Guide for the Design and Construction of Concrete Site Paving for Industrial and Trucking Facilities

Reported by ACI Committee 330

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Reported by ACI Committee 330

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This guide provides information useful in the design and construction of a successful site-paving project for heavy-duty industrial and trucking facilities. This information assists architects/engineers, contractors, and testing agencies with designing, detailing, constructing, repairing, and inspecting site paving. Engineers use this guide to make recommendations for the pavement support system, concrete mixture, pavement thickness, joint spacing, and load transfer devices. Thickness design tables are including for common over-the-road trucks and industrial lift trucks. Tables are also provided to check the pavement thickness for punching shear and concrete strength for bearing stress applied by loaded trailers that have been disconnected from the tractor. Contractors use this guide to understand proper ways to construct site paving with block or strip placements and avoid common mistakes made during construction. Proper placing, consolidating, and finishing techniques are described to construct a durable pavement that complies with the project documents. Inspectors and testing agencies use this guide to understand the design and be better equipped to monitor the project from stripping and grubbing of the site to concrete pavement curing. Testing and inspection included in this guide should only be done by individuals holding the appropriate certifications.

Keywords: industrial pavement; joint stability; lift truck; lug anchor; over-the-road truck; pavement support system; sustainable industrial pavement system; unreinforced concrete pavement.

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CHAPTER 1—GENERAL

1.1—Introduction

Concrete provides a strong and durable surface for vehicle maneuvering and storage areas, making it especially suited for site paving at industrial and trucking facilities. Concrete site paving for industrial and trucking facilities has many similarities to other types of concrete pavements, such as typical concrete parking lots, streets, and highways. Service distinctions may include traffic speed and zones dedicated specifically to multi-directional or channelized traffic flow. These facilities are often constructed to serve not only over-the-road trucks, but industrial lift trucks, such as those imposed by dolly wheels and trailer pads, tracked vehicles, other nontraditional vehicles, and other vehicular-related static loads such as trailers dropped on-site between loading and off-loading. Industrial and trucking facilities have paved areas that are generally larger in size than most parking lots. The scale of these projects and the comparatively high traffic count and special loads generally justify more attention to design than typical parking lots. These distinctions along with changing technologies initiated the development of this guide.

Note that ACI 330R can be used as a resource for some similarly-described facilities. Each document has been developed as a stand-alone guide that provides critical design information and recommended construction practices for successful paving projects. Guide selection to a specific project should consider the specific traffic level to be accommodated as well as the design load types, especially if they include industrial lift trucks and other special loads, the percentage of accommodated vehicles (which are very heavy), site geotechnical considerations such as in-place subgrade character and drainage, joint spacing, and potential future uses of the facility. In general, this guide is intended for facilities with heavier design loads, nonstandard vehicles, higher volumes of heavy trucks, or both. Examples of such facilities include warehouses, factories, truck terminals, heavy equipment sales and service distribution centers, and ports. ACI 330R is intended for use when truck loads are generally lighter, traffic volumes lower, or both, though many successful projects accommodating higher average daily truck traffic of mixed vehicle loads have been designed using ACI 330R. Examples of typical parking lots most consistent with the intended scope of ACI 330R would include concrete pavements for apartment complexes, shopping malls, convenience stores, gas stations, banks, and office buildings.

Concrete offers many advantages over asphalt for pavements at industrial or trucking facilities. Concrete provides greater surface and pavement system durability and favorable economics with respect to life-cycle costs, and sometimes even with initial construction costs. Facility night-time illumination can be provided at a lower cost with concrete due to concrete surface reflectance. Concrete also reduces traffic load stresses imposed on subbase and subgrade soils and can be constructed with a wide variety of construction equipment, ranging from hand tools and vibratory screeds, to laser-guided screeds and large highway paving equipment. The sustainable construction benefits of concrete are also an important consideration in pavement type selection (Chapter 9).

The paired values stated in inch-pound and SI units are usually not exact equivalents. Therefore, each system is to be used independently of the other. Combining values from the two systems could result in nonconformance with this guide.

1.2—Scope

This guide is based on the current knowledge and practices for the design, construction, and maintenance of concrete site pavements for industrial and trucking facilities, emphasizing the aspects of concrete pavement technology that are different from procedures used to design and construct floor slabs, parking lots, streets, and highways. This guide is neither a standard nor a specification, and it is not intended to be included by reference in construction contract documents.

