Rigid Pavement Technical Assistance

Resource for Local Jurisdictions

NRMCA
NATIONAL READY MIXED CONCRETE ASSOCIATION

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Acknowledgement

NRMCA wishes to acknowledge the authors and institutions that have been referenced in this resource document. It should be noted that reference to a particular document, author, or institution within this document does not implicitly or indirectly infer support of, or agreement to, the recommendations, statements, or claims herein.

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Executive Summary

As more local jurisdictions look to stretch their transportation infrastructure dollars, rigid pavements are being incorporated into their design standards as viable options with initial costs, many times, near or below the costs of flexible pavements. However, institutional knowledge regarding design, construction, inspection, and maintenance of rigid pavements may be lacking or out of date. With this in mind, the National Ready Mixed Concrete Association (NRMCA) has prepared the *Rigid Pavement Technical Assistance Resource for Local Jurisdictions* to facilitate the adoption of various forms of rigid pavements at the city and county level.

It must be understood that the adoption of state department of transportation (DOT) design methods, standard details, materials/construction specifications, and inspection procedures for rigid pavements may not be appropriate for all local roadways that typically carry significantly lower traffic volumes and axle weights. When DOT methods are adopted for local roads, rigid pavements tend to be over-designed and not optimized for the lower volume condition which leads to unnecessary additional costs incurred. Therefore, within this guide, the recommended design methods, details, specifications, and maintenance methods are applicable for streets and local roads or those roads that are generally classified as residential, collector, or arterial.

The term rigid pavements can apply to a number of different cement based paving materials. In this resource document, rigid pavement solutions that may be used for local roads include the following:

- Jointed Plain Concrete Pavements,
- Bonded or Unbonded Conventional Concrete Overlays,
- Roller Compacted Concrete Pavements,
- Pervious Concrete Pavements, and
- Full Depth Reclamation of Existing Pavements.

This document is intended to assist with the tasks of designing, specifying, detailing, constructing, and maintaining various rigid pavement types. It is important that each of these tasks is completed appropriately to achieve the long-term performance that is expected from the pavement. If any single task is not completed appropriately, the pavement may not achieve its intended performance goal and potentially impact the owner economically.

This resource is divided into tabs that cover the design, construction, and maintenance of rigid pavements. Within various tabs there are reference documents listed that provide significant detail and background regarding the topic being covered. It was the intent of this resource to refer the reader, as much as possible, to existing documents that provide the current practices of the industry as well as include information about other important topics such as sustainability which are becoming more and more important when making decisions about the pavement type to select for a given project.

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Tab 1 – Introduction to Rigid Pavements

Rigid pavements are comprised of one or more paving layers which include a cementitious material like portland cement, fly ash, slag, or other pozzolans that when combined with water and aggregate produces a stiff layer that uniformly distributes wheel load stress over a wide area. Jointed, unreinforced conventional concrete pavement is typically thought of when rigid pavements are mentioned. This is one type of rigid pavement, but many others exist and may be utilized in street and local road applications. In this guide, rigid pavement solutions for local roads include the following:

- Jointed Plain Concrete Pavement,
- Bonded or Unbonded Conventional Concrete Overlay,
- Roller Compacted Concrete Pavement,
- Pervious Concrete Pavement, and
- Full Depth Reclamation of Existing Flexible Pavement

For further information and discussion on all rigid pavement types, see the Portland Cement Association (PCA) document Guide to Cement Based Integrated Pavement Solutions.

Websites that provide significant information on rigid pavements and may be used for further background or reference are as follows:

Pave Ahead: An Initiative of the National Ready Mixed Concrete Association's Local Paving Division
paveahead.com

National Ready Mixed Concrete Association
nrmca.org

Ready Mixed Concrete (RMC) Research & Education Foundation
rmc-foundation.org

American Concrete Pavement Association
acpa.org

Portland Cement Association
cement.org

National Concrete Pavement Technology Center
cptechcenter.org

International Society for Concrete Pavements
concretepavements.org

American Concrete Institute (Technical Committees 325, 327, 330 and 522)
ACI 325: Concrete Pavements
ACI 327: Roller Compacted Concrete Pavements
ACI 330: Concrete Parking Lots and Site Paving
ACI 522: Pervious Concrete

Massachusetts Institute of Technology (MIT) Concrete Sustainability Hub (CSHub)
cshub.mit.edu

Seal/No Seal Group (Information on joint sealing)
sealnoseal.org

International Grooving and Grinding Association
igga.net

Federal Highway Administration – Concrete Pavements
fhwa.dot.gov/PAVEMENT/concrete/index.cfm

National Local Technical Assistance Program Association
nltapa.org

Tab 2 – Rigid Pavement Design Recommendations and Methods

Pavement Design Steps

Determining the correct combination of pavement layers and thicknesses for the project conditions and meets the performance goals can be achieved by following a logical progression of steps. These steps require data collection, analysis, and interpretation that are not always straightforward and include some level of engineering judgment. For most projects, however, the following steps may be used to determine the pavement cross section and associated details for a project:

Step 1: Determine Soil Properties (See Tab 4 - Determining the Design Values for Base Aggregate and Subgrade Soil Strength)

A judgment regarding the suitability of the existing soil that will become the pavement foundation is important so that other decisions about drainage improvement, the need for a base or soil stabilization, and other construction considerations may be made. The purpose of this step is to establish soil properties and characteristics to be used in the pavement design and determine those influencing site characteristics that require modifications to the pavement structure or adjacent works to accommodate those characteristics. In particular, determination of soil strength, applicable modulus (its stiffness), and matrix stability will be the result of the analysis. From this information, a report should be prepared that documents the findings from the geotechnical investigation. Once the subgrade properties are determined, the pavement section should be designed in accordance with the appropriate guidelines established by the owner.

Step 2: Determine Traffic Input (See Tab 5 - Traffic Conditions)

An assessment of the type, weight, and number of vehicles utilizing the pavement is another important aspect of the design process. Ideally, a traffic study will provide estimates of the average daily traffic and percent trucks at a minimum. If these data are not readily available, an educated estimate using the street classification can be used and is covered further in this tab under Street Classification and in Tab 5 – Traffic Conditions.

Step 3: Determine Concrete Strength (See Tab 9 – Concrete Mixtures)

The primary goal of specifying PCC properties and materials characteristics is to ensure that the concrete's strength provides adequate long-term performance as determined by joint spalling and faulting, and transverse slab cracking. Primary project variables that affect the required concrete strength are design life, climate, traffic, acceptable distress level criteria, joint spacing, and subgrade/base type.

