



Guide for Design and Construction of Concrete Parking Lots

4

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Guide for Design and Construction of Concrete Parking Lots

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Phil Weiss

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Concrete parking lots serve many transportation facilities, industrial plants, commercial developments, and multifamily housing projects. They are used for storing vehicles and goods, and 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 minimum maintenance.

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

Keywords: air entrainment; coatings; compacting; concrete construction; concrete durability; concrete pavements; concrete slabs; curing; dowels; drainage; economics; finishing; joints; joint sealants; loads (forces); load transfer; maintenance; parking facilities; quality control; reinforcing steels; repairs; resurfacing; soils; specifications; structural design; subbases; subgrades; thickness; tolerances; welded-wire fabric; workability.

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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.

Concrete parking lot pavements provide a hard surface for vehicle maneuvering and storage areas. Concrete parking lots also provide a surface that protects the underlying soil and reduces pressures imposed by design loadings to a level that the subgrade soils can support. Additionally, concrete parking lots, driveways, and access lanes are often constructed to serve specific types of traffic, such as cars and light trucks only or predominantly heavy delivery vehicles.

Typically, concrete parking lots do not serve the same broad spectrum of traffic loading, from light vehicles to heavy trucks, as are highways and arterial streets. Facilities designed to accommodate both light vehicles and heavier delivery trucks usually employ traffic controls to separate and channelize 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. Vehicles leak fuel and lubricants in parking lots. Vehicles in parking areas usually travel at low speeds, diminishing the importance of smoothness tolerances. Parking lots should also be designed to serve pedestrians.

Concrete parking lots range in size from small, such as at corner convenience stores and small multiple housing projects, to large, such as those for shopping centers and truck terminals. 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.

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 are:

- Concrete surfaces resist deformation from maneuvering vehicles;
- Concrete surfaces drain well on relatively flat slopes;
- Concrete has relatively simple maintenance requirements;
- Traffic-lane and parking-stall markings can be incorporated into the jointing pattern;
- Concrete is not adversely affected by leaking petroleum products;
- The light-reflective surface of concrete can be efficiently illuminated with minimal energy requirements and can help reduce summertime surface temperatures; and

- Concrete parking lots reduce the impacts of the urban heat island effect by providing a cooler urban environment and reducing ozone production.

1.2—Scope

This guide is based on the current knowledge and practices for the design, construction, and maintenance of concrete parking lots placed on the ground. It emphasizes the aspects of concrete pavement technology that are different from procedures used to design and construct slab-on-grade such as streets, highways, and floors. This guide is not a standard nor 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 towards 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 (that is, the Portland Cement Association method [Thickness 1984] and the AASHTO design method [AASHTO 1993]). 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, while parking lots usually serve fewer vehicles either parked or traveling at slow speeds. Many parking lot projects are not large enough to justify lengthy and detailed design calculations. For small parking lots, 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 are 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 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.

1.4—Definitions

California bearing ratio (CBR)—A bearing value for a soil that compares the load required to force a standard piston into a prepared sample of the soil, to the load required to force the standard piston into a well-graded crushed stone. (See ASTM D 1883) (The bearing value is usually expressed with the percentage omitted.)

Distributed steel reinforcement—Welded-wire fabric or bar mats used in pavement to hold the concrete together. This type of reinforcement does not contribute to the structural capacity of slabs on grade.

Dowelled joint—A joint that uses smooth parallel bars for load transfer, allowing for in-plane movement.

Expansive soils—Soils that exhibit significant volume changes caused by loss or gain of moisture.

Faulting—The differential vertical displacement of slabs adjacent to a joint or crack.

Frost-susceptible soil—Material in which significant detrimental ice aggregation will occur because of capillaries that permit the movement of moisture to the freezing zone when requisite moisture and freezing conditions are present.

Modulus of subgrade reaction k—The stress per 1 in. (25 mm) penetration of a circular plate into the subgrade and determined generally from the stress required to cause 0.05 in. (1.3 mm) penetration of a 30 in. (760 mm) diameter plate.

Panel—An individual concrete slab bordered by joints or slab edges.

Plain pavement — Unreinforced concrete pavement.

Plasticity index (PI) (also referred to as plasticity)—The range in the water content in which a soil remains plastic, which is also the numerical difference between liquid limit and plastic limit, as calculated according to ASTM D 4318.

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, as determined by 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 (S) or (SSV)—An index number that expresses the relative ability of a soil or aggregate mixture to support traffic loads through a flexible pavement structure; also, a

term found in the basic design equation developed from the results of the AASHTO Road Test.

Standard density—Maximum soil density at optimum moisture content according to ASTM D 698.

Subbase (also called base)—A layer in a pavement system between the subgrade and concrete pavement.

Subgrade—The soil prepared and compacted to support a structure or a pavement system.

Modulus of rupture—The theoretical maximum tensile stress reached in the bottom fiber of a test beam.

Tied joint—A joint that uses deformed reinforcing bars to prevent the joint from opening.

CHAPTER 2—PAVEMENT DESIGN

2.1—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, channelize 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 proper selection of 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 traffic should be discouraged from moving at high speeds.

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 to curl up or down. The tendency for 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 3 1/2 in. (90 mm) thick. Thinner slabs do not significantly reduce construction cost and because of their tendency to 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.

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Methods used to determine concrete pavement thickness are based on theoretical and laboratory studies that relate concrete stresses and fatigue characteristics to the nature of the underlying subgrade and the strength of the concrete, as well as to the magnitude and location of the loads on the slab. These studies have been supplemented by experimental pavements where design variables have been controlled and performance has been monitored closely. An example is the AASHTO Road Test (AASHTO 1962). Experimental pavement performance studies have been supplemented by studies of the performance of pavements built to commercial standards that carry random combinations of traffic and are exposed to environmental changes (Brokaw 1973). These studies have enabled paving technologists to gain knowledge about the performance of concrete pavements under controlled and normal conditions. Though the intent of the study was to provide data for the design of pavements intended to carry street and highway traffic, the data and analysis also provide useful information for those responsible for designing concrete parking lot pavements.

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

2.2—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 less severe due to load transfer provided by 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 curling or warping 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 to acceptable levels.

2.3—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), 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. 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.

Table 2.1—Subgrade soil types and approximate support values (Thickness 1984; Guide 1982)

Type of soil	Support	k , pci	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

Note: k value units can also be expressed as psi/in.

Table 2.2—Modulus of subgrade reaction k^*

Subgrade k value, pci	Sub-base thickness			
	4 in. (100 mm)	6 in. (150 mm)	9 in. (225 mm)	12 in. (300 mm)
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 sub-base				
50	170	230	310	390
100	280	400	520	640
200	470	640	830	—
Other treated sub-base				
50	85	115	170	215
100	175	210	270	325
200	280	315	360	400
300	350	385	420	490

*For different subbase applied over different subgrade, psi/in. (Thickness 1984; Airport 1978).

Note: k value units can also be expressed as psi/in.

2.4—Subgrade support

The subgrade is the underlying surface of soil or existing pavement on which the parking lot pavement will be constructed. The required pavement thickness and the performance of the pavement will depend in large part upon the strength and uniformity of the subgrade. 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; however, it is recommended that soil conditions and subgrade properties be determined by appropriate soils testing.

The ability of the subgrade soil to uniformly support the loads applied to it through the pavement is extremely important. Uniform subgrade support is the goal of proper site preparation. For example, a designer can require grading operations to blend soil types to improve uniformity. 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. For large projects, the soil should be classified according to one of the standardized systems. 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 tests. The relative bearing capacity expressed in terms of modulus of subgrade reaction k , CBR, resistance value R , SSV should be determined. For small projects, the selected value can be estimated. Table 2.1 shows ranges of values for several types of soil (Thickness 1984; A Guide 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 standard proctor density as determined by ASTM D 698.

It probably is not economical to use imported base material for the sole purpose of increasing k values. If a subbase is used, the increased support it provides should be considered in the thickness design. Table 2.2 is indicative of the effects of subbases on k values (Thickness 1984; Airport 1978).

Additional detailed information on subgrade investigation, subbases, and special subgrade problems can be found in Appendix B. See Table 6.1 for k values for existing flexible pavements.

2.5—Concrete properties

Concrete mixtures for paving should be designed to produce the required flexural strength, provide adequate durability, and have adequate workability for efficient placement, finishing, and texturing, considering the equipment the contractor will use.

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 will approach the concrete flexural strength, while compressive stresses remain small in relation to the compressive strength of the concrete. Consequently, flexural strength or the M_R of the concrete is used in pavement design to determine the thickness. Figure 2.1 shows the relationship between the flexural strength of concrete, M_R , and the compressive strength.

Flexural strength is determined by the modulus of rupture test in accordance with ASTM C 78. 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, it is more practical to use compressive strength testing for quality control in the field. On large projects, a correlation between flexural strength and compressive strength should be developed from laboratory tests on the specific concrete mixture to be used.

Table 2.3—Traffic categories*

1. Car parking areas and access lanes—Category A (autos, pickups, and panel trucks only)		
2. Truck access lanes—Category A-1		
3. Shopping center entrance and service lanes—Category B		
4. Bus parking areas, city and school buses Parking area and interior lanes—Category B Entrance and exterior lanes—Category C		
5. 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, A-1, B, C, or D for use with Table 2.4.

On smaller projects, an approximate relationship between compressive strength f'_c and flexural strength M_R can be computed by the following formula:

$$[\text{U.S. units}] \quad M_R = 2.3 f'_c{}^{2/3} \quad (2-1)$$

NOTE: This empirical equation (U.S. units) was developed using data from four different studies, conducted between 1928 and 1965 (Raphael 1984).

$$[\text{SI units}] \quad M_R = 0.445 f'_c{}^{2/3}$$

2.6—Thickness design

2.6.1 Basis for design—Thickness designs for concrete pavements are based upon laboratory studies, road tests, and surveys of pavement performance. The most commonly used methods are the AASHTO Design Equations, which were developed from data obtained at the AASHTO Road Test, and the Portland Cement Association Design Procedure (Thickness 1984), which is based on pavement resistance to fatigue and deflection. 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 these design methods were developed for analyzing and designing pavements for streets and highways, the research behind them has included thin pavements, and they can be used for parking lot design. The different design procedures give very similar thicknesses. 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 design methods cited above can be used for plain or reinforced pavements because the presence or lack of distributed steel reinforcement has no significant effect on the load-carrying capacity or thickness. Joint design, however, is affected by the presence of distributed reinforcement. Load transfer devices have a significant effect on pavement thickness, but they 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 2.7 and 2.8.

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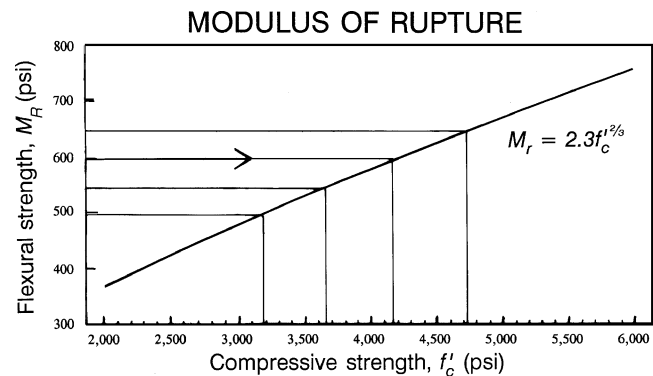


Fig. 2.1—Flexural-to-compressive strength relationship (Raphael 1984).

Tables 2.3 and 2.4 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 2.3 lists five different traffic categories ranging from passenger cars and light trucks to heavy trucks. Table 2.4 gives recommended pavement thicknesses for large and small numbers of trucks per day in five 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 2.1, 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 3200 psi (22 MPa) and 4800 psi (33 MPa) based on Eq. (2-1). Approximate cost comparisons indicate that the lower-strength concrete can sometimes be justified in areas where freeze-thaw 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 benefits of high strength such as improved durability. Table 2.4 can be used to assist the designer in this determination.

2.7—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 (expansion joints). To effectively control cracking due to tensile stresses created by restrained shrinkage and curling caused by temperature and moisture differentials, it is important to have the joints properly spaced. Properly spaced joints depend upon the thickness of the pavement, the strength of the concrete, 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. Closely spaced joints can result in smaller

Table 2.4—Twenty-year design thickness recommendations, in. (no dowels)

Traffic category	$k = 500$ (CBR = 50) M_R				$k = 400$ (CBR = 38) M_R				$k = 300$ (CBR = 26) M_R			
	650	600	550	500	650	600	550	500	650	600	550	500
A (ADTT = 0)*	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	4.0
A-1 (ADTT = 1)*	3.5	3.5	4.0	4.0	3.5	4.0	4.0	4.0	4.0	4.0	4.0	4.5
A-1 (ADTT = 10)	4.0	4.5	4.5	5.0	4.5	4.5	5.0	5.0	4.5	4.5	5.0	5.5
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	5.0	5.5	5.0	5.0	5.5	6.0	5.0	5.5	5.5	6.0
C (ADTT = 100)	4.5	5.0	5.5	6.0	5.0	5.0	5.5	6.0	5.0	5.5	5.5	6.0
C (ADTT = 300)	5.0	5.5	5.5	6.0	5.0	5.5	6.0	6.0	5.5	5.5	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	6.0	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

Traffic category	$k = 200$ (CBR = 10) M_R				$k = 100$ (CBR = 3) M_R				$k = 50$ (CBR = 2) M_R			
	650	600	550	500	650	600	550	500	650	600	550	500
A (ADTT = 0)	3.5	3.5	3.5	4.0	3.5	3.5	3.5	4.0	4.0	4.0	4.0	4.0
A-1 (ADTT = 1)	4.0	4.0	4.5	4.5	4.0	4.5	4.5	5.0	4.5	5.0	5.0	5.5
A-1 (ADTT = 10)	4.5	5.0	5.5	5.5	5.0	5.5	6.0	6.0	5.5	6.0	6.5	7.0
B (ADTT = 25)	4.5	5.0	5.5	6.0	5.0	5.5	6.0	6.5	5.5	6.0	6.5	7.0
B (ADTT = 300)	5.0	5.5	6.0	6.5	5.5	6.0	6.5	7.0	6.5	6.5	7.0	7.5
C (ADTT = 100)	5.5	5.5	6.0	6.5	6.0	6.0	6.5	7.0	6.5	7.0	7.5	8.0
C (ADTT = 300)	5.5	6.0	6.5	7.0	6.0	6.5	7.0	7.5	6.5	7.0	7.5	8.0
C (ADTT = 700)	6.0	6.0	6.5	7.0	6.5	6.5	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. See Appendix A. For thickness conversion to SI units, see Appendix E.

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.

2.7.1 Contraction joints—A contraction joint predetermines the location of cracks caused by restrained shrinkage of the concrete and by the effects of loads and 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 one-quarter of the slab depth 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. (See section 4.7.1.) The width of a cut depends upon whether the joint is to be sealed. A narrow joint width, generally 1/10 (2.5 mm) to 1/8 in. (3 mm) wide, is common for unsealed joints. 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. Trans-FDA, Inc.

Table 2.5—Spacing between joints

Pavement thickness, in. (mm)	Maximum spacing, ft (m)
3.5 (90)	8.5 (2.4)
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)

verse joints divide the paving lanes into panels. Contraction joint patterns should divide pavements into approximate 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 the thickness of the slab up to a maximum of 15 ft (4.5 m). See Table 2.5. In many instances, jointing patterns can be used to delineate driving lanes and parking stalls.

2.7.2 Construction joints—Construction joints provide the interface between areas of concrete placed at different times during the course of the project. They can be keyed or butt type, they may have dowels, or they may be tied. Butt-type joints do not provide load transfer, but load transfer usually is not required for parking lots serving light vehicles. The need for load transfer should be considered under heavy traffic. Keyways of half-round or trapezoidal shape provide load transfer across construction joints. If keyed joints are used, it is important to use the proper dimensions to avoid creating weak joints. Steel forms with improper keyway dimensions or

leave-in-place keyed shapes should not be used. Recommended keyway dimensions are shown in Appendix C. See Section 2.8.2 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 about 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.