Pavements for industrial and trucking facilities are designed similarly to parking lots, streets, and highways, but with a few key technical differences. Site pavements have most loads imposed on interior panels surrounded by other pavement, which provide varying degrees of panel edge support or load transfer on all sides. Other pavement applications may carry loads along and across relatively unsupported edges, where greater deflections and stresses are not a significant concern due to lighter design traffic. Streets and highways are commonly designed to drain toward an edge where storm water can be carried away from the pavement. Site pavements are commonly designed so a portion of the storm water is collected internally and conveyed away through underground systems. Site pavements often accommodate appurtenances, such as drainage structures, lighting standards, bollards, and fuel islands. Provisions for these appurtenances should be considered in the design, layout, and construction of the crack-control (jointing) system.

1.3—Background

Design practices for concrete site pavements have often varied by local experiences and are based on guidance derived from a combination of design references covering heavy pavements and floor slabs. The unique demands of these types of facilities have made it challenging for project designers to integrate all appropriate design protocols and consider all performance influences. This document is intended to respond to the need for a single, source guide on concrete site paving for industrial and trucking facilities.

Concrete pavement thickness is one of the critical design elements for industrial and trucking facility site paving applications, just as it is for parking lots and other mixed-vehicle pavements. This is true not only for engineering economy but also for the pavement structure to reliably carry loads from nontraditional vehicles and certain static loads. For concrete site paving, proper thickness design should minimize pavement stresses and deflections along joints and pavement edges. Many types of geotechnical site conditions that can successfully accommodate light traffic pavements are not appropriate for industrial and trucking facility site pavements without enhancement of the subgrade system, inclusion of one or more subbases, or both. This type of distinction also extends to load transfer considerations.

Subgrade improvement, joint spacing and layout, and load transfer strategies are important elements of industrial and trucking site pavement design. Thickness should reflect these considerations along with pavement stress levels for all envisioned loadings. Construction planning should consider surface durability needs and appropriate tolerances.

CHAPTER 2—NOTATION AND DEFINITIONS

2.1—Notation

B_n = nominal bearing strength
B_u = factored bearing load
E_C = modulus of elasticity
k-value = modulus of subgrade reaction
M_R = resilient modulus
M_R = resilient modulus
V_n = nominal shear strength
V_u = factored shear force

2.2—Definitions

ACI provides a comprehensive list of definitions through an online resource, "ACI Concrete Terminology," https://www.concrete.org/store/productdetail.aspx?ItemID=CT13. Definitions provided herein complement that source.

distributed steel reinforcement—welded-wire fabric or bar mats used in pavement to hold concrete together across cracks that form; this type of reinforcement is assumed not to contribute to the structural capacity of pavement.

dowelled joint—joint that uses smooth parallel bars or plates for load transfer, allowing for in-plane movement.

drainage—interception and removal of water from, on, or under an area or roadway.

expansive soils—soils that exhibit relatively significant shrinkage or expansion caused by loss or gain of moisture, often resulting in reduction of soil support; these soils are typically, but not always, classified as AASHTO A-6 and A-7 materials, or USCS type CH, MH or US soils with a plasticity index (PI) greater than 25.

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.

load transfer device—mechanical means designed to transfer wheel loads across a joint, normally consisting of dowels or dowel-type devices.

modulus of subgrade reaction, *k*—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.

moisture-density curve—graphical representation of the relationship between the compacted density of a subgrade soil to its moisture content, which is determined as a function of the compacted dry density.

pavement structure—combination of subbase, rigid slab, and other layers designed to work together to provide uniform, lasting support for imposed traffic loads and the distribution of loads to the subgrade.

reinforced pavement—pavement containing distributed steel reinforcing to control cracking due to shrinkage and temperature gradients.

resistance value *R*—stability of a soil, as determined by the Hveem Stabilometer using ASTM D1560 and ASTM D2844 or AASHTO T90 and T246, measures the horizontal pressure resulting from a vertical load.

sawing window—the period of time between which sawing of the concrete should be begun and completed.

soil support—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 (National Research Council 1962).