Concrete with a design flexural strength of about 600 to 650 psi can develop excellent long-term joint spalling resistance provided that (1) good sub-surface drainage conditions are present, (2) the concrete reaches low permeability level over time from additional curing (i.e. high resistance to physical and chemical deterioration from rapid chloride and water permeability test), (3) it has good entrained air void system (i.e. 6 to 8.5 percent), and (4) sound aggregate are used in the concrete mix.[1]

However, lower or higher flexural strengths may be acceptable depending on traffic types/frequency and the environmental conditions of the project. Other factors like the water to cementitious content ratio is known to be a major mix feature controlling compressive strength. Research demonstrates that a concrete mix with a water-cementitious ratio of 0.42 to 0.45, a cement content of about 565 lb/yd^3, and well-graded quality aggregate are important for development of durable mixtures. Several aggregate characteristics of the concrete mix are important to achieve good long-term pavement performance. These include aggregate inertness with respect to Alkali-Aggregate Reactivity (AAR) and Freeze-Thaw, and strong and large-sized coarse aggregate to ensure good cracking resistance and aggregate interlock. In addition, well-graded aggregate is beneficial in reducing the paste volume fraction. This potentially results in a lower coefficient of thermal expansion and drying shrinkage, both of which are important properties for avoiding premature transverse cracking.

When specifying the concrete mixture strength for use in the thickness design of a project, all the factors discussed above must be considered. Tab 9 – Concrete Mixtures provides information to help develop the mixture for a project specification.

[1]FHWA-RD-00-161 *The Effects of Higher Strength and Associated Concrete Properties on Pavement Performance* June 2001

Simplified Design Catalog for Conventional Concrete Pavement Streets and Roads

Concrete pavement design consists of determining the optimal pavement cross section, in terms of pavement layer thicknesses, for the given subgrade soil strength and traffic loadings (consisting of current and anticipated future traffic). In simple terms, the goal of concrete pavement design is to limit the pavement's flexural stress and fatigue damage caused by wheel loads thus reducing cracking that can occur.

The design table (see Table 3) provides recommended concrete pavement thicknesses for a range of street classifications, soil support conditions, and traffic levels. Other important design considerations like concrete strength, reliability, and the allowable number of slabs cracked at the end of the design life are all set based upon the street classification. If a designer wishes to modify these design considerations and obtain a different concrete pavement thickness, any of the design procedures covered in the section entitled Recommended Rigid Pavement Design Methods for Local Jurisdictions in this tab may be used. Other design methods for pervious concrete, roller compacted concrete, and concrete overlays are also discussed in that section.

The following defines the design inputs and other considerations in support of the recommended design thickness table at the end of this section (see Table 3).

Street Classification

Street functional classification is the process by which streets and highways are grouped into classes, or systems, according to the character of traffic service that they are intended to provide. According to the Federal Highway Administration (FHWA), there are three roadway functional classifications: arterial, collector, and local roads. All streets and highways are grouped into one of these classes, depending on the character of the traffic (i.e., local or long distance) and the degree of land access that they allow. These classifications are described by the FHWA as:

- Local – Consists of all roads not defined as arterials or collectors; primarily provides access to land with little or no through movement. This classification may also be referred to as residential.
- Collector – Provides a less highly developed level of service at a lower speed for shorter distances by collecting traffic from local roads and connecting them with arterials.
- Arterial – Provides the highest level of service at the greatest speed for the longest uninterrupted distance, with some degree of access control. Arterials are further divided into minor and principal (major) roadways depending on traffic and geometric conditions.

Edge Condition

The concrete pavement edge support condition refers to the outside edge of the concrete pavement and whether it consists of an unsupported edge like a dirt, grass, or asphalt shoulder or a supported edge with a curb and gutter, a widened lane, or a tied concrete shoulder. See Appendix 2-A for pictorial representations of various unsupported and supported edge conditions.

Support Classification

Concrete pavement design utilizes the combined underlying layers strength value immediately below the pavement slab to define the support condition. This composite strength value may or may not include a base over the subgrade and is defined as the modulus of reaction (*k*) with units of pounds per square inch per inch (psi/in).

The composite support classification in the design tables is defined as shown below:

- Classification 1 – k = 100 psi/in (CBR = 3.0, M_r = 4,000 psi)
- Classification 2 – k = 200 psi/in (CBR = 10.0, M_r = 9,500 psi)
- Classification 3 – k = 300 psi/in (CBR = 50.0, M_r = 28,000 psi)

*Where CBR = California Bearing Ratio and M_r = Resilient Modulus

When modulus of reaction values are below 100 psi/in, it is good practice to improve the underlying support to meet or exceed this value. Improvement may be accomplished by chemically stabilizing the existing soils using cement, lime, fly ash, or other means acceptable within the local jurisdiction. A base layer may also be included to increase the composite value. Further discussion regarding the composite modulus of reaction and how it is determined for design is covered in *Tab 3 - Determining the Soil and Base Support Value for Design*.

Transverse and Longitudinal Joint Spacing and Reinforcement (Dowels and Tie Bars)

The transverse joint spacing has been identified as one of the most important design details for good long term performance of concrete pavements and is determined as a function of the concrete slab thickness. The following transverse joint spacing as a function of the concrete slab thickness should be utilized for the thickness values found in the design Table 3.

Table 1. Maximum Transverse Joint Spacing in Feet as a Function of PCC Slab Thickness and Modulus of Reaction.

Thickness, in.	Modulus of Reaction, psi/in		
	100	200	300
4.5		7.5	6.0
5.0	9.0	8.0	6.5
5.5	10.0	8.5	7.0
6.0	11.0	9.0	8.0
6.5	11.5	9.5	8.5
7.0	12.0	10.0	9.0
7.5	13.0	10.5	10.0
8.0	13.5	11.5	10.5
8.5	14.0	12.0	11.0
9.0	14.5	12.5	12.0
9.5	15.0	13.0	
10.0	15.0		

In most cases, slabs should be kept as close to square as possible so the longitudinal joint spacing should match the transverse joint spacing. However, longitudinal joints should not be located in either wheel path and there may be other geometric constraints that will require more rectangular slabs. In these instances it is acceptable for the slab ratio to be 1:1.25 (T:L).

Dowels bars are assumed in the thickness design table for pavements greater than 8 inches in depth and in Subgrade Classifications 1 and 2. Dowel bars should be 1.25 inches in diameter when used. All dowels should be 18 inches long and placed at 12 inch spacing centered on the joint and at mid-depth of the slab.