Keyed joints may be formed or slipformed. 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. See Section 2.8.3.

Designers should recognize that when new concrete, with an inherent tendency to shrink, is tied to older concrete that has already gone through the shrinkage process, stresses will develop that can cause 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 3 ft (1 m) or more.

2.7.3 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-depth, 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. (See Fig. C-4, 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 so that the joint can be sealed with joint-sealant materials. The types of joint filler materials available include bitumi-

nous mastic, bituminous impregnated cellulose or cork, sponge 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.

2.8—Steel reinforcement in parking lot pavements

2.8.1 Distributed steel reinforcement—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 is 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 foot of slab width is computed by the following drag formula (Distributed 1955):

$$A = (LC_f wh)/24f_s \quad (2-2)$$

(For conversion of results to SI units, see Appendix E.)

where

- A = area of distributed steel reinforcement required/foot of slab, in.²;
- L = distance between joints, ft;
- 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);
- h = slab thickness, in.; and
- f_s = allowable tensile stress in distributed steel reinforcement, psi (a value of 2/3 yield strength is commonly used, for example 40,000 psi for Grade 60 steel).

Distributed steel reinforcement is 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, truck pavements with wide joint spacing typically require load transfer dowels. Distributed steel reinforcement should be supported on chairs or precast-concrete block to hold it in position, usually 2 in. (50 mm) below the top of the slab.

When pavement is jointed to form short panel lengths that will minimize intermediate cracking, distributed steel reinforcement is not necessary. The use of distributed steel rein-

forcement will not add to the load-carrying capacity of the pavement and should not be used in anticipation of poor construction practices.

2.8.2 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.

Plain (smooth) dowels across contraction joints in pavements provide load transfer while permitting the joints to move. Correct alignment and lubrication of the dowels is essential for proper joint function. 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 2.6 gives recommended dowel bar sizes for different slab depths (Joint Design for Concrete Highway and Street Pavements 1975). In thinner pavements of 7 in. (180 mm) and less, dowels can be impractical. Usually, it is more economical to keep joint spacing close, using aggregate interlock, and thicken the pavement slightly, if necessary, to reduce deflections.

2.8.3 Tie bars—Tie bars located as shown in Fig. C.1, should be used to tie only the first longitudinal joint from the pavement edge to keep the outside slab from separating from the pavement. 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 center line joints of entrance drives and access roads if there are no curbs. Refer to Table 2.7 for tie bar dimensions.

2.8.4 Irregular panels—In unreinforced parking lots, distributed steel reinforcement should be considered for odd-shaped panels. An odd-shaped panel is considered to be one in which the slab tapers to a sharp angle, when the length to width ratio exceeds 1.5, or when the slab is neither square nor rectangular. Distributed steel reinforcement should be calculated based on the drag formula (Eq. (2-2)).

2.9—Joint filling and sealing

Joints are 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. Closely spaced joints with very narrow 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 a joint wide enough to hold adequate sealant and careful application to minimize material deposited on the pavement surface. See ACI 504R for additional information on joint sealing.

2.10—Pavement grades

2.10.1 Surface drainage—It is vital to establish grades that will ensure proper drainage of parking lots. The design and construction should provide a parking area that is fast draining, quick-drying, and puddle-free. Where environmental

Table 2.6—Dowel size*

Slab depth, in. (mm)	Dowel diameter, in. (mm)	Dowel embedment, in. (mm) [†]	Total dowel length, in. (mm) [‡]
5 (125)	5/8 (16)	5 (125)	12 (300)
6 (150)	3/4 (19)	6 (150)	14 (360)
7 (180)	7/8 (22)	6 (150)	14 (360)
8 (200)	1 (25)	6 (150)	14 (360)
9 (230)	1-1/8 (29)	7 (180)	16 (400)

* All dowels spaced at 12 in. (300 mm) centers.

[†] On each side of joint.

[‡] Allowance made for joint openings and for minor errors in positioning dowels.

conditions dictate, parking lots can be designed to pond and hold storm water for regulated release.

2.10.2 Pavement slope or crown—To prevent puddling of water, the minimum pavement slope used should be 1% or 1/8 in./ft (3 mm/300 mm), and 2% or 1/4 in./ft (6 mm/300 mm) is recommended wherever possible. Flat grades can be used, because a concrete surface maintains its shape, provided the subgrade support remains uniform. Flat grades minimize the amount of earthwork during construction and can result in greater spacing of inlets. To prevent vehicles from dragging on the pavement, entrances should not exceed an 8% change in grade without the use of vertical curves. Driveways and entrances may be sloped up to 12%, but a maximum slope of 6% is generally recommended for areas where vehicles park. Disabled accessible (handicapped) spaces should be designed in accordance with the Americans with Disabilities Act (ADA).

2.10.3 Establishing grades—The project drawings should designate critical elevations in parking areas, such as changes in grade, crowns, or 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.

2.11—Curbs and islands

Large parking lots require special features to control, channelize, and segregate traffic; to keep parked vehicles on the pavement; to collect runoff; and to provide spaces for landscaping. These functions are usually fulfilled by edge curbs and islands formed by interior curbs. Islands can be paved or landscaped.

Curbs on any parking lot confine traffic to the paved surfaces and can direct the flow of runoff. Curbs can perform the function of confining the pavement structure. Preferably, curbs are constructed monolithically with pavement slabs, but they can be constructed separately. Curb and gutter sections are sometimes constructed first and then used as side forms for paving parking slabs. When used with concrete pavement, monolithic curbs or curb and gutter sections tied to the pavement with tie bars provide structural stiffness to the edges of the pavement.

Islands can provide some separation between pedestrians and vehicles. Islands can be placed to restrict turns of long vehicles and segregate trucks and buses to areas with heavy

Table 2.7—Tie bar dimensions

Slab depth, in. (mm)	Tiebar size, in. (mm)	Tiebar spacing			
		Distance to nearest free edge or to nearest joint where movement can occur			
		10 ft, in. (mm)	12 ft, in. (mm)	14 ft, in. (mm)	24 ft, in. (mm)
5 (125)	1/2 x 24 (13 x 610)	30 (760)	30 (760)	30 (760)	28 (710)
5-1/2 (140)	1/2 x 24 (13 x 610)	30 (760)	30 (760)	30 (760)	25 (630)
6 (150)	1/2 x 24 (13 x 610)	30 (760)	30 (760)	30 (760)	23 (580)
6-1/2 (165)	1/2 x 24 (13 x 610)	30 (760)	30 (760)	30 (760)	21 (530)
7 (180)	1/2 x 24 (13 x 610)	30 (760)	30 (760)	30 (760)	20 (510)
7-1/2 (190)	1/2 x 24 (13 x 610)	30 (760)	30 (760)	30 (760)	18 (460)
8 (200)	1/2 x 24 (13 x 610)	30 (760)	30 (760)	28 (710)	17 (430)
8-1/2 (215)	1/2 x 24 (13 x 610)	30 (760)	30 (760)	36 (910)	16 (410)
9 (230)	1/2 x 30 (13 x 760)	36 (910)	36 (910)	—	24 (610)

duty pavement. Where landscaping is desired, islands can be made large enough to provide areas for plantings.

The locations of islands should be established to facilitate construction without disrupting the parking lot jointing pattern if feasible. In some instances, it is desirable to establish final locations of islands after the jointing pattern is determined. Small islands that require fixed forms and finishing with hand-tools can be constructed after paving operations, if sufficient areas in the pavement are boxed out during initial paving.

Curbs are constructed in many shapes, but the predominant types are mountable (roll type) curbs and barrier (straight) curbs. Mountable curbs are preferred by many people for their appearance, and they are easier to construct by the slipform method. Barrier curbs can also be slipformed, but the process is easier if there is a slight batter to the exposed faces of the curbs. A description of the most commonly used curb sections is found elsewhere (Design 1978), and cross sections of typical curbs are shown in Appendix C.

Joints in the pavement slabs should be carried through adjacent curbs or curb and gutter sections. Thorough planning is necessary before separate curb and gutter sections are constructed. Longitudinal reinforcing steel is not needed in curbs if they are properly jointed and placed on a properly compacted subgrade.

CHAPTER 3—MATERIALS

3.1—Introduction

Concrete used to construct parking lot pavements should be batched, mixed, and delivered in accordance with ASTM C 94 or ASTM C 685. Components of the mixture should follow the requirements contained in other appropriate ASTM specifications. Proportioning concrete by the methods utilized in ACI 211.1 will help to ensure that the concrete used in parking lot paving will provide the required strength, long-term durability, economy, and workability envisioned by the owner, designer, and contractor. ACI 304R contains guidance on batching, mixing, and placing.

The proportions for the concrete can be established on the basis of previous field experience or laboratory trial batches. For most small parking lot projects, the effort and expense required to establish proportions by laboratory trials may not be justified if commercial ready-mixed concrete with the requisite performance history is available. Commercial mix-

tures proportioned and approved for use in state, city, or county paving will usually be adequate for parking lots. Ready-mixed concrete producers normally have standard mixtures with performance records that will be appropriate for parking lot projects.

3.2—Strength

Flexural strength is a critical property of concrete used for paving. Concrete strength is a function of the cementitious material content and the water-cementitious materials ratio (w/cm) selected for the mixture. Cubical-shaped coarse aggregates have been shown to increase flexural strength compared with rounded aggregates. Water-reducing admixtures can also be used to increase strength by reducing the amount of water needed to achieve a desired slump. Mixtures designed for high early strength can be provided if the pavement is to be used by construction equipment or opened to traffic in a shorter than normal period of time.

3.3—Durability

Few environments are as hostile to concrete as parking lot pavements in freezing-and-thawing climates. Traffic loads, freezing-and-thawing cycles, deicing salts, and sometimes soil sulfates or potential alkali silica reactivity can each cause pavement deterioration unless the concrete mixture is carefully proportioned to maximize durability. For heavy traffic loads or when durability is critical, a compressive strength of at least 4000 psi (28 MPa) should be specified. The use of reinforcing steel in areas where deicing salts or air-born salts are present may necessitate a higher compressive strength for the concrete to reduce permeability and increase the durability.

Concrete subjected to freezing and thawing should be air entrained. Table 3.1 provides recommended air contents based upon three exposure classifications. Mild exposure is a climate where the concrete will not be exposed to freezing or deicing salts. Moderate exposure is a climate where freezing is expected, but where the concrete will not be continually exposed to moisture or free water for long periods before freezing and will not be exposed to deicing agents. Severe climates expose the concrete to deicing chemicals or possible saturation by continual contact with moisture or free water before freezing.

Table 3.1—Recommended air contents

Nominal maximum size aggregate		Typical air contents of non-air-entrained concrete, %	Recommended average air content for air-entrained concretes, %		
in.	mm		Mild exposure	Moderate exposure	Severe exposure
3/8	10	3.0	4.5	6.0	7.5
1/2	13	2.5	4.0	5.5	7.0
3/4	19	2.0	3.5	5.0	6.0
1	25	1.5	3.0	4.5	6.0
1-1/2	38	1.0	2.5	4.5	5.5

Note: Tolerances: $\pm 1.5\%$. There is conflicting opinion on whether air contents lower than those given in the table should be permitted for high-strength (over 5500 psi) concrete. This committee believes that where supporting experience, experimental data, exists for particular combinations of material, construction practices, and exposure, the air contents can be reduced by approximately 1%.

Excessive soluble sulfates in the soil may lead to chemical reactions between the hydrated cement and the sulfate ions. These reactions can lead to deterioration of the concrete causing a progressive loss of strength and loss of mass. When sulfates in the soil exceed the limits given in ACI 201.2R, Type II or Type V cement or equivalent should be specified and used. The use of pozzolans or blended cements may be economical mitigation methods. Aggregates selected for paving should be durable for freezing-thawing exposures and should contain a minimum of porous cherts or deleterious materials that will contribute to freezing-and-thawing deterioration. Coarse aggregates meeting ASTM C 33 or local highway department specifications for concrete paving normally provide acceptable in-service performance. (See ACI 221R for additional guidance). Potential alkali silica reactivity (ASR) has become an important durability consideration for aggregates. Aggregates which test positive for potential ASR reaction should only be used with mitigation procedures. These include the use of low alkali cements, pozzolans, ground granulated blast furnace slag, and blended cements which have proven effect in ASR test programs. The best evidence of an aggregate's potential ASR properties is its service record for 10 or more years. (See ACI 221.1R)

Poor construction practices, such as indiscriminate addition of water, late saw cuts of joints and lack of curing will each reduce the durability of concrete. Additional information on curing is available in 4.6.

3.4—Economy

Economy is an important consideration in selecting the concrete to be used for paving. Well-graded aggregates, minimum cement contents consistent with strength and durability requirements, and admixtures are all factors that should be considered in proportioning economical concrete. Commonly available commercial mixtures proportioned with locally available materials are usually more economical than custom-designed mixtures. Concrete costs can be reduced by the incorporation of supplementary cementitious materials.

3.5—Workability

Workability is an important consideration in selecting concrete for a parking lot paving project. Slump for slipform paving is usually about 1 in. (25 mm). Concrete to be placed by hand or with vibrating screeds will require a higher slump, generally 4 in. (100 mm) or less. Water content, aggregate gradation, and air content are all factors that affect

workability. The maximum aggregate size should be no greater than 1/3 the depth of the slab.

3.6—Material specifications

Guidance for specifying concrete can be found in ASTM C 94. This comprehensive standard specification covers concrete manufacturing and delivery procedures and quality-control procedures. In the absence of specific specification requirements, the purchaser of ready-mixed concrete for paving projects should provide the producer with the size or sizes of coarse aggregate, slump desired at the point of delivery, and air content. In addition, one of the following should be given: strength requirements at 28 days or other specified age, strength requirements and the minimum acceptable cement content, or prescription for the mixture.

ASTM C 33 defines the requirement for grading and the quality of fine and coarse aggregate used in concrete. In some areas highway standard specifications for aggregates may vary slightly from ASTM C 33 but may be used because they are likely to conform more closely to local supplies and should produce acceptable paving concrete.

Requirements for air-entraining admixtures used in concrete are specified in ASTM C 260. Water-reducing, retarding and accelerating admixtures are usually specified by ASTM C 494. Requirements for fly ash used in concrete are in ASTM C 618, while ASTM C 989 specifies the requirements for ground granulated blast furnace slag to be used in concrete. ASTM C 150, C 595, and C 1157 are specifications for portland and other hydraulic cements. Each of these cementitious material specifications includes several types of cements and various mineral admixtures designed for specific uses and conditions and should be carefully selected to meet the needs of a particular project. The availability of a cement type in a particular geographical location should be verified.

Liquid-membrane-curing compounds offer the most simplistic method of curing concrete pavements. ASTM C 309 and ASTM C 1315 are the standard specifications for these materials.

Specification requirements for steel products used for paving projects can be found in: ASTM A 185, ASTM A 497, ASTM A 615, ASTM A 616, ASTM A 617, ASTM A 706, and ASTM A 820.

Specification requirements for Expansion Joint Material are found in ASTM D 994, D 1751, or D 1752. Those for Joint Sealing Materials are found in ASTM D 3406 for hot-poured elastomeric type sealants or Federal Specification TT-S-

001543a (COM-NBS) Sealing Compound: Silicone Rubber Base, and TT-S-00230c (COM-NBS) Sealing Compound, Elastomeric Type, Single Component.

CHAPTER 4—CONSTRUCTION

4.1—Introduction

Construction of parking lots should be accomplished in compliance with adequate plans and specifications to provide a pavement that will meet the owner's needs. Because the contractor is responsible for providing quality workmanship, ACI certified finishers and compliance with ACI 121R are recommended. This is especially important on small projects that can be constructed with little or no inspection. Construction starts with thorough planning, such as coordinating with other contractors on the site, determining the optimum size equipment for the project, arranging for a realistic delivery rate of concrete, determining the construction sequence, and arranging delivery routes for concrete trucks. A good way to accomplish this is to conduct a pre-construction conference attended by the architect/engineer, general contractor, excavator, utility subcontractor, paving subcontractor, concrete supplier, and testing agency.