stabilization—modification of soil or aggregate layers by incorporating stabilizing materials that will increase load-bearing capacity, stiffness, resistance to weathering or displacement, decrease swell potential, or all of these.

standard Proctor density—maximum soil density at optimum moisture content as defined in ASTM D698.

swelling soil—see **expansive soil**.

tied joint—joint that uses deformed reinforcing bars to inhibit the joint from opening.

window of finishability—the time available to complete all concrete placing and finishing operations required to achieve the desired surface tolerance and texture

CHAPTER 3—SUBGRADES AND SUBBASES

3.1—Pavement support system

The foundation layers on which a pavement is supported are important to the proper design of the pavement and are critical to its long-term performance under traffic. The foundation support system consists of a subgrade and, as needed, a subbase layer. Figure 3.1 presents a typical section through a concrete pavement showing subgrade and subbase layers. When the existing soil has adequate strength, volumetric stability, and nonpumping material properties, the pavement can be placed directly on the existing prepared, graded, and compacted subgrade. Subgrade soils alone, however, might not be an adequate foundation for concrete pavements that support heavy industrial or truck load applications. If the subgrade soils are not adequate, a subbase layer can be added to improve the strength and uniformity of the material directly under the pavement and improve its long-term performance. Subbases can also facilitate construction operations and schedules, as they can provide a stable working platform for paving operations.

The pavement foundation system provides support for the pavement and is included in the structural analysis of the pavement thickness using a support reaction. This is typically modeled as a subgrade reaction *k*-value, which is essentially a spring constant. Note that some methods of pavement analysis can structurally analyze a multi-layer rigid pavement system that includes the surface, subbase, and subgrade layers. These methods are beyond the scope of this guide. Finite element modeling or layer-elastic analysis can be employed for this type of multi-layer design, and can often result in optimized pavement sections. However, appropriate analysis and design computer programs and advanced expertise of the designer are necessary.

The foundation support system for a concrete pavement should provide the following characteristics:

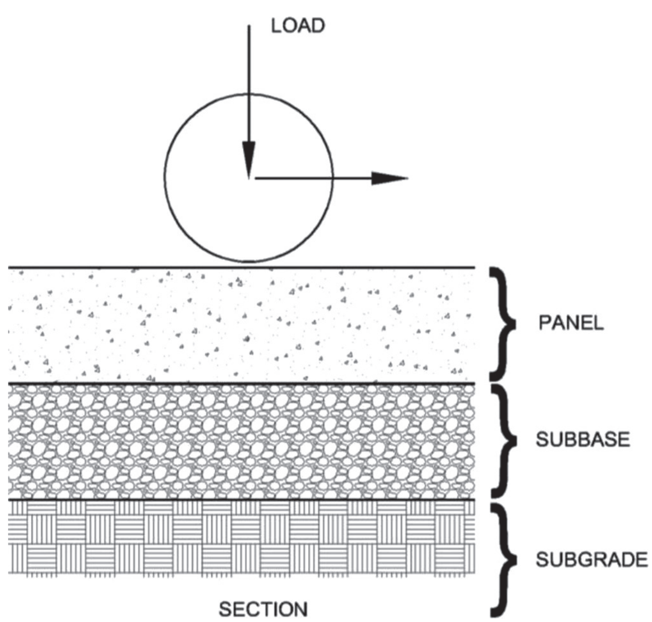

Fig. 3.1—Panel support system terminology.

(a) Adequate and uniform support
(b) Control of volumetric stability if subgrade materials are expansive
(c) Frost-heave resistance
(d) Resistance to erosion (pumping) under heavy loads
(e) Support of construction operations
(f) Appropriate drainage for the subbase/subgrade system used

Rigid concrete pavements require foundation systems that accomplish the tasks noted previously. The stiffness of concrete spreads surface loads over wide areas. Therefore, subgrade/subbase strength is not an overriding criterion for the system, as is the case for flexible pavement systems. Concrete pavement thickness is somewhat insensitive to foundation strength and stiffness; designing a stronger or thicker foundation system to achieve a thinner concrete pavement is not a cost-effective strategy. The other considerations noted previously, however, will often require subgrade modification, a subbase layer to achieve foundation support objectives, or both, as well as ensuring long-term performance of the concrete pavement.