Tie bars may not be required in the interior joints of city streets and low-volume roads if these are confined by a curb and gutter. Wide paved areas, whether or not confined by a curb and gutter, should be tied together in groups of no more than three lanes at a time. Tie bars should be used on center line joints of two-lane pavements where no curb and gutter exists to keep the slabs from separating. Longitudinal construction joints should be tied into the adjacent curb and gutter to use the structural benefit of the edge support.

Other information related to dowel/tie bars, joint types, joint sealing considerations, depth of saw cut, timing of sawing and other related details are covered in Tabs 5, 7, and 8 of this guide.

Traffic and Other Design Considerations

Traffic is characterized by defining the two-way Average Daily Truck Traffic (ADTT) that uses the pavement. It is assumed in the design table that traffic is equally divided in either direction and one-hundred percent (100%) of the heavy vehicles are in the design lane. Within the design table each street functional classification is subdivided into Low, Medium, and High two-way ADTT values which are not the same but are unique to the functional class. The values as well as other design considerations unique to each functional class are identified in Table 2.

Table 2. Design Parameters for Calculated Pavement Thicknesses in Table 3.

Street Classification	Two-Way ADTT			Reliability, %	Concrete Strength, psi[1]	Allowable Slabs Cracked, %[2]
	Low	Medium	High			
Local	3	10	20	75	550	25
Collector	50	250	500	85	600	20
Minor Arterial	200	400	600	90	600	15
Principal Arterial	500	1000	1500	95	650	15

Note 1: 28-day flexural strength of concrete mixture designed in accordance with procedures identified in Tab 9.
Note 2: Allowable percentage of mid-slab cracks at the end of the 30-year design life.

Table 3. Jointed, Unreinforced Conventional Concrete Pavement Thicknesses for Street Functional Classifications.

Concrete Pavement Slab Thickness, inches		Support Classification								
		1			2			3		
		Average Daily Truck Traffic			Average Daily Truck Traffic			Average Daily Truck Traffic		
Street Classification	Edge Condition	Low	Medium	High	Low	Medium	High	Low	Medium	High
Local	Unsupported	6.0	6.5	6.5	5.5	6.0	6.0	5.0	5.5	5.5
	Supported	5.0	5.5	5.5	4.5	5.0	5.0	4.5	4.5	5.0
Collector	Unsupported	7.0	7.5	8.0	6.5	7.0	7.0	6.0	6.5	7.0
	Supported	6.0	6.5	6.5	5.5	6.0	6.0	5.0	5.5	6.0
Minor Arterial	Unsupported	8.5	9.0	9.0	8.0	8.5	8.5	7.5	8.0	8.0
	Supported	7.5	8.0	8.0	7.0	7.0	7.5	6.5	7.0	7.0
Principal Arterial	Unsupported	9.5	10.0	10.0	9.0	9.0	9.5	8.5	8.5	9.0
	Supported	8.5	8.5	9.0	8.0	8.0	8.0	7.0	7.5	7.5

Recommended Concrete Pavement Design Methods for Local Jurisdictions

In those cases where the simplified method of pavement design shown above does not meet the needs of the designer, streets and local roads (SLR) constructed of conventional concrete should be designed using methods that recognize the unique loading and drainage conditions inherent to street or local road pavements. Additionally, the design methods should be applicable to jointed, unreinforced concrete pavement with or without curbs, subbases, or dowels. Concrete pavements in a city or county environment typically do not require longitudinal and/or transverse reinforcing steel. However, if steel is included, it is recommended to determine the pavement slab thickness as plain concrete and then add the minimum required amount of steel as necessitated by the local conditions.[2]

Other construction details like the transverse joint spacing, the need for steel dowels at joints or for a base, and whether to seal the joints, to name a few, are all important considerations that will affect the long-term performance of the pavement and should be understood and specified by the designer during the development of the pavement design.

Local roads paved with other rigid surfaces like roller compacted concrete (RCC) or pervious concrete should also be designed with methods that properly characterize these materials and have applicable response models.

The following pavement design methods are recommended for determining the optimal pavement layer thicknesses when the pavement cross section contains conventional, roller-compacted, or pervious concrete as well as for concrete overlays of existing asphalt, concrete, or composite pavements.

Jointed Plain Concrete Pavement (JPCP)[3]

Jointed, plain concrete pavement for street and local road applications is constructed using conventional portland cement concrete placed in rigid or semi-rigid, fixed in place forms or using slipform pavers. Transverse joints are spaced at distances typically ranging from 8 to 15 feet. Steel reinforcement is not used to increase pavement load carrying capacity and is not recommended in most situations. Steel dowels may be used to improve load transfer efficiency when truck traffic levels are sufficiently high. Longitudinal joints may be tied with deformed steel bars.

The methods recommended for design of JPCP in SLR applications are:

- PavementDesigner.org (based on 1984 PCA and 2005 ACPA StreetPave Methods)
- ACI 325.12R-02 Guide for Design of Jointed Concrete Pavements for Streets and Local Roads
- AASHTO Mechanistic-Empirical Pavement Design Guide and AASHTOWare Pavement ME Design[4]

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[2] See Tab 6 – Design Optimization Guidance for recommendations regarding steel in concrete pavements.
[3] Comprised of unreinforced conventional concrete.
[4] Should be limited to design of pavements expected to carry higher truck volumes like Collectors and Arterials.

PavementDesigner.org: Web-Based Structural Design for Parking Lot and Street Concrete Pavement

The free, web-based design tool utilizes engineering analyses to produce optimized designs for city, municipal, county, and state roadways. For existing concrete pavements and overlays, PavementDesigner.org may be used to estimate service life and/or failure criteria. The website also offers an asphalt cross-section input to create an equivalent rigid pavement design for the load carrying capacity determined for the asphalt pavement cross-section. The free website may be accessed at PavementDesigner.org.

ACI 325.12R-02: Guide for Design of Jointed Concrete Pavements for Streets and Local Roads

As stated in the introduction to this ACI guide, the procedure provides a perspective on a balanced combination of pavement thickness, drainage, and subbase or subgrade materials to achieve an acceptable pavement system for streets and local roads. Within this guide, recommendations are presented for designing a concrete pavement system for a low volume of traffic and associated joint pattern based upon limiting the stresses in the concrete or, in the case of reinforced slabs, maintaining the cracks in a tightly closed condition. Details for designing the distributed reinforcing steel and the load transfer devices are given, if required. The thickness design of low traffic volume concrete pavements is based on the principles developed by the Portland Cement Association and others for analyzing an elastic slab over a dense liquid subgrade, as modified by field observations and extended to include fatigue concepts. The guide may be purchased at concrete.org.