4.2—Subgrade preparation

A well-prepared, uniform subgrade at the correct elevation is essential to the construction of a quality pavement. Uniformity provides consistent support, and the proper elevation determines that the pavement will be the required thickness. The subgrade should support not only the pavement but also the paving equipment and construction traffic.

Earthwork operations should be coordinated with the installation of utilities to avoid conflict. The subgrade should be excavated or filled with suitable material to produce the required subgrade elevations. All noncompactible and otherwise unsuitable materials should be blended with other soils if possible, or removed and replaced with suitable material. Good practice dictates that filled sections be thoroughly compacted in layers to the specified density and should extend at least one foot beyond the formlines. The subgrade should not be uncompacted, disturbed, muddy, or frozen when paving starts. The subgrade should be prepared far enough ahead of the paving operation to permit uninterrupted paving. The subgrade should have a moist, dense, firm, and uniformly smooth surface when concrete is placed on it.

Sand cushions should not be used as a construction expedient in lieu of proper subgrade preparation. Granular aggregate subbases are not normally used for concrete parking lots. If a subbase is specified for some special reason, it should be placed on the prepared subgrade, compacted, and trimmed to the proper elevation.

All utility trenches and other excavations in the area to be paved should be backfilled to finish grade and thoroughly compacted in advance of the normal subgrade preparations. Backfill materials should be compacted with mechanical tampers in approximately 6 in. (150 mm) lifts. Controlled low-strength material—a mixture of granular and cementitious materials and water—is recommended for use in lieu of compacted backfill. (See ACI 229R.) If subsidence of compact-

ed trench backfill is evident before the paving covers it, it should be excavated and recompacted before paving.

The final fine grading should be checked with a template or other positive means to ensure that the surface is at the specified elevations. Suggested tolerances for fine grading are no more than 1/4 in. (6 mm) above or 1/2 in. (13 mm) below the design grade. Deviations greater than these tolerances can jeopardize pavement performance because small variations in thickness of thin pavements significantly affect load-carrying capacity. Excessive variations in thickness are indicative of poor control of grading or concrete placement.

4.3—Layout for construction

A layout to permit efficient use of paving equipment, to provide easy access for concrete delivery trucks, and to ensure good drainage of the site can expedite construction operations.

The contractor and engineer or inspector should agree on joint layout and construction methods before paving begins. A drawing showing the location of all joints and the paving sequence is helpful in establishing the agreement. Locations of drainage fixtures, lighting supports, and other fixed objects should be established with the joint pattern and construction methods in mind. Paving should be done in lanes. Paving-lane widths should be done in multiples of the joint spacings. The width will depend on the equipment and method selected by the contractor. Checkerboard placing should be avoided because it requires more time and forming materials, and usually results in less consistent surface tolerances and poorer joint load transfer.

4.4—Paving equipment

4.4.1 Forms—If forms are used they should be straight, of adequate cross section and strength, and held in place securely to resist the pressure of concrete and support the paving equipment without springing or settling. Forms can be made of wood, steel, or other accepted materials. Stay-in-place forms are not recommended for outdoor parking lots. Keyways attached to forms should conform to the dimensions shown in Appendix C.

4.4.2 Setting forms—The subgrade under the forms should be compacted, cut to grade, and tamped to furnish uniform support to the forms. Enough form pins or stakes should be used to resist lateral movement. All forms should be cleaned and oiled as necessary to obtain neat edges on the slab. Lines and grades of forms should be checked immediately before concrete placement and preferably after form-riding equipment has been moved along the forms.

4.4.3 Strike-off and consolidation—Concrete can be struck off and consolidated by using a mechanical paving machine, a vibrating screed, or by using a straight edge after consolidating with a hand-held vibrator. Screeds should be sufficiently rigid so that they do not sag between the form lines or ride up over a stiff mixture. They should also be adjustable to produce any specified crown.

4.4.4 Slipform paving—Instead of using fixed forms, the contractor can use a slipform paver designed to spread, consolidate, and finish the concrete in a single pass. Keyways can be formed in this process. The slipform paver should be

operated with as nearly a continuously forward movement as possible. All delivery and spreading of concrete should be coordinated so as to provide uniform progress without stopping and starting the machine. Coordination with the concrete supplier is especially important. When the slipform paver is to ride on the edge of a new concrete pavement, the concrete strengths should be greater than 2000 psi (14 MPa). Stringlines or other means for setting grade should be checked frequently.

4.5—Placing, finishing, and texturing

4.5.1 *Placing and consolidation*—The subgrade should be uniformly moist with no standing water. If the concrete is placed in hot, dry or windy conditions, the subgrade should be lightly dampened with water in advance of concreting. The concrete should be deposited as uniformly as possible ahead of the paving equipment and as close to its final position as possible so as to require a minimum of rehandling. The concrete should be thoroughly consolidated along the faces of the forms and struck off to the required elevation and cross section. If slipform equipment is used, the concrete should be of proper consistency to prevent excessive edge slump.

4.5.2 *Finishing*—Immediately following the strikeoff, the surface should be leveled with a bullfloat or a scraping straight edge. The surface should be finished no more than necessary to remove irregularities. All edges, tooled joints, and isolation joints should be rounded to the specified radius with appropriate tools. The use of hand or power floats and trowels is not necessary and is not recommended as this can result in scaling.

4.5.3 *Texturing*—As soon as the finished concrete has set sufficiently to maintain a texture, and no bleed water remains on the surface, the surface can be dragged with a short length of damp burlap or other material such as synthetic turf carpeting. Drags are sometimes attached to paving machines or screeds. As an alternative, the surface can be broomed to develop a skid-resistant surface and a uniform appearance.

4.6—Curing and protection

4.6.1 *Curing*—Use of white pigmented membrane-forming curing compounds meeting ASTM C 309 or ASTM C 1315 (Type II) should follow the normal curing procedure as recommended by the manufacturer. After finishing and texturing operations have been completed and immediately after free water has evaporated, the surface of the slab and any exposed edges should be uniformly coated with a high solids membrane-curing compound. It can be applied by a pressure sprayer, not to exceed 200 ft²/gal. (5 m²/L). Two applications at 90 degrees offset can be required on windy days. Other acceptable curing materials and methods can be used. These methods are described in more detail in ACI 308, Section 2.4.2.3.

4.6.2 *Cold-weather protection*—Cold-weather curing should provide protection from freezing while retaining moisture for the time necessary to achieve the desired physical properties in the concrete. Curing blankets or polyethylene

sheets sandwiching hay or straw serve both purposes. For additional information, refer to ACI 306R.

If the pavement is built in the fall in an area where deicer salts are routinely used and will be put into service before it dries for 30 days [above 40 F (4 C)] after curing, a linseed oil or other surface treatment is recommended. The materials used should allow water vapor to escape. NCHRP Report 244 (Concrete 1981) presents a thorough appraisal of the effectiveness of many sealers used to prevent the intrusion of deicing salts into concrete. Additional information on materials to protect vulnerable concrete from freezing-thawing damage is found in Section 6.2.

If linseed oil is used, two applications of a mixture of equal volumes of boiled linseed oil and mineral spirits should be applied to dry pavement at a temperature above 50 F (10 C). The first application should be approximately 360 ft²/gal. (9 m²/L) and the second application about 630 ft²/gal. (16 m²/L). With dry pavements and ambient temperatures above 50 F (10 C), each application should be absorbed in about one hour.

4.6.3 *Hot-weather precautions*—In hot weather, transporting, placing, and finishing of concrete should be done as quickly as practical. It is important to schedule concrete deliveries at the proper time.

Plastic shrinkage cracking sometimes occurs during, or soon after, finishing operations with any combination of high air temperature, low relative humidity, and high wind velocity. When concrete is placed during hot weather, extra precautions should be taken to maintain the subgrade in a moist condition, reduce the time between placing and finishing, and protect the concrete to minimize evaporation. Refer to ACI 305R for additional information on preventing problems during hot weather.

4.6.4 *Protection against rain*—When rain is imminent during paving operations, paving should be stopped, and all steps necessary to protect the hardening concrete should be taken. The contractor should have available enough plastic sheeting on the project site to completely cover any surfaces that may be damaged in the event of rain. There should also be adequate weights available to keep the plastic sheeting from blowing away. If the pavement is being constructed along a slope, the fresh concrete should be protected from water above washing across the surface.

4.7—Jointing

4.7.1 *Contraction joints*—Contraction joints can be formed to the dimensions in Section 2.7.1 by sawing, tooling, or using inserts. If inserts are used, they should be installed vertically, flush with the surface, and continuous between edges.

Sawing transverse joints should begin as soon as the concrete has hardened sufficiently to avoid excessive raveling. Two types of saws can be used to form contraction joints: early-entry dry-cut saws and conventional (either wet or dry cut) saws. The depths of joints, using a conventional saw, should be at least 1/4 of the slab thickness. When early sawing is desired, an early-entry dry-cut saw should be used and the depth of the sawcut should be at least 1 in. (25 mm) for slabs that are less than 9 in. (230 mm) thick. Typically, joints

produced using conventional processes are made within 4 to 12 h after the slab has been finished in an area—4 h in hot weather to 12 h in cold weather. For early-entry dry-cut saws, the time of cut is immediately after initial set of the concrete in that joint location, which will typically vary from 1 h after finishing in hot weather, to 4 h after finishing in cold weather. Timing of the sawing operations will vary with the manufacturer and equipment. The goal of sawcutting is to create a weakened plane as soon as the joint can be cut without creating raveling at the joint. The sawing of any joint should be discontinued or omitted if a crack occurs at or near the joint location before or during sawing. If extreme conditions make it impractical to prevent erratic cracking by early sawing, the contraction joints should be formed by other methods.

If joint sealing is required (see Section 2.9), the joints should be thoroughly cleaned and the sealing materials installed without overfilling, in accordance with the manufacturer's instructions, before the pavement is opened to traffic.

4.7.2 Isolation joints—Isolation joints should be used to separate drainage structures, existing islands, light standards, building foundations, and existing approach pavements from the parking lot pavement. Joint material should be continuous from form to form, extend from top of slab to the subgrade, and be shaped to the curb section.

4.8—Striping

When concrete is striped, it is important to have a clean surface, free of dirt, loose materials, laitance, grease, and oil. The striping materials should be applied in accordance with the manufacturer's recommendations and be compatible with the curing compound used.

4.9—Opening to traffic

Automobile traffic should not be allowed on the slab for three days, and all other traffic should be kept off the slab for at least seven days. However, this assumes normal summer temperatures [above 60 F (15 C)]. In colder weather, more time should be allowed. Alternatively, tests may be made to determine that the concrete has gained adequate strength [usually 3000 psi (21 MPa)] to resist damage from equipment.

CHAPTER 5—INSPECTION AND TESTING

5.1—Introduction

The scope of the inspection and testing program for any given project is most often stipulated in the project specifications. Even on small projects, an adequate quality-assurance program can be developed. The inspection and testing program should be designed so that it ensures compliance with the contract requirements but does not add unnecessary costs or delays during the construction process. See ACI 311.4 R for guidance on development of the inspection and testing program.

While the contractor is the one who bears the full responsibility for compliance with all contract requirements, the owner may feel justified in hiring testing and inspection services on some projects to monitor contract compliance. The agency providing these services should be accredited and in

full compliance with ASTM C 1077 and E 329. These services may vary from occasional visits to full-time inspection. This chapter is intended to describe complete inspection services where the project is large enough to warrant them. On other projects, the services can be scaled down as the owner and the parking lot designer deem appropriate. ACI SP-2 is a good reference for both the contractor and inspector.

5.2—Subgrade preparation

Subgrade inspection is an important part of any concrete parking lot construction project. The subgrade is the foundation upon which the concrete is supported. Poor preparation of the subgrade can result in detrimental effects on performance. Pavement thickness is based on subgrade support capacity when it has been compacted as specified. The soils at the parking lot site and the intended borrow areas should be observed and, if necessary, sampled and tested to confirm the soil types and identify any problem conditions that may require special treatment, such as stabilization or removal. If the soils to be used are different from those that were expected based on the design investigation, they should be tested to determine their supporting capacities and necessary compaction requirements. At the start of construction, the moisture content and the moisture-density relationships for the soils to be used in the subgrade should be checked to aid in determining the amount of water that needs to be added to the soil or the amount of drying necessary to achieve the required compaction. In-place density tests should be performed to confirm that the contractor is obtaining the required compaction. A full-scale testing program may require at least one test per 2000 yd² (1670 m²) of area per 6 in. (150 mm) lift, with a minimum of three tests per lift in accordance with ASTM D 698.

Subgrade elevations should be checked throughout the grading operations to verify that the grades are correct. The final elevation should allow forms and stringlines to be set within the specified tolerances.

5.3—Concrete quality

Ensuring that the concrete meets the specified quality can be accomplished if all parties have an understanding with the concrete supplier and the contractor as to everyone's concerns before the paving operations begin. An inspector may wish to visit the concrete production facility and look at the batching equipment and the delivery trucks to verify that they meet the requirements for the project. Current certification of plant and equipment in accordance with a recognized program, such as that of the National Ready Mixed Concrete Association, can preclude such a visit. The sources and types of aggregates, cement, and admixtures should be identified. The production facility should have the capability to check aggregate gradations daily as well as the capability to periodically check the moisture contents of the aggregates and adjust the batch proportions as necessary. The information required on the delivery tickets by ASTM C 94 and the distribution of these tickets should be confirmed. The location and sequence of testing concrete should also be coordinated at this time. The anticipated delivery rates should be discussed. The contractor should give the inspector and the concrete

supplier adequate notice that paving is going to take place to allow them to do their jobs properly.

Checking the properties of the fresh concrete is especially important in the early stages of the project, particularly on a small project that will probably be complete before any of the acceptance strength test results are received. The slump, air content, density, and temperature of the fresh concrete should be checked at least once for every 5000 ft² (460 m²) of pavement and at least once a day. Strength specimens should be molded for testing at the same frequency.

While the design of pavements is generally based on the flexural strength of the concrete, it is more practical to use some other type of test in the field for acceptance testing. Compressive strength or splitting-tensile strength (ASTM C 496) can be correlated with the flexural strength. The correlations required for a project can be determined in the laboratory at the time the concrete mixture is evaluated. The test specimens for acceptance strength testing should be properly stored and cured in accordance with ASTM C 31 before testing, particularly during the first 24 h. All test results should be recorded and reported to the contractor and supplier as soon as possible so that any problems can be corrected in a timely manner. While most concrete is accepted based on the strength at 28 days determined with standard-cured cylinders, it may be necessary to test field-cured specimens at earlier ages to determine when the pavement has adequate strength to allow traffic on it. It is essential that the contractor does not allow traffic on the pavement until it has adequate strength and curing. This determination should be made by the engineer or owner's representative. The required curing time can be estimated, based on prevailing temperatures and experience, but a more accurate determination can be made using field-cured cylinders. See Section 4.9.

The performance of all sampling, testing, and inspection should be in accordance with standardized procedures that are spelled out in the project specifications. The specifier should require that all sampling and testing be performed by personnel who have met the requirements of the appropriate ACI or equivalent certification program and have proof of certification.

5.4—Construction operations

It is important to check stripping of topsoil and vegetation in both the borrow areas and in the parking lot areas to confirm that undesirable amounts of organic materials are not incorporated in the subgrade. Proofrolling all areas to receive fill, as well as those areas that have been cut, should be conducted to confirm that adequate subgrade support is available for filling operations and in cut areas. The proofrolling should be accomplished with a minimum 7-1/2 ton (6800 kg) roller or loaded dump truck with equal weight, and any areas that are observed to deflect greater than 1/2 in. (13 mm), should be stabilized or removed and replaced with well-compacted materials. If rutting or pumping is evident during the preparation of the subgrade, corrective action should be taken. Rutting normally occurs when the surface of the base is wet and the underlying soils are firm. Pumping normally occurs when the surface of the base is dry and the underlying soils are wet.