Concrete pavement designs incorporate a spring constant, called the modulus of subgrade reaction, or *k*-value, to account for the subgrade stiffness and its reaction with the concrete pavement. The *k*-value is determined by the plate load test (AASHTO T235; ASTM D1194), which is performed by placing a 30 in. (760 mm) diameter plate on the subgrade and loading it with a very heavy load. The *k*-value is found by dividing the plate pressure by plate deflection under the load. The plate load test is seldom conducted, however, and *k*-values are often calculated by a correlation from a more common soil test such as resilient modulus (M_R) (AASHTO T307) or California Bearing Ratio (CBR) (ASTM D1883; AASHTO T193). Guidance on *k*-values for various subgrade and subbase conditions is provided in 3.3 and 3.4. Information on using a dynamic cone penetrometer (DCP) (ASTM D6951/6951M) to correlate CBR values for subgrade soils is found in Appendix A.2.

It is highly recommended that a licensed professional architect/engineer with competence in geotechnical engineering be involved in soil evaluation and recommendations for subgrades and subbases for industrial pavements.

3.2—Subgrade/subbase failure modes

A well-designed concrete pavement can fail prematurely if the foundation system fails to maintain uniform support. This can happen in several ways. It is the function of the subgrade and subbase to prevent pavements from failing due to the effects that follow.

3.2.1 *Weak and wet soils*—Weak soils are generally wet and compressible, potentially resulting in an unstable construction platform and isolated weak spots that cause abrupt changes in pavement support.

3.2.2 *Erosion at joints and cracks and pumping*—For erosion of the subgrade or subbase to occur at joints, the following four conditions must exist: 1) poor load transfer (no dowel bars); 2) heavy and fast moving traffic; 3) a pumpable subgrade/subbase material; and 4) water presence. These conditions can cause a loss of support at joints, resulting in faulting. Faulting is the differential, often vertical, displacement between panels at a joint. Faulting can also occur in a similar manner at random cracks within a panel, especially if it occurs outside of areas that require positive load transfer via a dowel.

3.2.3 *Frost action*—Frost-susceptible foundation material can cause frost heaving during the winter months, and subgrade softening in the spring, both of which can result in uneven support. This results in degradation of ride quality, as well as increased stresses in the concrete, causing cracking.

3.2.4 *Expansive soils*—Expansive soils can shrink or swell, depending on their moisture state. The effect on concrete pavement is similar to that from frost action: uneven support, degradation of ride quality, and cracking.

3.3—Subgrade considerations

Every pavement foundation begins with the subgrade—the natural soils that ultimately support all the pavement layers above. The uniformity and long-term stability of the foundation soils affect the performance and constructability of the concrete pavement. If a subgrade will be the only layer in the foundation system, it is vital that it is also can support the paving operations during construction.

The in-place subgrade soil conditions and properties should be determined by appropriate soils testing on the area to be paved. The extent of the geotechnical investigation should be determined by the magnitude of the project and by conditions discovered that may warrant a more detailed examination. Typical soil borings are spaced 100 to 300 ft (30.5 to 91.4 m) apart and should generally extend 5 to 10 ft (1.5 to 3.0 m) below the planned finished grade. A geotechnical investigation should include soil identification and classification for determining the properties of in-place soils and their suitability for use as foundation soils. The soil should be classified according to one of the standardized systems, such as the Unified Soil Classification System (USCS) (ASTM D2487) or the AASHTO M145 system. Laboratory testing on subgrade soils should include moisture content, Atterberg limits, sieve analysis, and moisture-density relationship. The modulus of subgrade reaction (*k*-value), CBR, resistance value (*R*-value), or soil support value (SSV) can also be determined for design purposes. The resilient modulus (M_R) can be measured through AASHTO T307. Figure 3.3 provides the approximate interrelationship among various soil classifications and bearing types (Packard 1984). Information on soil classification are found in Appendix A.1.

The modulus of subgrade reaction (*k*-value) is normally used as the design parameter for concrete pavements. Table 3.3 shows typical *k*-values for three broad classifications of subgrade soils (American Concrete Pavement Association [ACPA] 2012).

Corrective action should be taken if problem subgrade soils are encountered. Problem subgrade soils that may potentially cause a negative effect on the performance of the concrete pavements are this soil type:
(a) Pumping
(b) Frost-susceptible