AASHTO Mechanistic-Empirical Pavement Design Guide and AASHTOWare Pavement ME Design

For pavements in the city or county environment that will carry significant heavy vehicle traffic (i.e. > 100 buses, trash trucks, delivery trucks, etc. per day), the *AASHTO Mechanistic-Empirical Pavement Design Guide (MEPDG), Interim Edition: A Manual of Practice* may be used. This guide provides the pavement designer with a state-of-the-practice analysis tool for evaluating pavement structures using mechanistic-empirical principles, using project specific traffic, climate, and materials data for estimating damage accumulation over a specified pavement service life. This manual is applicable to designs for new, reconstructed, and rehabilitated flexible, rigid, and semi-rigid pavements. Performance and distress predictions models are used to aid the pavement designer in determining the desired pavement section. The guide may be purchased at bookstore.transportation.org.

The *AASHTOWare Pavement ME Design* software (formerly known as DARWin ME) supports AASHTO's *Mechanistic-Empirical Pavement Design Guide, Interim Edition: A Manual of Practice* and is a production-ready software tool to support the day-to-day operations of public and private pavement engineers. The software may be purchased at aashtoware.org.

AASHTO MEPDG Low Volume Pavement Design Guide

Part 4, Chapter 1 of the *Mechanistic-Empirical Pavement Design Guide* provides design tables specifically for low volume roadways. For the purposes of MEPDG Part 4, low volume is considered a roadway that carries less than 750,000 heavy vehicles (FHWA Classes 4-13) over its design life. This equates to approximately 70 heavy vehicles per day growing at a compounded rate of 4% annually over a 20-year design period. The design thickness tables of MEPDG Part 4 were developed using the mechanistic-empirical procedures described in the above MEPDG and Pavement M-E paragraph. The guide may be purchased at bookstore.transportation.org.

Roller Compacted Concrete (RCC) Pavement

Roller-Compacted Concrete Pavement may be used as a surface course or as a base course with an overlay. In either case the RCC pavement should be designed using methods that properly account for the rigid RCC layer. RCC pavements have reduced shrinkage because RCC mixtures contain lower water and cement contents as compared to conventional concrete mixes. However, the structural behavior of RCC pavements is similar to that of equivalent conventional concrete pavements.

Thickness design for RCC pavements employs the same basic strategy as for conventional concrete pavements. The strategy requires keeping the pavement's flexural stress and fatigue damage caused by wheel loads within allowable limits. In the structural design, the pavement thickness is a function of the expected loads, concrete strength, and characteristics of supporting base and subgrade.

The methods recommended for design of RCC in SLR applications are:

- Guide for Roller-Compacted Concrete Pavements (SN298)
- All methods recommended for Jointed Plain Concrete Pavement shown above[5]

Guide for Roller-Compacted Concrete Pavements (SN298)

The Guide provides a means of evaluating and designing roller-compacted concrete for industrial pavements such as container ports, rail and truck terminals, and industrial yards that are subjected to heavy off-highway vehicles and equipment. It can also be adapted for street and local roads carrying conventionally loaded vehicles. The publication *Guide for Roller-Compacted Concrete Pavements (SN298)* can be purchased at cement.org.

Pervious Concrete Pavement

Pervious concrete pavement is a unique and effective means to address important environmental issues and support green, sustainable growth. By capturing stormwater and allowing it to seep into the ground, porous concrete is instrumental in recharging groundwater, reducing stormwater runoff, and meeting U.S. Environmental Protection Agency (EPA) stormwater regulations. With pervious concrete, carefully controlled amounts of water and cementitious materials are used to create a paste that forms a thick coating around aggregate particles. A pervious concrete mixture contains little or no sand, creating a substantial void content. Using sufficient paste to coat and bind the aggregate particles together creates a system of highly permeable, interconnected voids that drains quickly. Both the low mortar content and high porosity also reduce strength compared to conventional concrete mixtures, but sufficient strength for most SLR applications is readily achieved.

[5] When using these design methods reliability should be increased by 5%.

The design thickness for a pervious concrete cross section is determined by conducting a structural design and a hydrologic design. The thickest cross section determined from these two analyses is selected as the design section. The structural design is conducted using the reduced concrete flexural strength value of the pervious concrete layer in the same design methods used for conventional concrete. Hydrologic design determines the volume of water to be handled by the pervious cross section and is a function of the drainage area, the subsurface soil permeability, and the environmental conditions at the site.

The methods recommended for design of Pervious Concrete in SLR applications are:

- ACI 522R-10: Report on Pervious Concrete (Hydrologic and Structural Design)
- ACPA PerviousPave (Hydrologic and Structural Design)
- PavementDesigner.org for Structural Design only

ACI 522R-10: Report on Pervious Concrete
This report provides technical information on pervious concrete's application, design methods, materials, properties, mixture proportioning, construction methods, testing, and inspection. The guide may be purchased at concrete.org.

ACPA PerviousPave
PerviousPave is design software that provides results optimized for both structural and stormwater-management requirements by determining the required minimum thickness for pervious concrete pavement, based on the design traffic, design life, and other structural inputs, and the required subbase/reservoir thickness necessary to satisfy stormwater management requirements, based on the volume of water to be processed by the pavement within the required maximum detention time. The software can be purchased at pavement.com.

Concrete Pavement Overlays
There are six recognized categories of overlays using conventional concrete. These are

1. Bonded Concrete Overlays of Concrete Pavements
2. Bonded Concrete Overlays of Asphalt Pavements
3. Bonded Concrete Overlays of Composite Pavements
4. Unbonded Concrete Overlays of Concrete Pavements
5. Unbonded Concrete Overlays of Asphalt Pavements
6. Unbonded Concrete Overlays of Composite Pavements

Designing either bonded or unbonded concrete overlays is a process that begins with characterizing the existing pavement, defining critical design variables, and then proceeding with calculations to determine the required overlay thickness. Thickness design for each of these conditions in street and local road applications may be conducted using the methods outlined in the *Guide to Concrete Overlays: Sustainable Solutions for Resurfacing and Rehabilitating Existing Pavements* published by the Concrete Pavement Technology Center (CP Tech Center) at Iowa State University. The guide can be downloaded at cptechcenter.org.