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The spreading of the fill materials should be checked to confirm that the lifts are thin enough to be compacted as required by the project specifications. The final elevations of the subgrade should be carefully checked to verify that the grades are true and that there are no high spots that will result in thin areas in the concrete slab. No grading work should be accomplished when the subgrade is wet or frozen.

If a granular aggregate subbase is specified, it should be of proper gradation to allow the material to be spread with minimal segregation and to allow compaction to the grades specified. The in-place moisture content and density of the granular base course should be determined in a manner and frequency similar to that specified for the subgrade if the material lends itself to density testing. If the granular base is a well-draining and open-graded material, then conventional density testing is not applicable. A heavy vibrating roller should be used to ensure that such materials have been adequately set.

Before placing concrete, forms should be checked to see that they are at the proper elevation and that they have the proper alignment. If forms are not used in small or irregularly shaped areas, a series of construction stakes driven in the subgrade can be used to provide the contractor with the necessary elevation references. The construction stakes should be driven into the subgrade to the top of the slab elevations at various locations. Proper control is critical because insufficient thickness due to poor grade control can be a serious deficiency.

The concrete arriving at the job site should be tested as outlined in Section 5.3. Adjustments to the mixture should not be made unless approved by the engineer or owner's representative.

It is also important to check that the curing compound is placed or curing actions are taken as soon as the concrete has attained final setting. The curing procedures should cover all of the concrete placed. If joints are tooled or formed with pre-molded inserts, proper alignment should be verified. If sawing is to be used, the concrete should be checked periodically to see when joints can be cut. Finally, it is essential that the contractor does not allow traffic on the pavement until it has achieved adequate strength and curing. See Section 4.9 and 5.3.

Even with the best construction techniques, there may be occasional cracks. As long as load transfer can be maintained across these occasional cracks, these panels should be acceptable. As long as the parking lot slab is still structurally sound, it will not be worthwhile to resort to slab removal to improve the aesthetics of the parking lot. Workmanship defects, such as over-finishing, can be very important if durability is affected, but not if the only result is some variation in surface texture. Whether or not variations in texture or appearance are serious enough to warrant remedial action or replacement is strictly subjective.

CHAPTER 6—MAINTENANCE AND REPAIR

6.1—Introduction

Concrete parking lot pavements generally perform for many years with minimal maintenance and few repair costs. There are exceptions, however, and well-intended designs and con-

struction efforts may result in failures and distress. This chapter provides guidance on acceptable maintenance procedures and repair techniques for concrete parking lot pavements.

6.2—Surface sealing

The deterioration of parking lot pavements caused by deicing chemicals and moisture intrusion can be a serious problem in freezing-and-thawing environments. Proper air entrainment and adequate curing are essential before the surface is exposed to deicing chemicals and freezing-thawing cycles. If these steps are neglected, durability may be affected.

If concrete starts to show signs of poor durability, protection is necessary because surface spalling from freezing-thawing action and steel corrosion from salt intrusion can result. Research studies and field trials indicate that there are several protective coatings available that protect against salt attack on concrete pavements. It is imperative to use a sealer that allows water vapor to escape from the pavement. Perhaps the most economical protective coating with the longest history of use is a mixture of 50% boiled linseed oil and 50% mineral spirits. Rates of application for this mixture should be the same as given in Section 4.6.2. Some recent studies have shown that the boiled linseed oil/mineral-spirits mixture is not effective in protecting concrete for long periods of time (Concrete 1981). There is also a darkening of the concrete caused by the linseed oil mixture.

Other materials are suitable for protecting concrete, including acrylics, epoxies, urethanes, methylmethacrylates, and siloxane/silane water repellents. The siloxane/silane repellents have the advantage of allowing the substrate to dry out normally, therefore preventing damage from a buildup of moisture below the film-forming material. They have also been proven effective in restricting chloride ion penetration, protecting the concrete from deicing chemicals in northern states and airborne salt in marine and coastal areas.

In the case of proprietary products, independent testing laboratory documentation is suggested to establish conformance with ASTM C 672, ASTM E 303, AASHTO T 259, AASHTO T 260, and NCHRP 244 (II & IV) (Concrete 1981).

Before specifying one of these products, its performance under similar conditions of use should be determined. Application should always be in accordance with the manufacturer's instructions.

Before applying any sealer, the concrete should be cleaned by pressure washing or other means recommended by the product manufacturer and allowed to dry for at least 24 h at temperatures above 60 F (15 C) and humidities below 60%. Some old, especially dirty, concrete may require a more aggressive preparation of the surface.

6.3—Joint and crack sealing

Joints in concrete parking lots are frequently sealed, but in many successfully performing parking lots the joints are not sealed. Close joint spacing and proper drainage will minimize the infiltration of water through joints into the subgrade. Light traffic (less than 100 trucks per day) will not cause pumping of unsealed joints under most conditions. Pumping is not usually an issue with automobile traffic.

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In the event that poor subsoil conditions and heavy truck traffic (more than 100 trucks per day) warrant extra precautions, either cold-poured or hot-poured sealing materials can be used to seal the joints. Preformed materials, common in highway pavements, are seldom used in parking lots.

Refer to ACI 504R for selecting the proper joint sealants. Before sealing, the joint opening should be thoroughly cleaned with compressed air to remove all foreign matter. All contact faces of the joint should be cleaned to remove loose material and should be surface dry when hot-poured sealing materials are used. Sealing materials should be carefully installed so that sealants will not be spilled on exposed concrete. Any excess material on the surface of the concrete should be removed immediately and the pavement surface cleaned. Manufacturers' instructions for mixing and installing the joint materials should be followed explicitly. The top of the sealing compound is normally 1/8 in. to 1/4 in. (3 mm to 6 mm) below the adjacent concrete surface. Cracks can be routed (widened and deepened using special bits) and sealed. This will reduce concrete spalling at the crack faces and reduce water penetration. Chapter 3.3 of ACI 224.1R offers detailed guidance on routing and sealing cracks. Often it is more cost effective to remove and replace badly cracked panels than to attempt crack repair.

6.4—Full-depth repair

The most effective repair method for badly cracked and deteriorated pavement panels is full or partial replacement. It is important to determine and correct the cause of the slab failure before starting repairs. Localized subgrade problems should be corrected. If the pavement panels failed because of heavier than anticipated loads, replacement panels should be thickened to provide additional load-carrying capacity.

6.4.1 Repair location and joint types—The engineer should determine the boundaries and joint type for each repair. For parking lots carrying light traffic, a rough-faced joint that relies on aggregate interlock for load transfer is adequate. Repairs in parking lots carrying heavy truck or bus traffic should be doweled to the existing pavement. Repair boundaries should be selected so that all of the underlying deterioration is removed. Minimum length for undoweled repairs is 6 ft (2 m). The repair should not be less than half the panel width.

6.4.2 Preparation of the repair area—Preparation requires sawing boundaries if they do not follow existing joint patterns. Partial-depth cuts, approximately 50% of the pavement thickness, are recommended, followed by removal of all concrete with pneumatic tools. This procedure is less expensive than full-depth cutting and provides some aggregate interlock due to a rough face. Concrete to be removed should be broken up with a pavement breaker or jackhammer. Wrecking balls should not be used, because shock waves will damage adjacent concrete. Breakup should begin at the center of the repair area, not at saw cuts. Broken concrete can be removed with a backhoe.

After the concrete has been removed, the subgrade should be examined to determine its condition. All material that has been disturbed or that is loose should be removed and re-

placed with similar or improved materials. If standing water exists in the repair area, it should be removed and the subgrade dried before new concrete is placed.

It is difficult to obtain adequate compaction of new subgrade or base materials in a confined repair area. Replacement of the deteriorated subgrade with concrete or controlled low-strength material (see ACI 229R) can be the best alternative.

6.4.3 Dowels—If dowels are required, they can be installed by drilling holes into the exposed face of the existing slab. A quick-setting, nonshrinking mortar or a high-viscosity epoxy should be used to grout the dowels into the existing slabs.

If panel joints include dowels or ties from the original slab, they should be straightened or realigned as necessary for correct positioning.

6.4.4 Concrete placement—The concrete placement and finishing techniques should follow acceptable procedures found in previous sections of this document. Extra attention should be given to ensure that the repair is well vibrated around the edges and that it is not overfinished. If the repair will be opened to traffic early, consideration should be given to the use of specially designed, high-early strength concrete mixtures. Repairs should be properly cured to ensure satisfactory performance.

6.5—Undersealing and leveling

Loss of support beneath concrete pavement slabs is a major factor in accelerating deterioration. Loading is also a factor in this type of deterioration. Generally, pavements carrying less than 100 heavy trucks per day are not subject to pumping and loss of subgrade support. This type of failure may, however, occur in truck and bus parking lots constructed on poor subgrade. Techniques for injecting grout mixtures under the slab to restore subgrade support and leveling depressed slabs (Techniques 1984) may be used as a maintenance procedure for parking lots. The cost of undersealing and leveling should be compared with the cost of full-depth repairing.

6.5.1 Undersealing—A variety of grout mixtures, including cement/loam top soil slurry, cement/limestone dust slurry, cement/pozzolan slurry, and cement/fine-sand slurry have been used. Success of cement grout undersealing depends upon the experience of the contractor. Undersealing of parking lot pavement should be performed on a localized basis. Jointed concrete pavements typically pump at joints and medium to high severity transverse cracks. Holes are drilled through the slab approximately 2 ft (.60 m) away from the joint or crack. The grout mixture is carefully pumped under the slab to fill voids. Care should be taken not to raise the slab above grade. Traffic should be kept off the slab long enough to allow for adequate curing.

6.5.2 Leveling—Leveling, or slab-jacking, consists of pumping cement grout under pressure beneath the slab to raise the slab slowly until it reaches the desired elevation. Settlement can occur anywhere along the pavement but is usually associated with fill areas.

Experience is important in determining the best location for grout holes. A general guideline is that the holes should be placed in about the same location as hydraulic jacks
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would be placed if it were possible to get them under the pavement. Holes should be placed not less than 12 in. (300 mm) or more than 18 in. (450 mm) from slab edges or transverse joints. Distance between holes should not be more than 6 ft (2 m). A taut stringline secured at least 10 ft (3.0 m) from the end of the depression should be used to monitor the raising of the slab as the grout is injected. To minimize cracking, no portion of the slab should be raised more than 1/4 in. (6 mm) at a time. Once the slab has been raised to proper position, traffic should be kept off until the grout has set.

6.6—Overlay

Both concrete and asphalt parking lot pavement can be rehabilitated with concrete overlays. To ensure satisfactory performance of the overlay, factors that caused the deterioration and failure of the original pavement should be determined and either corrected or recognized in the design of the concrete overlay. Parking lot pavement failures can usually be attributed to one or more of the following factors: drainage problems, traffic overload, subgrade conditions, inadequate pavement section, poor construction, inadequate mixtures, or substandard materials.

6.6.1 Concrete overlay on existing concrete parking lot pavement—Portland cement concrete overlays on existing parking lots will normally be jointed, although continuously reinforced overlays might be considered for lots carrying large volumes of heavy vehicles. Jointed overlays can be unbonded, partially bonded, or fully bonded. Figure 6.1 summarizes overlay design procedure. Joints in overlays should always match joints in bonded and partially bonded overlays. Cracks in existing pavements will tend to reflect through fully or partially bonded concrete overlays.

6.6.1.1 Unbonded overlays—Unbonded overlays are achieved only if steps are taken to prevent bonding of the overlay to the existing slab. Asphalt concrete has been used for this purpose. There is evidence, however, that layers of asphalt of less than 1 in. (25 mm) do not provide an adequate bondbreaker for completely independent action of the slabs. Unbonded overlays are suitable for existing concrete pavements that are badly broken.

6.6.1.2 Partially bonded overlays—Partially bonded overlays result whenever fresh concrete is placed directly on relatively sound, clean existing slabs. Unless steps are taken to prevent bond, it is usually assumed some degree of bond will be achieved between the overlay and the existing pavement, so the overlay is assumed to be a partially bonded overlay. This is probably the most practical way to overlay parking areas.

6.6.1.3 Fully bonded concrete overlay—To achieve a fully bonded overlay, it is necessary to carefully prepare the surface of the existing pavement before placing the overlay. This preparation should include removing all oil, grease, surface contaminants, paint, and unsound concrete.

In addition to cleaning the surface, a grout made from sand and cement or neat cement may be placed on the cleaned dry surface in front of the overlay operation. The grout can be broomed or applied with a high-pressure sprayer, and it should be applied to completely dry pavement surfaces. The concrete

Table 6.1—Support modulus of existing pavement

Subgrade k , pci	Support modulus k_m , pci*			
	Existing pavement thickness, surface + base course, in. (mm)			
	4 in. (100 mm)	6 in. (100 mm)	9 in. (225 mm)	12 in. (300 mm)
50	75	85	120	170
100	140	160	210	280
200	230	270	350	510
300	330	370	460	600

* k value units can be also expressed as psi/in.

Note: For thickness conversion to SI units, see Appendix E.

high-temperature changes (such as, early spring and late fall), or they can experience early debonding problems.

Fully bonded overlays should be used only when the existing pavement is in good condition or where serious distress has been repaired. Joints in the overlay should be sawed directly above the joints in the existing slab as soon as possible. The joint should be cut completely through the overlay to avoid secondary cracking (ACI 325.1R).

6.6.2 Concrete overlay on asphalt pavement—The thickness required for a concrete overlay on an existing asphalt pavement is a function of the type and volume of traffic, strength of the subgrade below the new overlay, and the properties of the concrete used. The improved strength of the subgrade is attributable to the asphalt and can be estimated using Table 6.1 (Design 1985). Once the support modulus is determined, the same thickness design, joint layout, and construction procedures described in previous chapters should be followed.

Areas of the parking lot that exhibit excessive deterioration and serious failure should be considered for special treatment before they are resurfaced. Special treatments could involve subgrade strengthening, improved drainage or replacement of the asphalt in the affected area.

6.7—Parking lot cleaning

Oil and grease dripping from vehicles can cause unsightly dark stains on concrete parking areas. Generally, petroleum stains do not harm the concrete or cause deterioration. Given enough time, oxidation and weathering will make the stain less noticeable. If the stains are aesthetically unacceptable, there are several physical and chemical methods that can remove oil and grease from concrete (Removing 1984). If the stains are particularly heavy or jelled, scrape off as much residue as possible before further cleaning. Dry portland cement or other absorbent materials can be used to absorb wet oil before starting other cleaning operations.

6.7.1 Abrasive blasting—Sand- or shot-blasting are effective means of removing some stains from concrete parking lots. (Shot-blasting will not remove heavy grease.) Blasting is less time consuming than chemical methods. It will remove approximately 1/16 in. (2 mm) of the concrete surface. Blasting should be done by a specialty contractor and can be more expensive than chemical cleaning. High-pressure water equipment can also be effective.

6.7.2 Chemical cleaners—There are a variety of commercial driveway cleaners available. Many contain sodium FDA, Inc.

metasilicate and petroleum distillate. Generally, these cleaners are poured over the area to be cleaned and scrubbed in with a stiff brush. Rinsing the surface with water removes the cleaner and oil stains.

Scrubbing the stain with a strong soap solution, scouring powder, or trisodium phosphate (TSP) will also remove oil and grease.

For particularly stubborn stains, spread a stiff paste of 5% sodium hydroxide (NaOH) solution mixed with ground limestone over the discolored area. After 24 h, the paste can be scraped off and the area thoroughly rinsed with warm water.

Proper protective clothing should be worn when sand-blasting or using chemical cleaners.

CHAPTER 7—REFERENCES

7.1—Referenced standards and reports

The documents of the various standards-producing organizations referred to in this document are listed below with their serial designations. The users of this document should check directly with the sponsoring group if it is desired to refer to the latest revision.

