also be useful in some of the thinner sections (7 in. [180 mm] and less) for which traditional round dowels are impractical. There are other potential benefits to this type of dowel design as well. Less steel is required because the increased bearing area reduces the stress on both the concrete and the dowel. This geometry is also less sensitive to construction tolerances, and some differential movement of adjacent slab panels is afforded longitudinally along the joint. Special attention is recommended to consolidation of concrete around plate dowels.

3.8.3 Tie bars—Tie bars should be used to tie only the first longitudinal joint from the pavement edge to keep the outside slab from separating from the pavement (for location, refer to Fig. C.1 of Appendix C). Tie bars are not required in the interior joints of parking lots and other wide, paved areas because they are confined by surrounding slabs. Tie bars should be used on centerline joints of entrance drives and access roads that have a single longitudinal joint. Tie bar dimensions are shown in Table 3.7.

3.8.4 Irregular panels—In unreinforced parking lots, distributed steel reinforcement should be considered for irregular panels. An irregular panel is considered to be one in which the slab tapers to a sharp angle, when the length-to-width ratio exceeds 1.7, or when the slab is neither square nor rectangular. Distributed steel reinforcement should be calculated based on the drag formula (Eq. (3-3)). Even with

Table 3.7—Lengths and spacings for No. 4, 1/2 in. (13 mm) diameter tie bars

Slab thickness, in. (mm)	Tie bar length, in. (mm)	Tie bar spacing, in. (mm)		
		Distance to nearest free edge or to nearest joint where movement can occur		
		12 ft (3.7 m) or less	14 ft (4.3 m)	16 to 24 ft (4.9 to 7.3 m)
5 (125)	24 (610)	30 (760)	30 (760)	28 (710)
5-1/2 (140)	24 (610)	30 (760)	30 (760)	25 (630)
6 (150)	24 (610)	30 (760)	30 (760)	23 (580)
6-1/2 (165)	24 (610)	30 (760)	30 (760)	21 (530)
7 (180)	24 (610)	30 (760)	30 (760)	20 (510)
7-1/2 (190)	24 (610)	30 (760)	30 (760)	18 (460)
8 (200)	24 (610)	30 (760)	28 (710)	17 (430)
8-1/2 (215)	24 (610)	30 (760)	26 (660)	16 (410)
9 (230)	30 (760)	36 (910)	30 (760)	24 (610)

distributed steel reinforcement, a greater incidence of out-of-joint cracking should be anticipated in irregular panels.

3.9—Joint filling and sealing

Joints are often left unfilled without affecting performance, but joint filling and sealant material should be used to minimize the infiltration of water and solid materials into the joint openings where local experience has shown this to be necessary. Closer joint spacings with narrower openings minimize the amount of water that can drain through a joint and the amount of solid materials that can enter the joint. If a sealant is used, it should be able to withstand repeated movement while preventing the intrusion of water and solids. This requires proper width and depth of the sealant reservoir, as recommended by the sealant manufacturer, and careful application to minimize material deposited on the pavement surface. Refer to ACI 504R for additional information on joint sealing.

3.10—Pavement grades

3.10.1 Establishing grades—Project drawings should designate critical elevations in parking areas, such as changes in grade, to designate crown, and at all intake structures. It is vital that grades be established in sufficient detail to provide positive drainage in all gutters, around all islands and structures, and especially in intersections and pedestrian walkways. The construction layout crews should make sure that grade stakes are set at each change in slope.

3.10.2 Surface drainage—It is vital to establish grades that will ensure drainage of parking lots. The design and construction should provide a parking area that is fast-draining, quick-drying, and puddle-free. The drainage design plan should be coordinated with the jointing plan to avoid the channeling of surface water along a joint. Where environmental conditions dictate, parking lots can be designed to hold storm water for regulated release using pervious concrete. Refer to ACI 522R for additional information.

3.10.3 Pavement slope—To prevent puddling of water, the minimum pavement slope used should be 1% or 1/8 in./ft (3 mm/300 mm); 2% or 1/4 in./ft (6 mm/300 mm) is recommended wherever possible. Minimal slope can be used because a concrete surface maintains its shape, provided that