PavementDesigner.org may also be used to determine overlay thickness. This version designs jointed plain concrete overlays for all six overlay conditions (bonded on asphalt, unbonded on asphalt, bonded on concrete, unbonded on concrete, bonded on composite, unbonded on composite). This software utilizes new engineering analyses to produce optimized designs for city, municipal, county, and state roadways. For existing concrete pavements and overlays, *PavementDesigner.org* may be used to estimate service life and/or failure criteria. The software may be accessed at PavementDesigner.org.

A mechanistically based bonded concrete overlay of asphalt mechanistic-empirical design procedure (BCOA-ME) was developed at the University of Pittsburgh under the FHWA Pooled Fund Study TPF 5-165. A website has been developed and acts as a repository for all information relating to the BCOA-ME. The information on the website is sorted based on its intended use and can be retrieved by clicking on the appropriate links from within the website. The BCOA-ME can be run directly from the website by clicking on the “Design Guide” link at: engineering.pitt.edu/Vandenbossche/BCOA-ME/.

NRMCA Pavement Design Assistance Program (DAP)

NRMCA offers street and local road pavement design assistance to its members, state affiliates, and other interested parties. The application form details the information required to complete a concrete pavement design proposal and should be filled out as thoroughly as possible prior to submission to NRMCA. Design assistance can be provided for new pavements, reconstruction of existing pavement (i.e. major rehabilitation), or for an overlay of an existing pavement. Assistance is available for all rigid pavement types including conventional, roller compacted, and pervious concrete.

Recommended concrete pavement thicknesses are determined using acceptable engineering practices for the anticipated soil, environmental, and loading conditions. Typically, the *PavementDesigner.org* design software is utilized to determine the optimal pavement design thickness. Other methods may be utilized depending on the local design requirements or to fulfill the needs of the applicant.

Recommendations for whether aggregate or stabilized base materials are needed for optimal pavement performance are provided by NRMCA. Recommendations regarding the need for subgrade stabilization will also be provided.

A suggested reference specification entitled *Guide Specification for Materials and Construction of Jointed Unreinforced Concrete Pavement for Streets and Local Roads* (see Tab 7 and Tab 14) is also available for use by owners and their design consultants to define material and construction requirements, criteria, and expectations of material suppliers and construction contractors. Suggested typical design details which may include curbs, gutters, contraction joints, isolation joints, construction joints, thickened edges, tied joints, doweled joints, etc. are also provided.

Life-Cycle Cost Analysis to determine the total cost of ownership will be completed if accurate cost data is provided or can be obtained.

The designs provided by NRMCA are to be used for educational purposes and a disclaimer stating that the design suggestions are not every known fact about the concrete pavement but complies with current industry standards is included in the report. The final design is the responsibility of the engineer on record for the project but the design suggestions provided by NRMCA may be used by the engineer of record after they have reviewed the design, understood how it was developed, and met the other requirements of their state board of professional registration for engineers.

Additional information on the design assistance program may be found on the web at the Pave Ahead Design Center website paveahead.com/register.

Appendix 2-A: Pictorial Representation of Concrete Pavement Edge Support Conditions

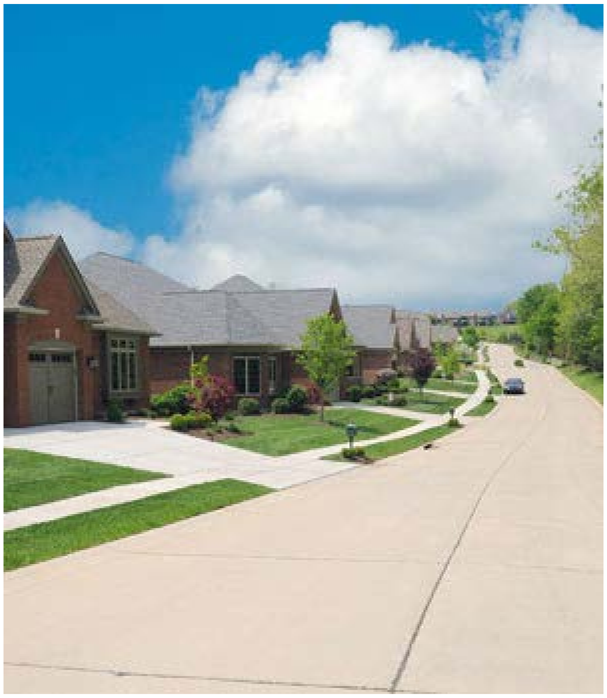

Figure 2. Unsupported Edge (Grass Shoulder) of a Concrete Pavement in a Residential Setting.

Figure 1. Unsupported Edge (Asphalt Shoulder) of a Concrete Pavement in an Urban Setting.

Figure 4. Supported Edge (Curb & Gutter) of a Concrete Pavement in a Rural Setting.

Figure 5. Supported Edge (Inside Widened Lane) of a Concrete Pavement in an Urban Setting.

Figure 3. Supported Edge (Tied Shoulders) of a Concrete Pavement in a Rural Setting.

Tab 3 - Recommended Language for Inclusion of Rigid Pavement in Local Codes

There are various means for including rigid pavement, in its various forms, as an acceptable paving material for streets and local roads and will be dependent upon the structure of the governing ordinances established by the City or County. Typically the Municipal Ordinances and Development Codes define the rules and regulations which govern the processes of operating a city or county. The specific design criteria and other requirements for infrastructure development are typically defined and governed by a manual of engineering practice, standard specifications for materials and construction, and standard details for construction.

Pavement Type Selection

Pavement type selection is the process used to determine which pavement cross section will be used on a given project. The selection process generally includes the following steps:

1. identification of feasible pavement alternatives,
2. the consideration of economic and noneconomic (e.g. environmental) factors, and
3. the selection of the preferred alternative(s).

The pavement type selection decision is generally based upon the results from a life cycle cost analysis that determines the total cost of ownership for various pavement structures that are being compared. Typically, the pavement section with the lowest cost over the evaluation period is selected to be constructed for the project. However, other factors like the environmental impact of building, using, maintaining, and recycling a pavement may also be used separately or in combination with the results of an LCCA to make a pavement type selection decision. Environmental analyses are called Life Cycle Assessments or LCA's. Both economic (LCCA) and environmental (LCA) evaluation methods are covered in more detail below.