AASHTO

- T 259 Resistance of Concrete to Chloride Ion Penetration
- T 260 Sampling and Testing for Total Chloride Ion in Concrete and Concrete Raw Materials

ACI

- 121R Quality Management System for Concrete Construction
- 201.2R Guide to Durable Concrete
- 211.1 Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete
- 221R Guide for Use of Normal Weight and Heavyweight Aggregates in Concrete
- 224.1R Causes, Evaluation, and Repair of Cracks in Concrete
- 229R Controlled Low-Strength Materials
- 304R Guide for Measuring, Mixing, Transporting, and Placing Concrete
- 305R Hot Weather Concreting
- 306R Cold Weather Concreting
- 308 Standard Specification for Curing Concrete
- 311.4R Guide for Concrete Inspection
- 311.5R Concrete Plant Inspection and Field Testing of Ready-Mixed Concrete
- 325.1R Design of Concrete Overlays for Pavements
- 504R Guide to Sealing Joints in Concrete Structures
- SP-2 Guide for Concrete Inspection

ASTM

- A 185 Specification for Steel Welded Wire Fabric, Plain, for Concrete Reinforcement
- A 497 Specification for Steel Welded Wire Fabric, Deformed, for Concrete Reinforcement
- A 615 Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement
- A 616/ Specification for Rail-Steel, Deformed

- A 616M Plain Bars for Concrete Reinforcement
- A 617 Specification for Axle-Steel Deformed and Plain Bars for Concrete Reinforcement
- A 706 Specification for Low-Alloy Steel Deformed Bars for Concrete Reinforcement
- A 820 Specification for Steel Fibers for Fiber Reinforced Concrete
- C 31 Standard Practice for Making and Curing Concrete Test Specimens in the Field
- C 33 Specification for Concrete Aggregates
- C 78 Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
- C 94 Specification for Ready-Mixed Concrete
- C 150 Specification for Portland Cement
- C 260 Specification for Air-Entraining Admixtures for Concrete
- C 293 Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading)
- C 309 Specification for Liquid Membrane-Forming Compounds for Curing Concrete
- C 494 Specification for Chemical Admixtures for Concrete
- C 496 Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens
- C 595 Specification for Blended Hydraulic Cements
- C 618 Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete
- C 672 Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals
- C 685 Specification for Concrete Made by Volumetric Batching and Continuous Mixing
- C 989 Specification for Ground Iron Blast-Furnace Slag for Use in Concrete and Mortars
- C 1077 Standard Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation
- C 1157 Standard Performance Specification for Hydraulic Cement
- C 1315 Standard Specification for Liquid-Membrane Forming Compounds having Special Properties for Curing and Sealing Concrete
- C 1404 Standard Test Method for Bond Strength of Adhesive Systems Used with Concrete as Measured by Direct Tension
- D 698 Test Methods for Moisture-Density Relations of Soils and Soils Aggregate Mixtures, Using a 5.5 lb Rammer and 12 in. Drop
- D 994 Specification for Preformed Expansion Joint Filler for Concrete Bituminous Type
- D 1751 Standard Specification for Preformed Expansion Joint Filler for Concrete Paving and Structural Construction (Nonextruding and Resilient Bituminous Types)
- D 1752 Standard Specification for Preformed Sponge Rubber and Cork Expansion Joint Fillers for Concrete Paving and Structural Construction
- D 1883 Standard Test Method for CBR (California Bearing Ratio) Laboratory—Compacted Soils
- D 2487 Test Method for Classification of Soils for Engineering Purposes
- D 3282 Practice for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes
- D 3406 Standard Specification for Joint Sealant, Hot-Applied, Elastomeric-Type, for Portland Cement Concrete Pavements
- D 4318 Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
- E 303 Measuring Surface Frictional Properties using the British Pendulum Tester
- E 329 Agencies Engaged in the Testing and/or Inspection of Materials Used in Construction
- TT-S-001543a (COM-NBS) Sealing Compound: Silicone Rubber Base (for Caulking, Sealing and Glazing in Buildings and Other Structures)
- TT-S-00230c (COM-NBS) Sealing Compound, Elastomeric Type, Single Component (for Caulking, Sealing and Glazing in Buildings and Other Structures)

These publications may be obtained from the following organizations:

American Concrete Institute
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ASTM International
100 Barr Harbor Dr.
West Conshohocken, PA 19428

Federal Specifications
Business Service Center
General Services Administration
7th and D Street SW
Washington, DC 20407

7.2—Cited references

AASHTO Guide for Design of Pavement Structures, 1993, American Association of State Highway and Transportation Officials, Washington, D.C., 464 pp.

"AASHTO Road Test: Report 5—Pavement Research," 1962, *Special Report* No. 61E, Highway Research Board, Washington D.C., 252 pp.

"Airport Pavement Design and Evaluation," 1978, *Advisory Circular* No. 150/5320-6C, Federal Aviation Administration, Washington D.C., Dec., 159 pp.

Brokaw, M. P., 1973, "Effect of Serviceability and Roughness at Transverse Joints on Performance and Design of

Plain Concrete Pavement,” *Highway Research Record* No. 471, Highway Research Board, pp. 91-98.

“Concrete Industrial Driveways,” 1969, *Concrete Information* No. IS016.05P, Portland Cement Association, Skokie, Ill., 7 pp.

“Concrete Safety Barrier and Curb Manual,” 1979, *Publication* No. 7912, American Concrete Pavement Association, Arlington Heights, 52 pp.

“Concrete Sealers for Protection of Bridge Structures,” 1981, *NCHRP Report* No. 244, Transportation Research Board, Washington D.C., Dec., 128 pp.

“Design of Concrete Overlays (Whitetopping) for Asphalt Parking Lots,” 1985, *Publication* No. PA153.01P, Portland Cement Association, Skokie, Ill., 8 pp.

“Design of Non-Reinforced Concrete Pavements by the Brokaw Method,” 1978, *Engineering Bulletin*, Canadian Portland Cement Association, Winnipeg, Manitoba, Sept., 15 pp.

“Distributed Steel for Concrete Pavement,” 1955, *Concrete Information* No. IS114.01P, Portland Cement Association, Skokie, Ill., 3 pp.

“Guide for the Analysis and Selection of Alternate Pavement Types Using the AASHTO Performance Equation,” 1982, *Publication* No. 8302, American Concrete Pavement Association, Arlington Heights, Ill., 33 pp.

“How Big is a Truck—How Sharp Does it Turn,” 1974, Operations Council, American Trucking Association, Washington D.C., 33 pp.

“How to Plan Parking Areas,” 1974, *Catalog* No. PPA-2, Federal Sign and Signal Corporation, Park Forest South, Ill., May, 15 pp.

Holtz, W. G., and Gibbs, H. J., 1957, “Engineering Properties of Expansive Clays,” *Transactions*, ASCE, V. 121.

“Joint Design for Concrete Highway and Street Pavements,” 1975 (Revised 1980), *Concrete Information* No. IS059.03P, Portland Cement Association, Skokie, Ill., 13 pp.

“Pavement Analysis Software,” 1993, *MC016P*, American Concrete Pavement Association, Skokie, Ill.

“PCAPAV, Thickness Design of Highway and Street Pavements,” 1985, *Computer Program* MC003.01X, Portland Cement Association, Skokie, Ill.

Publication 1281, 1965, National Academy of Sciences, National Research Council, Washington, D.C.

Raphael, J. M., 1984, “Tensile Strength of Concrete,” *ACI JOURNAL*, V. 81, No. 2, Mar.-Apr., pp. 158-165.

“Recommended Guidelines for Parking Geometrics,” 1989, *Publication* No. 8002-89, National Parking Association, Washington D.C., Aug., 31 pp.

“Removing Oil Stains from Concrete Pavements,” 1984, *Promotion Pointers* No. 235, National Ready Mixed Concrete Association, Silver Spring, Jan., 2 pp.

“Shipper-Motor Carrier Dock Planning Manual,” 1973, (*ANSI MH8.1-1973*), May, Operations Council, American Trucking Association, Washington D.C., May, 69 pp.

“Subgrades and Subbases for Concrete Pavements,” 1995, *Concrete Paving Technology TB011.02P*, American Concrete Paving Association.

“Techniques for Pavement Rehabilitation,” 1984, *Training Course Manual, Participant's Notebook*, U.S. Department of Transportation, Federal Highway Administration, Washington D.C., June.

ment of Transportation, Federal Highway Administration, Washington D.C., June.

“Thickness Design for Concrete Highway and Street Pavements,” 1984, *Engineering Bulletin* No. EB109.01P, Portland Cement Association, Skokie, Ill., 46 pp.

“Thickness Design for Concrete Highway and Street Pavements, Canadian Edition/Metric,” 1984, *Engineering Bulletin* No. EB209.03P, Portland Cement Association, Skokie, Ill., 44 pp.

Yoder, E. J., and Witzczak, M. W., 1975, *Principles of Pavement Design*, 2nd Edition, John Wiley & Sons, New York, 711 pp.

“Unified Soil Classification System,” 1953, *Technical Memorandum* No. 3-357, Corps of Engineers, U.S. Waterways Station, Vicksburg, Miss.

APPENDIX A—PROCEDURES FOR CONCRETE PAVEMENT DESIGN

A.1—Source of thickness tables

The tables presented in Chapter 2 for selecting the thicknesses of parking lot pavements are based on the Portland Cement Association design method (Thickness 1984). A computer program based on the finite-element method (PCA-PAV 1985) was used to facilitate the calculations, but the thickness can be determined using other methods to calculate the stresses induced in pavement slabs. To illustrate how this can be done, two nomographs were prepared (Fig. A.1 and A.2) to determine the stresses that result from the applications of various single and tandem axle loads to slabs of different thicknesses. The other variable needed to use the nomographs is the modulus of subgrade reaction, or k . Both nomographs were prepared for interior slabs with a load transfer by aggregate interlock on all sides—the prevailing condition in a parking lot.

An iterative process is used to determine the required thickness. First, a trial thickness is assumed. For each class of axle, a line is drawn from the assumed thickness shown on the right ordinate to the diagonal line representing the applied axle load. From there, a line is drawn vertically to the curve representing the subgrade support, and then a line is drawn to the left ordinate to find the imposed stress. The imposed stress divided by the modulus of rupture of the concrete is the stress ratio. This stress ratio can be used with Fig. A.3 to estimate the allowable load repetitions by drawing a horizontal line at the calculated stress ratio and finding the intersection with the PCA curve. From the intersection, a line is drawn downward to the log scale to estimate the total number of those loads that can be applied before the slab fails. The estimated number of loads during the design, live of the slab, is divided by the allowable number of loads to find the percentage of the slab fatigue capacity that has been used. This process is repeated for all anticipated load levels, and the amount of fatigue life that has been used is totaled. A slab is considered to have satisfactory thickness if less than 125% of the fatigue is used. Total fatigue can exceed 100% because the concrete will continue to gain strength beyond the design strength.

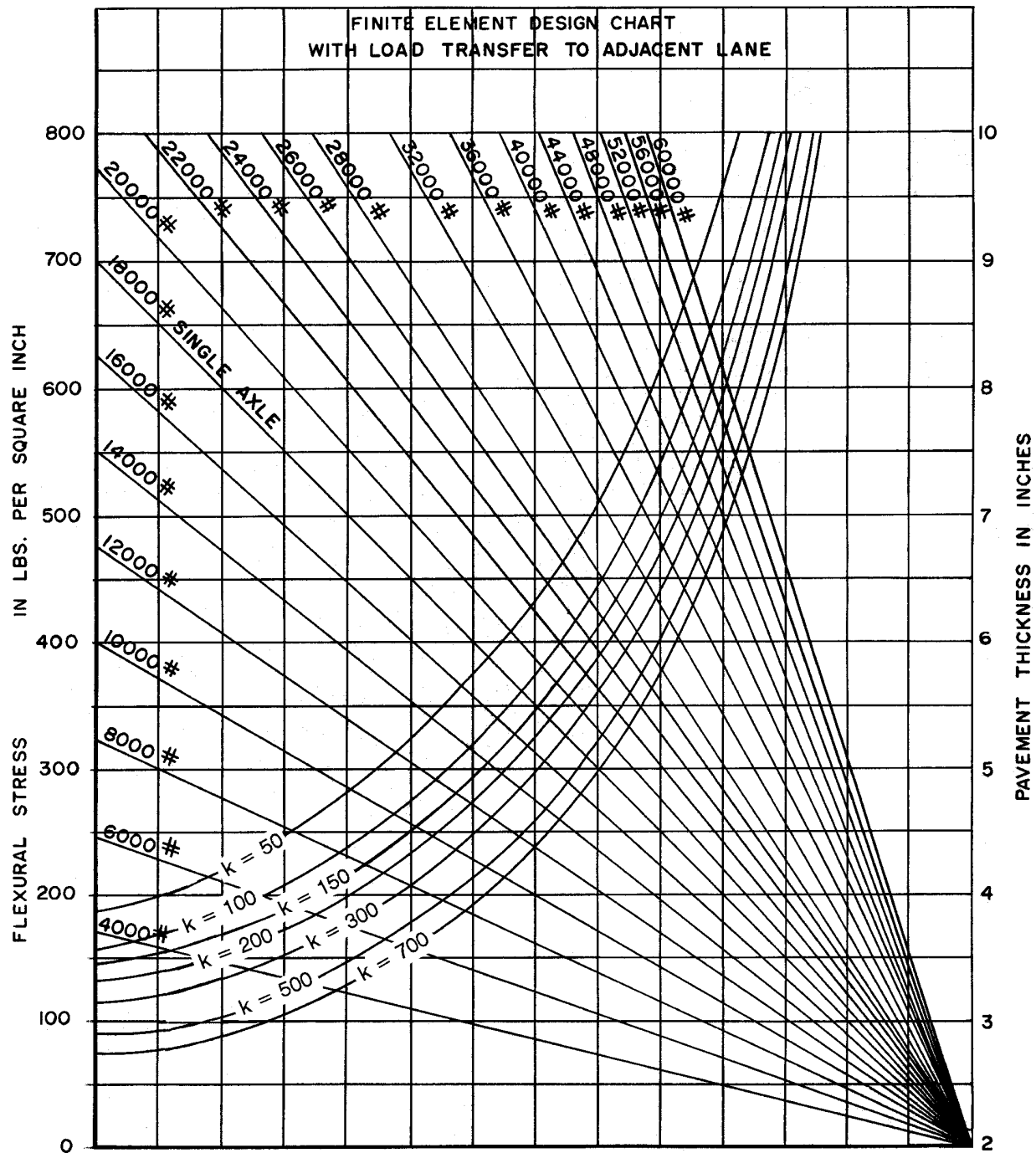


Fig. A.1—Nomograph for estimating flexural stress in slab of given thickness for single axle load.

This procedure is illustrated by the following example:

A driveway is to be built to carry two delivery trucks per day for 20 years. Each truck is expected to have a single front axle with a load of 10 kips (44 kN) and a tandem rear axle of 26 kips (115 kN). The subgrade is a clay with $k = 100$ psi/in (27.2 MPa/m).

2 trucks per day for 20 years =
 $2 \times 20 \times 365 = 14,600$ repetitions
 Assume a 4 in. (100 mm) pavement with $M_R = 650$ psi (4.5 MPa)

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Using the single-axle nomograph, the stress for each front axle is found to be 375 psi (2.6 MPa).

The stress ratio = $\text{stress}/M_R = 375/650 = 0.58$

Using the tandem-axle nomograph, the stress for each rear axle is found to be 405 psi (2.8 MPa).

The stress ratio = $405/650 = 0.62$

From the PCA curve in Fig. A.3, allowable load repetitions for single axles equal 50,000 and for the tandem axles equal 17,500.

Fatigue consumption = expected loads / allowable loads

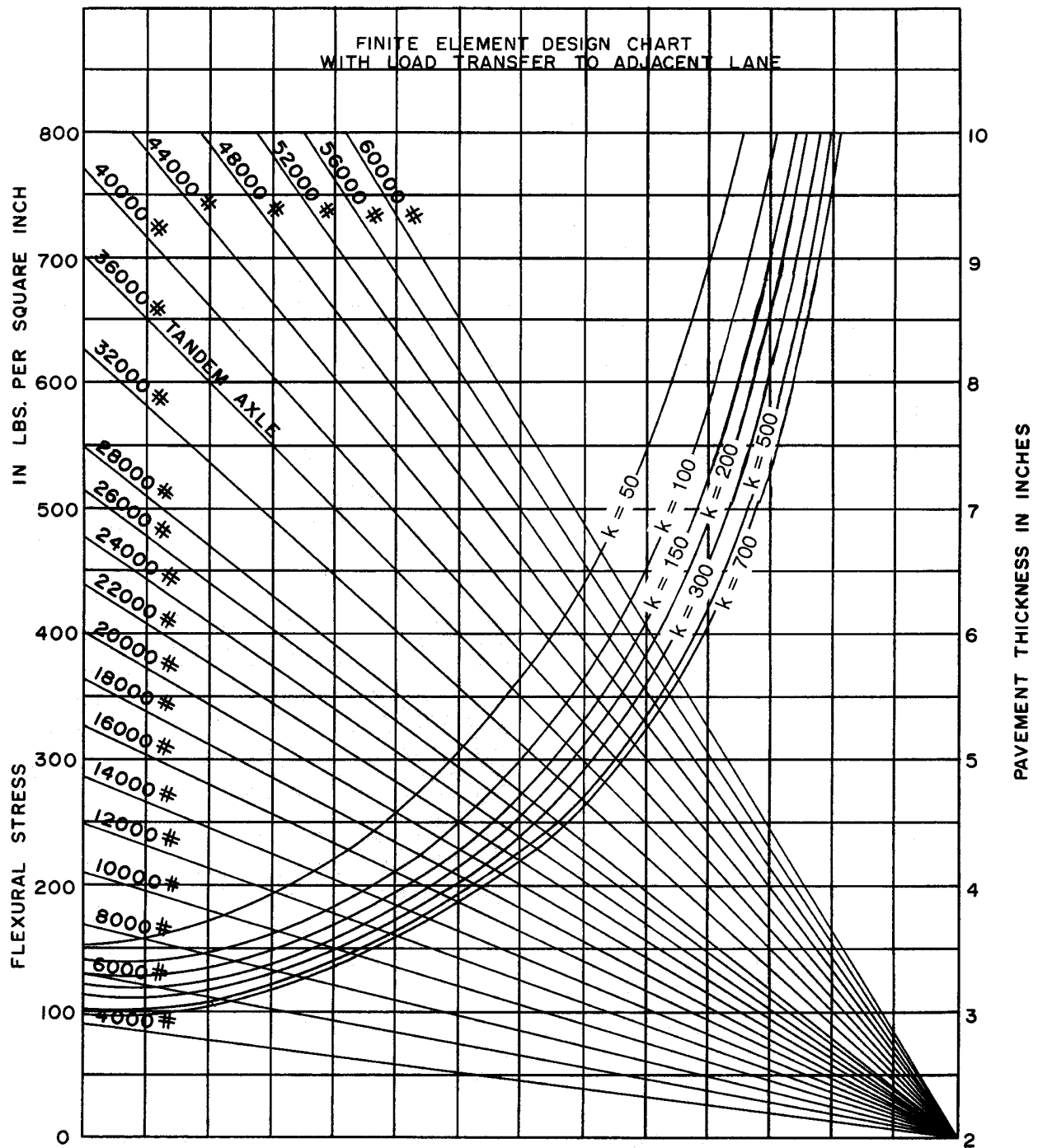


Fig. A.2—Nomograph for estimating flexural stress in slab of given thickness for tandem axle load.

Fatigue consumption, single axles = $14,600/50,000$
= 29%

Fatigue consumption, tandem axles = $14,600/17,500$
= 83%

Total fatigue consumption = 112% (< 125%)

The 4 in. (100 mm) pavement is acceptable.

The computer program (PCAPAV 1985) used to develop Table 2.4 performs iterations similar to this example for the FDA, Inc.

specific input axle-load distributions. The four distributions of vehicles used to set up the five traffic categories in Table 2.3 are shown in Table A.1. Category A is for passenger cars only, and all axle loads are assumed to be less than 4 kips (18 kN). Categories B and C, developed by the Portland Cement Association, are composites of data averaged from several loadometer tables representing appropriate pavement facilities. Category A-1 is the same as Category B, except in Category A-1 the heaviest axle loads have been eliminated. Category D consists only of tractor semitrailer trucks with gross weights of 80 kips (360 kN). The assumed design life used in Table 2.4 was 20 years.

Table A.1—Axle-load distributions used for preparing design Table 2.3 and 2.4

Axle load, kips	Axles per 1000 trucks*			
	Category A-1†	Category B	Category C	Category D
Single axles				
4	1693.31	1693.31	—	—
6	732.28	732.28	—	—
8	483.10	483.10	233.60	—
10	204.96	204.96	142.70	—
12	124.00	124.00	116.76	—
14	56.11	56.11	47.76	—
16	38.02	38.02	23.88	1000
18	—	15.81	16.61	—
20	—	4.23	6.63	—
22	—	0.96	2.60	—
24	—	—	1.60	—
26	—	—	0.07	—
28	—	—	—	—
30	—	—	—	—
32	—	—	—	—
34	—	—	—	—
Tandem axles				
4	31.90	31.90	—	—
8	85.59	85.59	47.01	—
12	139.30	139.30	91.15	—
16	75.02	75.02	59.25	—
20	57.10	57.10	45.00	—
24	39.18	39.18	30.74	—
28	68.48	68.48	44.43	—
32	69.59	69.59	54.76	2000
36	—	4.19	38.79	—
40	—	—	7.76	—
44	—	—	1.16	—
48	—	—	—	—
52	—	—	—	—
56	—	—	—	—
60	—	—	—	—

*Excluding all two-axle, four-tire trucks.

†Category A is passenger cars only.

The other widely-used pavement design method is the AASHTO procedure (AASHTO 1993). This was developed from pavement performance at the AASHTO Road Test, which was conducted during the period of 1958 to 1960. The 1993 AASHTO Guide followed three interim versions of the guide, and it constitutes a major revision of previous versions. The AASHTO Guide contains design procedures and algorithms for construction and reconstruction of rigid and flexible pavements. The rigid pavement design procedure can be used to find the required pavement thickness to carry the design traffic with an acceptable loss in serviceability.

A computer program is also available to implement the AASHTO procedure (Pavement 1993). The program will compute the required pavement thickness for design traffic, or it will analyze a selected thickness for traffic-carrying capacity.

In the AASHTO procedures, all vehicle axle loads are expressed in terms of 18 kips (80 kN) equivalent axles. The guide and computer program include procedures for converting, Inc.

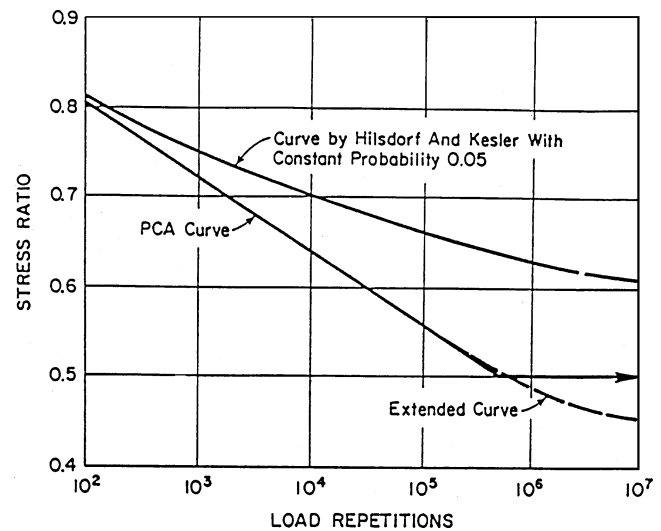


Fig. A.3—Fatigue relationships.

ing single-, tandem-, and triple-axle loads of various magnitudes into 18 kip equivalents.

APPENDIX B—SUBGRADE

B.1—Introduction

The designer should give careful consideration to the specific subgrade soils at the site. Troublesome subgrade conditions should be accommodated in the design. The engineer should make the best use of the soil information available.

B.2—Soil classification

Unlike manufactured products, such as concrete or steel, the properties of subgrade soils are highly variable from site to site and even within a job site. Over time, geotechnical engineers have developed a number of standard classification systems to characterize the engineering properties of soils.

The most commonly used classification is the Unified System, originally developed by Arthur Casagrande and later standardized by ASTM D 2487. In this system, the division point between coarse-grained and fine-grained soils is the No. 200 (0.075 mm) sieve. If more than 50% of the soil passes the No. 200 (0.075 mm) sieve, it is classified as fine-grained. If more than 50% of the soil is retained on the No. 200 (0.075 mm) sieve, it is classified as coarse-grained. Other components of the classification system are the liquid limit (LL) and the plasticity index (PI), which are physical tests to distinguish between silts and clays.

The soils are identified in the Unified System using letter combinations from the following list of letter symbols:

- G = gravel
- S = sand
- M = silt
- C = clay
- W = well graded
- P = poorly graded
- L = low-liquid limit
- H = high-liquid limit
- O = organic

In the AASHTO system, soils are divided into two major groups: granular materials containing 35% or less, passing the No. 200 (0.075 mm) mesh sieve, and clay and clay-silt materials containing more than 35% passing the No. 200 (0.075 mm) mesh sieve. The soil components are further classified as gravel, coarse sand, fine sand, silt, or clay. The final classification parameter is the Group Index (GI), computed from sieve analysis data, the liquid limit (LL), and the Plasticity Index (PI). The AASHTO system and its Group Index formula are described in ASTM D 3282.

Soils described by a unique description of a classification system generally exhibit similar engineering properties, regardless of location. Table B.2 shows general properties for soils classified in the ASTM system.

B.3—Problem soils

Unfortunately, parking lots cannot always be built on coarse-grained soils, which generally provide excellent subgrades. The designer may need to use less-desirable soils that are subject to frost action and soil expansion; therefore, the designer should understand how to minimize problems these soils can cause.

B.4—Expansive soils

Expansive soil types and the mechanisms that cause soil volume change are well-known by geotechnical and highway engineers. Test procedures for identifying expansive soils are also well-known and commonly used. Table B.4 shows the approximate relationships between soil plasticity and expansion. Normally, a soil with a high degree of expansion potential is needed to cause bumps, depressions, or waves in the pavement.

Most soils sufficiently expansive to cause distortion of pavements are in the AASHTO A-5 or A-7 groups. In the Unified Soil Classification system, these soils are classified as CH, MH, or OH. Soil survey maps prepared by the USDA Soil Conservation Service can be helpful in determining soil classifications at the parking lot site. When highly expansive soils are believed to be present, additional soil tests should be used to better define the expected volume changes and subsequent pavement movement.

Expansive soils can be controlled effectively and economically by the following:

- *Subgrade grading operations*—Swelling can be controlled by placing the more expansive soils in the lower parts of embankments and by cross-hauling or importing less expansive soils to form the upper part of the subgrade. Selective grading can create reasonably uniform soil conditions in the upper subgrade and will help ensure gradual transitions between soils with varying volume change properties. In deep cuts into highly expansive soils, a great deal of expansion can occur because of the removal of the natural surcharge load and absorption of additional moisture. Because this expansion usually takes place slowly, it is advisable to excavate deep cuts well in advance of other site grading work.
- *Compaction and moisture control*—Soil volume changes can also be reduced by adequate moisture and

density controls during subgrade compaction. It is very important to compact highly expansive soil at 1 to 3% above optimum moisture content, as determined by ASTM D 698. Expansive soils compacted slightly wet-of-optimum expand less, have higher strengths after wetting, and absorb less water.

- *Nonexpansive cover*—In areas with prolonged periods of dry weather, highly expansive subgrades may require a cover layer of low-volume change soil. This layer will help minimize changes in the moisture content of the underlying expansive soil. A low-volume-change layer with low to moderate permeability is usually more effective and less costly than permeable, granular soil. Highly permeable, open-graded subbase materials are not recommended as cover for expansive soils because they allow more moisture to reach the subgrade.

Local experience with expansive soils is always an important consideration in pavement design.

B.5—Frost action

Field experience with concrete pavements has shown that frost action damage is usually caused by abrupt, differential heave rather than subgrade softening during thawing. Design of concrete pavement projects should be concerned with reducing nonuniformity of subgrade soil and moisture conditions that could lead to differential heaving.

For frost heave to occur, three conditions are required: a frost-susceptible soil; freezing temperatures penetrating the subgrade; and a supply of water. Heaving is caused by the growth of ice lenses in the soil. As freezing temperatures penetrate the subgrade, water from the unfrozen portion of the subgrade is attracted to the frozen zone. If the soil has a high capillary suction, the water moves to ice crystals initially formed, freezes on contact, and expands. If a supply of water is available, the ice crystals continue to grow, forming ice lenses that will eventually lift or heave the overlying pavement. The worst heaving usually occurs in fine-grained soils subject to capillary suction. Low-plasticity soils with a high percentage of silt-size particles (0.05 to 0.005 mm) are particularly susceptible to frost heave. These soils have pore sizes that are small enough to develop capillary suction but are large enough for rapid travel of water to the freezing zone.

To a large degree, frost heave can be mitigated by appropriate grading operations, as well as control of subgrade compaction and moisture content. If possible, grade lines should be set high enough that frost-susceptible soils are above the capillary range of the ground-water table. Pockets of highly frost-susceptible soil should be removed and backfilled with soils like those surrounding the pocket. Fine-grained soils should be compacted slightly wet of ASTM D 698 optimum moisture content. Where high grades are impractical, subgrade drainage or non-frost-susceptible cover should be considered. The thawing of frozen subgrade reduces subgrade support of the pavement. Because rigid pavements distribute loads over large areas, there is usually no damage from these short-term conditions.

Table B.2—Soil characteristics pertinent to parking lot pavements

Major divisions		Letter	Name	Compress- ibility and expansion	Drainage characteristics	Compaction equipment	Typical design values		
							CBR	Subgrade modulus k , pci	
(1)	(2)	(3)	(6)	(11)	(12)	(13)	(15)	(16)	
Coarse- grained soils	Gravel and gravelly soils	GW	Well-graded gravels or gravel-sand mixtures, little or no fines	Almost none	Excellent	Crawler-type tractor, vibratory compactor, rubber-tired roller, steel-wheeled roller	40 to 80	300 to 500	
		GP	Poorly graded gravels or gravel-sand mixtures, little or no fines	Almost none	Excellent	Crawler-type tractor, vibratory compactor, rubber-tired roller, steel-wheeled roller	30 to 60	300 to 500	
		GM	d	Silty gravels, gravel-sand-silt mixtures	Very slight	Fair to poor	Rubber-tired roller, sheepsfoot roller; close control of moisture	40 to 60	300 to 500
			u		Slight	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	20 to 30	200 to 500
		GC	Clayey gravels, gravel-sand- clay mixtures	Slight	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	20 to 40	200 to 500	
	Sand and sandy soils	SW	Well-graded sands or grav- elly sands, little or no fines	Almost none	Excellent	Crawler-type tractor, vibratory compactor, rubber-tired roller	20 to 40	200 to 400	
		SP	Poorly graded sands or grav- elly sands, little or not fines	Almost none	Excellent	Crawler-type tractor, vibratory compactor, rubber-tired roller	10 to 40	150 to 400	
		SM	d	Silty sands, sand-silt mixtures	Very slight	Fair to poor	Rubber-tired roller, sheepsfoot roller; close control of moisture	15 to 40	150 to 400
			u		Slight to medium	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	10 to 20	100 to 300
		SC	Clayey sands, sand-clay mixtures	Slight to medium	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	5 to 20	100 to 300	
Fine- graded soils	Sils and clays, LL < 50	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey sils with slight plasticity	Slight to medium	Fair to poor	Rubber-tired roller, sheepsfoot roller; close control of moisture	15 or less	100 to 200	
		CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Medium	Practically impervious	Rubber-tired roller, sheepsfoot roller	15 or less	50 to 150	
		OL	Organic silts and organic silt-clays of low plasticity	Medium to high	Poor	Rubber-tired roller, sheepsfoot roller	5 or less	50 to 100	
	Sils and clays, LL > 50	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	High	Fair to poor	Sheepsfoot roller, rubber-tired roller	10 or less	50 to 100	
		CH	Inorganic clays of high plasticity, fat clays	High	Practically impervious	Sheepsfoot roller, rubber-tired roller	15 or less	50 to 150	
		OH	Organic clays of medium to high plasticity, organic silts	High	Practically impervious	Sheepsfoot roller, rubber-tired roller	5 or less	25 to 100	
		Highly organic soils		Pt	Peat and other highly organic soils	Very high	Fair to poor	Compaction not practical	—

Notes:

1. Extracted from Corps of Engineers Military Standard 619B, revised.
2. In Column (3), division of GM and SM groups into subdivisions of “d” and “u” are for roads and airfields only. Subdivision is on the basis of Atterberg limits: suffix “d” (such as GM) is used when the liquid limit is 25 or less, and the plasticity is 5 or less; suffix “u” is used otherwise.
3. In Column (13), the equipment listed will usually produce the required densities with a reasonable number of passes when moisture conditions and thickness of lift are properly controlled. In some instances, several types of equipment are listed because variable soil characteristics within a given soil group may require different equipment. In some instances, a combination of two types may be necessary.
4. Units for k value can also be expressed in psi/in.