Another method that may also be used to select a pavement type for a project is the Alternate Design/Alternate Bidding (AD/AB) process. The Portland Cement Association (PCA) defines AD/AB as a contracting process that gives the contractor a choice to bid on either a rigid, flexible, or composite pavement option, thereby increasing the number of bidders on each job which enhances competition. PCA further states that the benefits of (AD/AB) are:

- Allows multiple paving material industries to participate.
- Increasing the bid pool and competition has proven to result in lower bid prices.
- Considers future expenditures.
- Can lead to innovative solutions and lower costs.

Regardless of the method used to select a pavement type for a project, the end goal should be the development of a competitive environment wherein various paving materials participate in the bidding process. More information about how competition in the paving market can benefit taxpayers and owners may be found at the *Alliance for Pavement Competition* website. Additional information about the pavement type selection process may also be found in NCHRP Report 703 Pavement Type Selection.

Life Cycle Cost Analysis

Life Cycle Cost Analysis (LCCA) is the standard method for costing long-lived construction projects. The LCCA process determines the full costs of mutually exclusive construction options, finding the project design with the lowest total lifetime cost. LCCA evaluates the total economic worth of an infrastructure project by analyzing the initial construction costs plus all future maintenance, user, reconstruction, rehabilitation, restoring, and resurfacing costs discounted to Net Present Value using Office of Management and Budget (OMB) discount rates. Life cycle cost analysis is used to compare alternatives that provide equivalent performance over an analysis period that is at least as long as the life of the most durable alternative; using appropriate historical data and best available estimates for anticipated future maintenance schedules that represent the most current design standards; and using best practice cost estimation procedures that – as best as possible – accurately represent the Owner Agency's expected expenditures over the analysis period in order determine the alternate with the lowest cost of ownership.

Some of the primary inputs to an LCCA are cost values like the initial materials and construction costs and the future maintenance and rehabilitation costs. Other costs may include user delay costs and agency administrative costs like design, engineering, inspection, and traffic control derived during the life-cycle. Other inputs include the analysis period, the anticipated maintenance and rehabilitation activities, the real discount rate for converting future costs to present value, and the remaining service life to determine the salvage benefit of the project at the end of the analysis period.

Model legislative language (i.e. an example bill for consideration at the state legislative level) for implementation of economic considerations in pavement type selection by using LCCA may be found in Appendix 3-A of this Tab.

Life Cycle Assessment

Similar to LCCA, life cycle assessment (LCA) considers how the environment is affected by a roadway over all life-cycle phases, from initial construction to demolition. In an LCA, system boundaries are drawn to capture each mechanism by which pavements impact the environment. These boundaries not only include the materials and activities needed to construct the infrastructure, but also the operation, maintenance, and end of life phases of the life cycle. For pavements, this means accounting for traffic delay, lighting demand, future maintenance, and other phases and components that occur after the pavement is initially put in service. The basic components of a pavement LCA can be seen in the following:

Materials	Construction	Use	Maintenance	End of Life
• Extraction • Production • Transportation	• Equipment • Traffic delay • Transportation	• Rolling resistance • Carbonation • Albedo • Lighting • Leachate	• Materials Phase • Construction Phase	• Equipment • Landfilling • Recycling/reuse • Transportation

While it is important to understand the potential sources of environmental impact over the life cycle, it is often not necessary to quantify each of these elements. Designers, engineers, and decision makers should manage the LCA in such a way that the boundaries are consistent with the goals and scope of a particular study. Drawing upon the best available data, the environmental impacts from each element of the life cycle can be quantified. The infrastructure life cycle is broken down in order to evaluate the relative magnitude of impacts and identify the drivers behind those impacts.

For pavements, the use phase is often important, but the distribution of impacts over the life cycle tends to be correlated with traffic volume. High-volume pavements may have large impacts from traffic-related components (e.g., traffic delay, rolling resistance), whereas impacts from low-volume pavements will likely be dominated by materials-related components. The ability to break down the life cycle and quantify the impact of each element is a key strength of the LCA approach.

Additional information on rigid pavement sustainability and the LCA process may be found in Tab 12 – Sustainability.

The following section contains model ordinance language that may be used at the local level to implement both economic (LCCA) and environmental (LCA) considerations when conducting pavement type selection.

Model Ordinance Language for Implementing Life-Cycle Approach to Pavement Type Selection

The language shown herein may be used at the local level (city or county) in the Development Code but may also be included in the Municipal Ordinances or other governing documents as necessitated by the local situation. The language provided in sections 1.0 through 6.0 is not intended to be exhaustive or expected to cover all design criteria, requirements, or specific local conditions. Modifications to these sections may be necessary for clarity, to fit within the current governing structure, and/or to address local conditions.

1.0 General Requirements

Pavement thickness shall be designed by a Professional Engineer based on a current soils analysis, roadway use, traffic loadings, and life span of proposed pavement. A Geotechnical Investigation is required for the completion of the design for the proposed facilities. Pavement design shall be prepared by the Professional Engineer based on the design method(s) referenced below in *Section 4.0 Pavement Design Methods*.

2.0 Pavement Types[1]

Portland cement concrete or rigid type pavements acceptable for use on streets and local roads include:

1. Conventional portland cement concrete pavement with or without a base on subgrade[2]
2. Pervious concrete with or without base on subgrade
3. Roller-compacted concrete as a riding surface with or without a base on subgrade[2]
4. Roller-compacted concrete as a base on subgrade[2] with an asphaltic overlay
5. Bonded or unbonded concrete overlays

3.0 Pavement Type Selection

Pavement type selection shall be based upon economic and non-economic factors. Economic factors shall be assessed by a life-cycle cost analysis conducted in accordance with *Section 5.0 Life-Cycle Cost Analysis (LCCA)*. Non-economic factors shall be assessed by a life-cycle assessment conducted in accordance with Section *6.0 Sustainability and Environmental Life-Cycle Assessment (LCA)*.

4.0 Pavement Design Methods

The methodology used for the design of new and rehabilitated conventional, jointed concrete pavement, overlays, roller-compacted concrete, and pervious concrete shall be designed using the methods described in *Tab 2 – Rigid Pavement Design*.

[1] Acceptable pavement types listed are for portland cement concrete or rigid type pavements only. A similar list should be included for asphaltic concrete or flexible type pavements acceptable to the local jurisdiction.
[2] The base and subgrade may be unstabilized or stabilized. The base and/or subgrade shall be prepared in accordance with the geotechnical report recommendations and the materials and construction standard specifications.

5.0 Life-Cycle Cost Analysis (LCCA)

Life Cycle Costs Analysis is the process for evaluating the total economic worth of an infrastructure project by analyzing the initial construction costs plus all future maintenance, user, reconstruction, rehabilitation, restoring, and resurfacing costs discounted to Net Present Value using Office of Management and Budget (OMB) discount rates. Life cycle cost analysis is used to compare alternatives that provide equivalent performance over an analysis period that is at least as long as the life of the most durable alternative; using appropriate historical data and best available estimates for anticipated future maintenance schedules that represent the most current design standards; and using best practice cost estimation procedures that – as best as possible – accurately represent the Agency's expected expenditures over the analysis period in order determine the alternate with the lowest cost of ownership.

Specific criteria for implementing the LCCA are found in Appendix 3-A.

6.0 Sustainability and Environmental Life-Cycle Assessment (LCA)[3]

An environmental LCA technique shall be used that takes into account the environmental impacts of:

- Material manufacturing, including resource extraction and recycled content;
- Related transportation;
- On-site construction;
- Regional variation in energy use, transportation and other factors;
- Maintenance, repair and rehabilitation effects; and
- Use Phase

[3]Criteria specifically established for LCA may be found on the NRMCA website at http://www.nrmca.org/Codes/downloads/Life%20Cycle%20Assessment%20Model%20Ordinance.pdf.

Appendix 3-A: Model LCCA Legislation

National Ready Mixed Concrete Association
Life-Cycle Cost Analysis for Transportation Infrastructure Investment

Why is conducting Life-Cycle Cost Analysis Important?

NRMCA supports a balanced and competitive transportation infrastructure investment program—a mix of concrete and asphalt pavements—so that citizens receive increased value, safety and sustainability for fewer tax dollars. For transportation infrastructure projects, transportation and public works agencies should select pavements based on data-driven design and cost considerations utilizing life-cycle costing methodologies. Additionally, both concrete and asphalt pavements should be considered for all road projects through an Alternate Design/Alternate Bidding (ADAB) program. This practice requires equivalent "apples to apples" designs for proposed projects for all pavement types and a life-cycle cost analysis to determine the best value for tax payers. Projects for which LCCA may be utilized include new roadways, reconstruction of existing roadways, or resurfacing of existing roadways where added structural capacity extends the life of the pavement beyond its intended service life. The attached model legislation provides a pathway to equitable transportation infrastructure investment for a state or local jurisdiction.

What is a Life-Cycle Cost Analysis (LCCA)?

Life Cycle Costs Analysis is the process for evaluating the total economic worth of an infrastructure project by analyzing the initial construction costs plus all future maintenance, user, reconstruction, rehabilitation, restoring, and resurfacing costs discounted to Net Present Value using Office of Management and Budget (OMB) discount rates. Life cycle cost analysis is used to compare alternatives that provide equivalent performance over an analysis period that is at least as long as the life of the most durable alternative; using appropriate historical data and best available estimates for anticipated future maintenance schedules that represent the most current design standards; and using best practice cost estimation procedures that – as best as possible – accurately represent the Agency's expected expenditures over the analysis period in order determine the alternate with the lowest cost of ownership.

Some of the primary inputs to an LCCA are cost values like the initial materials and construction costs and the future maintenance and rehabilitation costs. Other costs may include user delay costs and agency administrative costs like design, engineering, inspection, and traffic control derived during the life-cycle. Other inputs include the analysis period, the anticipated maintenance and rehabilitation activities, the real discount rate for converting future costs to present value, and the remaining service life to determine the salvage benefit of the project at the end of the analysis period.

What are the important considerations for an LCCA?

Equitable Design Comparisons
For an LCCA to be effective, the design alternatives being compared must be functionally and structurally equivalent and have similar performance over the analysis period. Therefore, consideration must be given to the design procedure(s) used to determine the pavement cross sections being compared. For highway projects (i.e. projects associated with the federal highway system or high volume roadways under the management of the state department of transportation), it is recommended that the *AASHTO Mechanistic-Empirical Pavement Design Guide (MEPDG)* and its software *Pavement M-E* be utilized to develop the cross sections. To determine equivalent sections, consideration must also be given to establishing comparable distress failure criterion for all pavement types (i.e. flexible, rigid, and composite) which maintains equivalent performance over the pavement's life. Additional key inputs like proper subgrade and traffic characterization must also be considered when developing equitable

designs. Other design procedures that accomplish these goals may be utilized. For further detailed discussion please see the report *"Methodology for the Development of Equivalent Pavement Structural Design Matrix for Municipal Roadways"* by *Applied Research Associates*.

Rehabilitation Activities and Timing

Rehabilitation activities and timing should be assigned based upon what the most likely rehabilitation activities will be for the pavement sections being designed and analyzed. The correct rehabilitation activities may not necessarily be what the Agency has done in the past nor may the timing be based upon the historical timeframes upon which they were administered. For proper comparisons of life cycle costs, the type and timing of rehabilitation activities should be based upon current best practice and anticipated life within the locale.

Analysis Period

The analysis period is the time over which the LCCA is conducted. It is not the same as the performance period upon which the pavement structural design is completed. It is recommended that the analysis period contain at least two rehabilitation cycles which may improve the economic comparisons. The model legislation recommends an analysis period of 50 years. Shorter analysis periods may be used with the understanding that the results may be biased. The analysis period should never be less than 35 years.

Cost Threshold

The pavement materials and construction cost at which an LCCA should be used for pavement selection is set at $500,000 for highway projects (i.e. projects associated with the federal highway system or high volume roadways under the management of the state department of transportation) but could be reduced to $250,000 for street and road projects within counties and municipalities.

User and Agency Costs

If user and agency costs are the same for all design alternatives then they can be dropped from the LCCA; however, it is unlikely that user and agency costs will be the same for different pavement alternatives and therefore should be included in the analysis. The Federal Highway Administration's (FHWA) Economic Primer on LCCA provides discussion on user and agency cost inclusion at: http://www.fhwa.dot.gov/infrastructure/asstmgmt/primer04.cfm

LCCA Probabilistic Approach

Accounting for uncertainty in LCCA inputs allows risk to be assessed in the decision making process. While this is beneficial it may be unrealistic for some agencies to effectively incorporate uncertainty. In these situations deterministic analysis is acceptable. However, it is recommended when deterministic analyses are conducted that a sensitivity analysis be undertaken to better understand how variation in key inputs like costs, rehabilitation timing, etc. will affect the LCCA results.