B.6—Mud-pumping

Mud-pumping is the forced displacement of fine-grained subgrade soil and water from slab joints, cracks, and pavement edges. It is caused by frequent deflection of slab edges by heavy wheel loads. Highway studies have shown that the following three factors are necessary for mud-pumping to occur: a subgrade soil that will go into suspension, free water between the pavement and subgrade or subgrade saturation, and frequent passage of heavy loads (Subgrades 1995).

Normally, pavements that carry less than 200 heavily loaded trucks (18,000 lb [80 kN] axle weights) per day will not be damaged by pumping, especially if speeds are low; therefore, they do not require subbases. Most parking lots do
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not have this traffic volume and, therefore, are not susceptible to mud-pumping.

If a subbase is required, 4 to 6 in. (100 to 150 mm) of well-compacted granular material is normally adequate. Cement, lime, Class C fly ash or other stabilization agents can also be used. Unstabilized subbases have little influence on pavement thickness design. They cannot be economically justified on the basis of reduced pavement thickness in most cases. On the other hand, stabilized subbases improve pavement support and influence pavement thickness.

B.7—Support uniformity

Uniformity of support for a concrete pavement is key to its longevity. Only the most often-used methods for achieving

Table B.4—Approximate relationship between soil plasticity and expansion*

Data from index tests [†]			Probable expansion and total volume change [‡] (due to saturated condition), %	Degree of expansion
Colloid content, % minus 0.001 mm	Plasticity index	Shrinkage limit, %		
28	35	11	30	Very high
20 to 31	25 to 41	7 to 12	20 to 30	High
13 to 23	15 to 28	10 to 16	10 to 20	Medium
15	18	15	10	Low

*Derived from Holtz and Gibbs (1956). Copied from National Academy of Sciences—National Research Council, *Publication 1281* (1965).

[†]All three index tests should be considered in estimating expansive properties.

[‡]Based on a vertical loading of 1.1 lb/in.²

subgrade uniformity will be discussed herein. One of the more common methods is through the use of subgrade moisture control. During the compaction process of soils, either natural to the location or haul-in materials, good control of moisture content is important. For medium- and light-duty traffic, the optimum moisture content and desired compaction characteristics are usually determined by ASTM D 698. Typical variations that should be achieved with fine-grained soils (silts and clays) are moisture contents within 3% of optimum. An exception to this rule is for expansive clays that are more appropriately compacted with the moisture at the upper end of the optimum range and at a density approximately 3% less than would be used for nonexpansive, fine-grained soils.

Subgrade uniformity can also be enhanced with natural subgrade soils by ripping the material to a depth of 4 to 6 in. (100 to 150 mm), adjusting the moisture content, if appropriate, and recompacting at a more uniform moisture and density. Methods of adjusting the moisture content include aeration of the soil, mixing in drier soil, watering, and then discing or blading for uniformity of distribution. None of these procedures require excessive or sophisticated work or equipment.

Compaction uniformity will occur with good moisture contents and watchful operation of compaction equipment. By making approximately the same number of passes on each area of the subgrade, the compaction densities will be similar. With uniform moisture contents, it is possible to obtain compacted densities in a range of $\pm 5\%$ of target density.

Solid rock is not a desirable material for either the establishment of subgrade elevations or as an immediate pavement foundation. The first effort should be to raise the subgrade elevation to avoid the rock. If this is not possible, the rock should be removed to a depth of approximately 6 in. (150 mm) below the pavement subgrade elevation and replaced with compacted soil.

APPENDIX C—SUGGESTED JOINT DETAILS

C.1—Pavement joint details

Pavements are jointed to control cracking due to tensile stresses caused by shrinkage, and by the combined effects of loads and warping, and to facilitate construction. The description and use of the types of joints are discussed in Section 2.7. Figures C.1 to C.6 provide details for the various joint types.

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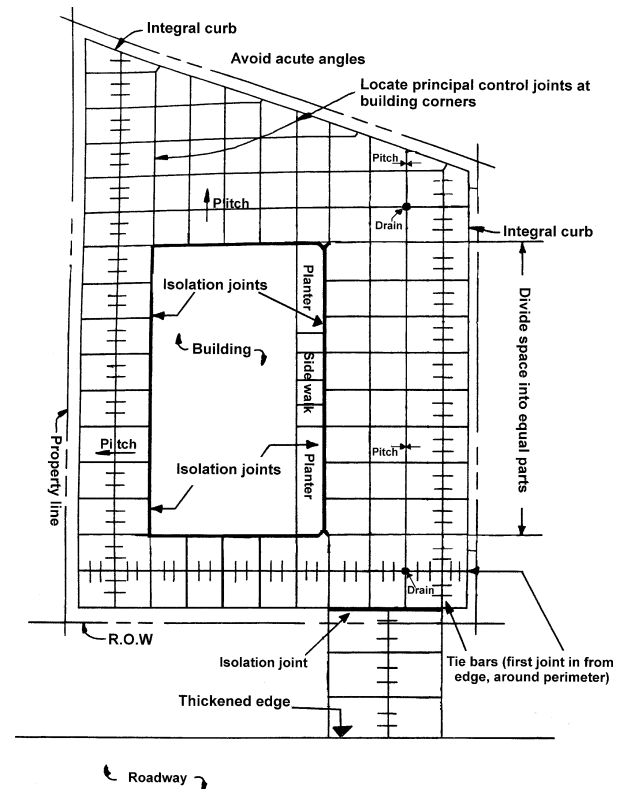


Fig. C.1—Typical joint layout for parking area.

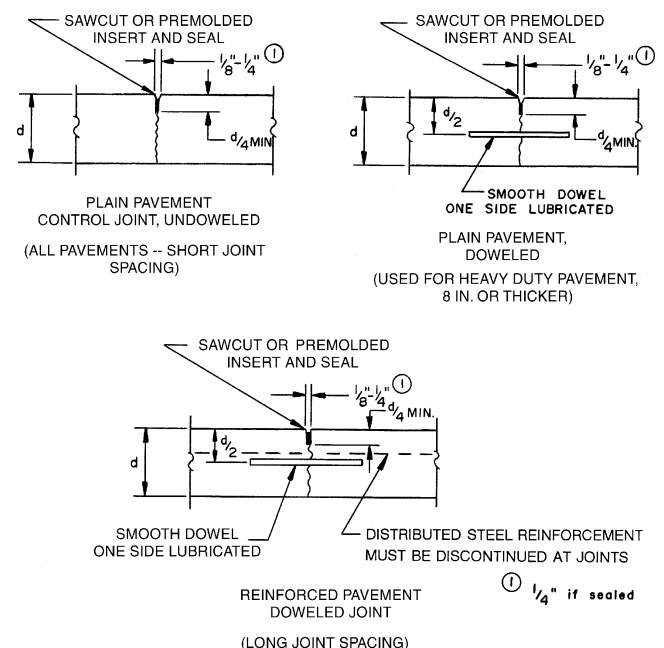
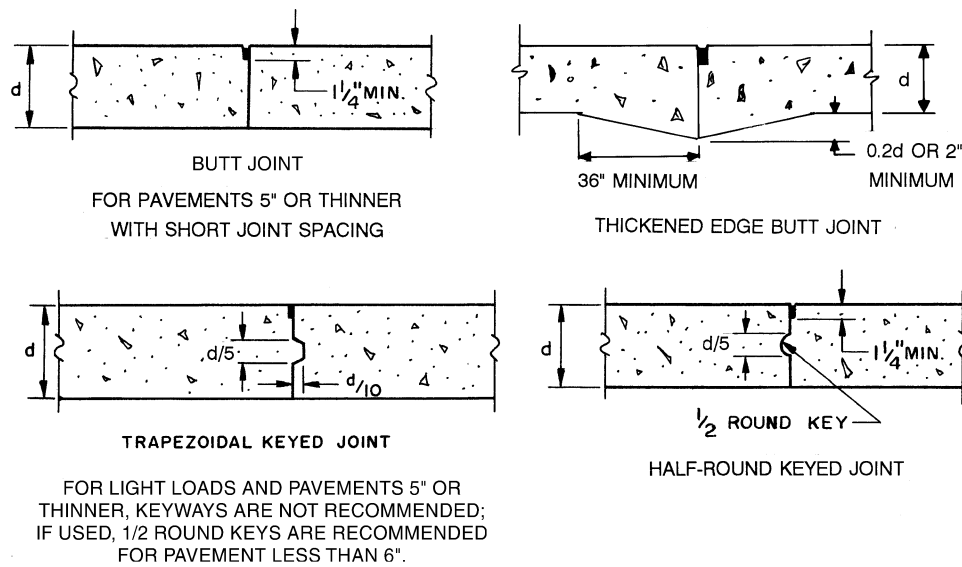


Fig. C.2—Contraction joint details (longitudinal or transverse). Note: for conversion to SI units, see Appendix E.

APPENDIX D—PARKING LOT GEOMETRICS

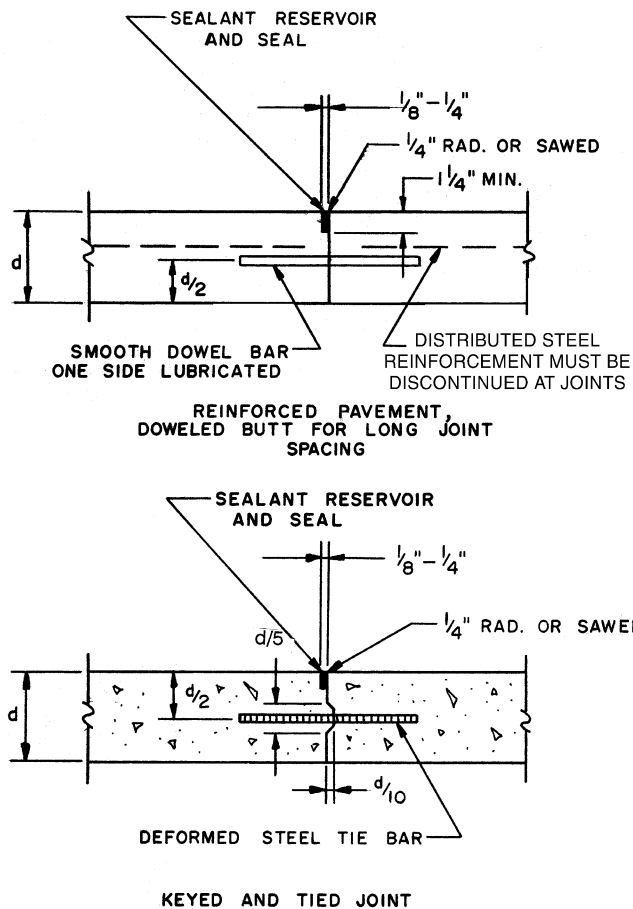
D.1—Parking requirements

Local zoning regulations usually dictate the minimum numbers of parking spaces required for various types of buildings. Many local regulations also specify minimum sizes of parking spaces. The parking space requirements in Table D.1(a) are typical. Table D.1(b) shows dimensions for



All details may require dowels if joint spacing exceeds plain pavement guidelines for spacing.

Fig. C.3(a)—Construction joint details (longitudinal or transverse). Note: for conversion to SI units, see Appendix E.



Use only in middle third of normal joint interval for lane-at-a-time longitudinal lane paving

Fig. C.3(b)—Construction joint details (longitudinal or transverse). Note: for conversion to SI units, see Appendix E.
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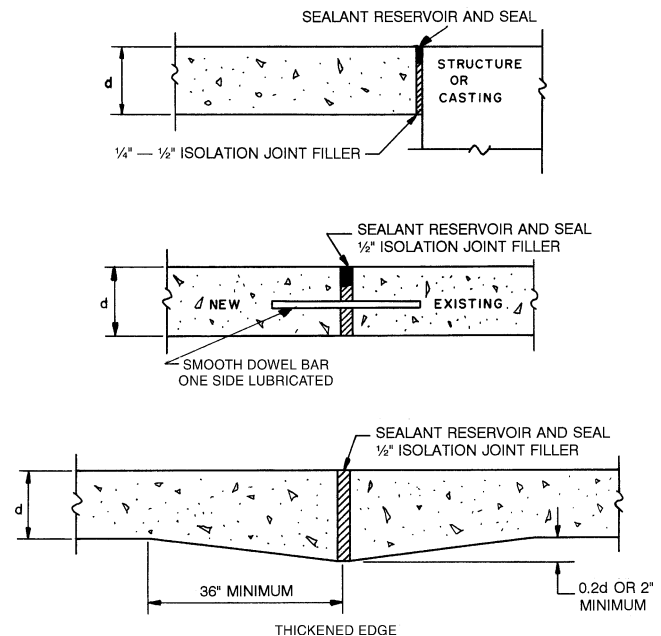


Fig. C.4—Isolation joints. Note: for conversion to SI units, see Appendix E.

parking spaces of common widths and various angles. Aisles should be 24 ft (7.3 m) wide for two-way traffic. Aisle width will depend on parking angle for one-way traffic.

Right-angle, or 90-degree, parking, permits two-way travel in aisles and is considered to be the most economical arrangement. A 90-degree pattern is the simplest to lay out, but parking is more difficult than parking at smaller angles.

One-way travel is used with parking angles less than 90 degrees. Wider parking spaces allow the use of narrower aisles. For the optimum layout of parking spaces for any given

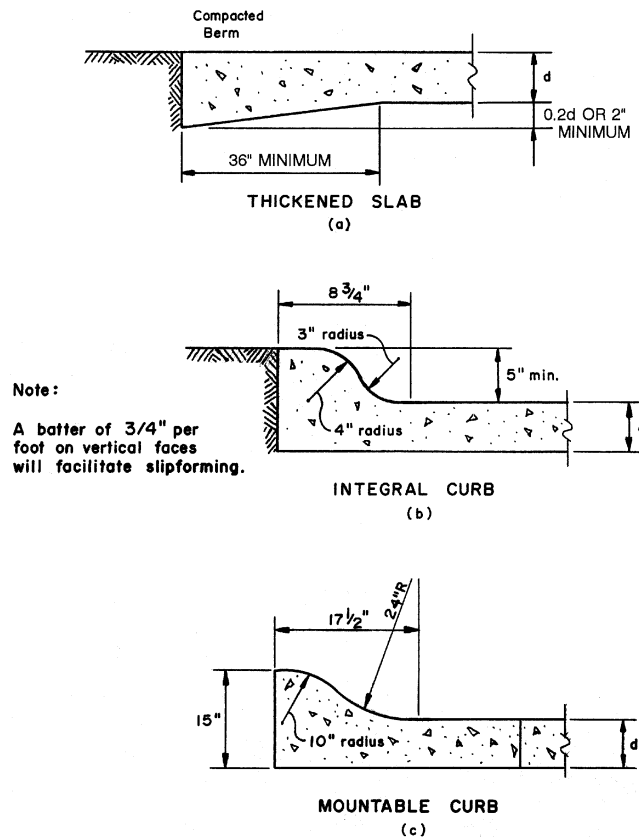


Fig. C.5—Curbs and thickened edges. Note: for conversion to SI units, see Appendix E.

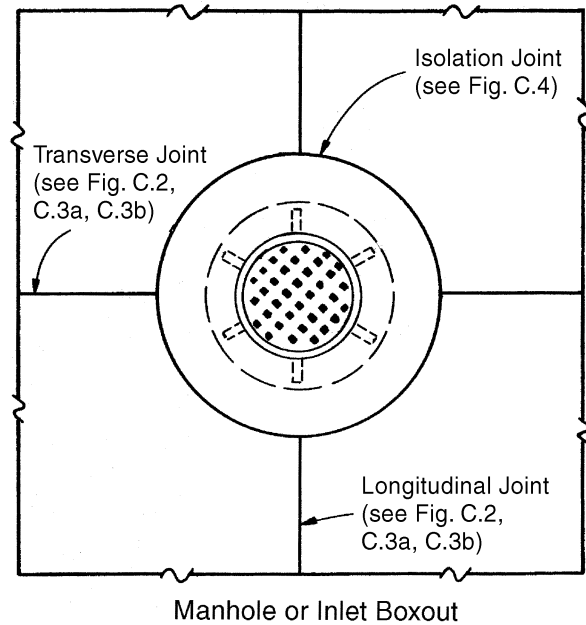
Table D.1(a)—Typical parking space requirements

Type of building	Parking requirement, one per stall
Multifamily dwelling	2/3 families
Theaters, auditoriums, etc.	5 seats
Hotels	2 rooms
Retail stores and office buildings	250 ft ² (23 m ²)
Hospitals	2-5 beds
Industrial plants	2-5 employees
Wholesale businesses	2-5 employees
Restaurants	3 seats
Colleges and high schools	2-5 students
Shopping centers, 25,000 to 400,000 ft ² (2320 to 37,160 m ²)	250 ft ² (23 m ²)
Shopping centers, 400,000 to 600,000 ft ² (37,160 to 55,740 m ²)	225 ft ² (21 m ²)
Shopping centers, over 600,000 ft ² (over 55,740 m ²)	200 ft ² (19 m ²)

size and shape of a parking lot, several trial and error layouts will probably be necessary. Tables are available (Recommended 1989) to facilitate the calculation of critical stall dimensions.

D.2—Entrances and exits

Entrances and exits should be well-defined and located so as to have as little effect as possible on traffic movement on adjacent streets. Local standards usually prescribe lengths of acceleration-deceleration lanes at entrances and minimum FDA, Inc.



1. All catch basins, manholes, or other fixtures should be separated from the pavement and curb by boxing out as shown above. Joint material should extend completely through curb and slab. Manhole castings within the pavement should be boxed in like manner except when telescoping-type castings are used.

2. When a joint falls within 5 ft of catch basins, manholes, or other structures, shorten one or more panels either side of opening to permit joint to fall on round structures.

Fig. C.6—Fixture details. Note: for conversion to SI units, see Appendix E.

distances from intersections. Reservoir space is important at entrances and exits on busy streets. Figure D.2 gives dimensions for curb returns.

D.3—Truck-parking facilities

Dimensions to allow adequate space for maneuvering and parking trucks vary greatly depending upon the size and types of trucks. A truck terminal used by a single type of vehicle may have standard-size spaces. A service area, adjacent to a highway, that will cater to trucks of all sizes can be designed for the entire parking lot to handle the largest and heaviest trucks, or it may be advantageous to segregate single units,

Table D.1(b)—Parking space dimensions (Recommended 1989)

Small cars									
Angle	Interlock reduction	Overhang	Vehicle projection	Aisle width	Module widths				
	i	o	VP	AW	W ₁	W ₂	W ₃	W ₄	W ₅
45 deg	2 ft, 0 in.	1 ft, 5 in.	15 ft, 3 in.	11 ft, 6 in.	26 ft, 9 in.	42 ft, 0 in.	40 ft, 0 in.	38 ft, 0 in.	39 ft, 2 in.
50 deg	1 ft, 10 in.	1 ft, 6 in.	15 ft, 9 in.	12 ft, 0 in.	27 ft, 9 in.	43 ft, 6 in.	41 ft, 8 in.	39 ft, 10 in.	40 ft, 6 in.
55 deg	1 ft, 8 in.	1 ft, 8 in.	16 ft, 1 in.	12 ft, 10 in.	28 ft, 11 in.	45 ft, 0 in.	43 ft, 4 in.	41 ft, 8 in.	41 ft, 8 in.
60 deg	1 ft, 5 in.	1 ft, 9 in.	16 ft, 4 in.	13 ft, 4 in.	29 ft, 8 in.	46 ft, 0 in.	44 ft, 7 in.	43 ft, 2 in.	42 ft, 6 in.
65 deg	1 ft, 2 in.	1 ft, 10 in.	16 ft, 6 in.	14 ft, 0 in.	30 ft, 6 in.	47 ft, 0 in.	45 ft, 10 in.	44 ft, 8 in.	43 ft, 4 in.
70 deg	1 ft, 0 in.	1 ft, 11 in.	16 ft, 7 in.	14 ft, 10 in.	31 ft, 5 in.	48 ft, 0 in.	47 ft, 0 in.	46 ft, 0 in.	44 ft, 2 in.
75 deg	0 ft, 9 in.	1 ft, 11 in.	16 ft, 6 in.	16 ft, 0 in.	32 ft, 6 in.	49 ft, 0 in.	48 ft, 3 in.	47 ft, 6 in.	45 ft, 2 in.
90 deg	0 ft, 0 in.	2 ft, 0 in.	15 ft, 6 in.	20 ft, 0 in.	35 ft, 6 in.	51 ft, 0 in.	51 ft, 0 in.	51 ft, 0 in.	47 ft, 0 in.

Large cars									
Angle	Interlock reduction	Overhang	Vehicle projection	Aisle width	Module widths				
	i	o	VP	AW	W ₁	W ₂	W ₃	W ₄	W ₅
45 deg	2 ft, 4 in.	2 ft, 1 in.	18 ft, 0 in.	13 ft, 0 in.	31 ft, 0 in.	49 ft, 0 in.	46 ft, 8 in.	44 ft, 4 in.	44 ft, 10 in.
50 deg	2 ft, 1 in.	2 ft, 4 in.	18 ft, 8 in.	13 ft, 8 in.	32 ft, 4 in.	51 ft, 0 in.	48 ft, 11 in.	46 ft, 10 in.	46 ft, 4 in.
55 deg	1 ft, 10 in.	2 ft, 5 in.	19 ft, 2 in.	14 ft, 8 in.	33 ft, 10 in.	53 ft, 0 in.	51 ft, 2 in.	49 ft, 4 in.	48 ft, 2 in.
60 deg	1 ft, 8 in.	2 ft, 7 in.	19 ft, 6 in.	16 ft, 0 in.	35 ft, 6 in.	55 ft, 0 in.	53 ft, 4 in.	51 ft, 8 in.	49 ft, 10 in.
65 deg	1 ft, 4 in.	2 ft, 9 in.	19 ft, 9 in.	17 ft, 0 in.	36 ft, 9 in.	56 ft, 6 in.	55 ft, 2 in.	53 ft, 10 in.	51 ft, 0 in.
70 deg	1 ft, 1 in.	2 ft, 10 in.	19 ft, 10 in.	18 ft, 4 in.	38 ft, 2 in.	58 ft, 0 in.	56 ft, 11 in.	55 ft, 10 in.	52 ft, 4 in.
75 deg	0 ft, 10 in.	2 ft, 11 in.	19 ft, 9 in.	20 ft, 0 in.	39 ft, 9 in.	59 ft, 6 in.	58 ft, 8 in.	57 ft, 10 in.	53 ft, 8 in.
90 deg	0 ft, 0 in.	3 ft, 0 in.	18 ft, 8 in.	24 ft, 8 in.	43 ft, 4 in.	62 ft, 0 in.	62 ft, 0 in.	62 ft, 0 in.	56 ft, 0 in.

Notes:
O =parking angle;
W₁ = parking module width (wall-to-wall), single-loaded aisle;
W₂ = parking module width (wall-to-wall), double-loaded aisle;
W₃ = parking module width (wall-to-interlock), double loaded aisle;
W₄ = parking module width (interlock-to-interlock), double-loaded aisle;
W₅ = parking module width (curb-to-curb), double-loaded aisle;
AW = aisle width;
WP = stall width parallel to aisle;
VP = projected vehicle length measured perpendicular to aisle;
S_L = stall length;
S_W = stall width;
o = overhang clearance; and
i = interlock reduction.
For conversions to SI units, see Appendix E.

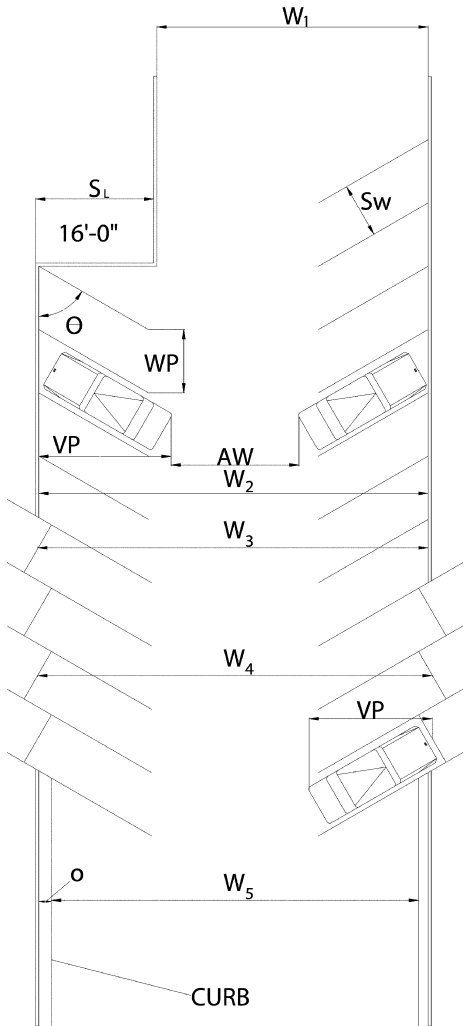
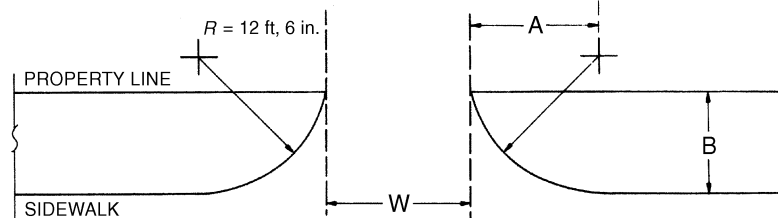


Table D.3—Suggested dimensions for maneuver areas (How to 1974)

Type	Truck width, in. (m)	Vehicle width, in. (m)	Wheelbase, in. (m)	Overall length, ft (m)	Min. turn radius, ft (m)*
Single	65 (2.5)	96 (2.4)	250 (6.3)	33 (10.0)	45 (13.7)
Tractor-semitrailer	77 (2.0)	96 (2.4)	138 (3.5)	55 (16.8)	50 (15.2)
Double trailer	77 (2.0)	96 (2.4)	104 (2.6)	65 (19.8)	50 (15.2)

*Turning radius is measured from the turning center to the outside front wheel of the truck.



A	B	ENTRANCE W	EXIT W
9'9"	4'6"	14'9"	11'6"
10'6"	5'6"	14'0"	10'9"
11'0"	6'6"	13'6"	10'0"
11'6"	7'6"	13'0"	9'6"
12'0"	8'6"	12'6"	9'3"

Table gives curb returns required to permit a car traveling 1 ft from curb to turn into parking lot and clear parked cars by 1 ft. Exit dimensions permit the reverse.

Fig. D.2—Entrance and exit curb returns for parking lots (How to 1974). Note: for conversion to SI units, see Appendix E.

tractor semitrailers, and twin trailer units. Parking-space length and width, and driving-lane turning radii requirements (as well as pavement thickness) can be tailored to the different types of traffic. Table D.3 gives suggested dimensions for maneuver areas for typical sizes. These dimensions should be checked before designing the parking lot. Trailer lengths vary; widths up to 102 in. (2.6 m) are now in use.

D.4—Additional information

There are many sources for information to aid in providing adequate spaces for parking and maneuvering vehicles. These include trade associations and parking lot equipment suppliers. Information from some of these sources is included in this appendix, and several publications are listed in Section 7.2.

APPENDIX E—SI (METRIC) TABLES

CONVERSION FACTORS—INCH-POUND TO SI (METRIC)*

To convert from	to	multiply by
Length		
inch (in.)	millimeter (mm)	25.4E [†]
foot (ft)	meter (m)	0.3048E
yard (yd)	meter (m)	0.9144E
mile (mi)	kilometers (km)	1.609
Area		
square foot (ft ²)	square meter (m ²)	0.0929
square yard (yd ²)	square meter (m ²)	0.8361
Volume (capacity)		
ounce (oz)	cubic centimeter (cm ³)	29.57
gallon (gal.)	cubic meter (m ³) [‡]	0.003785
cubic foot (ft ³)	cubic meter (m ³)	0.02832
cubic yard (yd ³)	cubic meter (m ³) [‡]	0.7646
Force		
kilogram force (kg)	newton (N)	9.807
kip force (kip)	newton (N)	4448
pound force (lb)	newton (N)	4.448
FDA, Inc.		

Pressure or stress (force per area)

kilogram-force/square meter (kg/m ²).....	pascal (Pa).....	9.807
kip-force/square inch (ksi)	megapascal (MPa).....	6.895
newton/square inch (N/m ²)	pascal (Pa).....	1.000E
pound-force/square foot (lb/ft ²)	pascal (Pa).....	47.88
pound-force square inch (psi)	kilopascal (kPa).....	6.895

Bending moment or torque

inch-pound-force (in.-lb).....	newton-meter (Nm).....	0.1130
foot-pound-force (ft-lb)	newton-meter (Nm).....	1.356
meter-kilogram-force (m-kg)	newton-meter (Nm).....	9.807

Mass

ounce-mass (avoirdupois) (oz)	gram (g).....	28.34
pound-mass (avoirdupois) (lb)	kilogram (kg).....	0.4536
ton (metric).....	megagram (Mg).....	1.000E
ton (short, 2000 lbm).....	megagram (Mg).....	0.9072

Mass per volume

pound-mass/cubic foot (lb/ft ³)	kilogram/cubic meter (kg/m ³).....	16.02
pound-mass/cubic yard (lb/yd ³)	kilogram/cubic meter (kg/m ³).....	0.5933
pound-mass/gallon (lb/gal.)	kilogram/cubic meter (kg/m ³).....	119.8

Temperature[§]

deg Fahrenheit (F)	deg Celsius (C)	$t_C = (t_F - 32) 1.8$
deg Celsius (C).....	deg Fahrenheit (F)	$t_F = 1.8t_C + 32$

*This selected list gives practical conversion factors of units found in concrete technology. The reference source for information on SI units and more exact conversion factors is of "Standard for Metric Practice" (ASTM E 380). Symbols of metric tie units are given in parentheses.

[†]E indicates that the factor given is exact.

[‡]One liter = 0.001 m³, or 1000 cm³.

[§]These equations convert one temperature reading to another and include the necessary scale corrections. To convert a difference in temperature from F to C divide by 1.8 only, that is, a change from 70 to 88 F represents a change of 18 F or 18/1.8 = 10 C deg.