About NRMCA

Founded in 1930, the National Ready Mixed Concrete Association is the leading industry advocate. Our mission is to provide exceptional value for our members by responsibly representing and serving the entire ready mixed concrete through leadership, promotion, education, and partnering to ensure ready mixed concrete is the building material of choice.

The attached model legislation could be used by NRMCA Affiliates, NRMCA members and other stakeholders in supporting the use of LCCA for transportation infrastructure investment decisions at the state, county or municipal levels. For additional information on concrete's role in transportation infrastructure visit www.nrmca.org or contact Brian Killingsworth, PE, NRMCA Executive Vice President, Local Paving, at (210) 508-4923 or bkillingsworth@nrmca.org.

Disclaimer

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By: [*Insert legislative sponsor's name followed by co-sponsors*]

A BILL concerning

Transportation Infrastructure Investment Act of [Year]

FOR the purpose of requiring the [*State or Jurisdiction*] to define, adopt, and implement a procedure for supporting cost effective decisions related to transportation infrastructure investment; to require the [*State or Jurisdiction*] to conduct a life-cycle cost analysis for transportation infrastructure projects prior to funding appropriation; and provides that the [*State or Jurisdiction*] shall design and award these projects utilizing pavement designs and materials having the lowest life-cycle cost.

SECTION 1: BE IT ENACTED BY THE [*State or Jurisdiction*]:

A. DEFINITIONS

a. LIFE-CYCLE COST - The concept of including acquisition, operating, and disposal costs or salvage value when evaluating various design alternatives.

b. LIFE-CYCLE COST ANALYSIS (LCCA) - A process for evaluating the total economic cost of an infrastructure project by analyzing initial construction costs as well as discounted future costs of maintenance, rehabilitation, user, agency, and disposal costs or salvage value over a 50-year analysis period.

i. User Costs - Driver and resident costs as an aggregation of three separate components: Fuel and Vehicle Operating Costs (VOC), Crash Costs, and User Delay Costs.

ii. Agency Costs - Includes all construction costs related to initial construction and rehabilitation activities. Agency costs also include administrative, design/engineering, and construction management costs for future maintenance and rehabilitation or reconstruction activities. It does not include administrative, design/engineering, and construction management costs associated with initial construction because they are normally similar for both alternates.

iii. Salvage Value - The remaining service life of the pavement at the end of the analysis period calculated using straight-line depreciation.

c. ALTERNATE DESIGN/ALTERNATE BID (AD/AB) - A process under which an agency determines from engineering and economic analysis that at least two project designs, utilizing different construction materials and methods and their forecasted performance and life-cycle costs are comparable and therefore warrants solicitation of bids for each alternative on a project. AD/AB will be utilized when life-cycle costs, for at least two designs using different construction materials, are shown to be within 35%.

d. TRANSPORTATION INFRASTRUCTURE PROJECT - Highway, street, road, or other projects that include pavement surfaces used by vehicles and which pavement cost estimates developed by the [*State or Jurisdiction*] meet or exceed $500,000. Projects for which LCCA will be utilized include new roadways, reconstruction of existing roadways, or resurfacing of existing roadways where added structural capacity extends the life of the pavement beyond its intended service life. LCCA will not be utilized on projects where lanes are added to an in-place facility and no structural capacity is added to the existing pavement structure.

e. BASELINE STRATEGY - A set of defined maintenance and rehabilitation strategies that describe the activities such as maintenance, preservation, reconstruction, rehabilitation, restoration, resurfacing, overlays, etc., and time or year that the activities are performed, to maintain a given pavement type at acceptable performance levels over the analysis period.

f. MECHANISTIC DESIGN PROCEDURE - A pavement design procedure primarily based on a scientific approach that relies on the mechanics of structural behavior to loading where the fundamental material properties and geometric properties of the structure being loaded are known. The procedure may also incorporate some empiricism to reflect historical observed pavement performance. These procedures are used to determine the initial pavement cross sections and the timing of activities used in the baseline strategy.

SECTION 2:

A. DUTIES AND RESPONSIBILITIES

a. Starting no later than six months after the effective date of this act, [*State or Jurisdiction*] shall conduct a LCCA for each transportation infrastructure project and select project alternatives based on lowest life-cycle cost.

   i. The LCCA required by this act may be obtained from government or private sector entities and conducted for an analysis period of 50 years.

   ii. The [*State or Jurisdiction*] shall develop a baseline strategy for each payment type based on the historical performance of existing pavements with similar designs and loading.

   iii. The [*State of Jurisdiction*] shall modify the baseline strategies to take into account:

      1. improvements in design methods, specifications, and materials technology;

      2. taking into consideration pavement performance of existing pavements having similar design and use; or

      3. predicted performance utilizing design procedures based primarily on mechanistic design principals that are validated and calibrated using historical performance of existing pavements.

   iv. The LCCA shall use the most recent White House Office of Management and Budget (OMB) 30 year real interest rate found in Circular A-94 Appendix C or 10 year rolling average of the 30-yr OMB real interest rate to discount future costs to present value.

   v. The cost estimates utilized in the LCCA shall be developed using the GAO “Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Program Costs” so that costs estimates reflect the most likely initial construction and rehabilitation expenditures for that pavement alternate. Such cost will include the use of material specific escalation rates.

      1. Material specific escalation rates shall be established for asphaltic and portland cement based materials used in future maintenance and rehabilitation activities;

2. shall reflect changes in relative commodity prices over time by calculating the difference in historical or estimated inflation rates and the general rate of inflation; and

3. shall be applied to the costs for both the initial construction costs and future rehabilitation and maintenance activities at the year the activity takes place.

vi. The LCCA shall utilize a probabilistic approach and software suitable for the analysis outlined herein.

b. No later than twelve month after the effective date of this act, [*State or Jurisdiction*] shall utilize mechanistic design procedures for the design of all pavement cross sections associated with transportation infrastructure projects.

i. The designed pavement cross sections shall be functionally and structurally equivalent over the performance life for all pavement types (i.e. flexible, rigid, or composite) compared in the LCCA.

ii. Maintenance and rehabilitation schedules for the designed pavement cross sections shall be developed using the type and timing of activities based upon current industry best practice and anticipated life within the locale and pavements must be maintained at the same condition over the analysis period.

c. No later than 12 months after the effective date of this act, the [*State or Jurisdiction*] shall utilize the Alternate Design/Alternate Bid process for all transportation infrastructure projects.

B. REPORTING

a. The [*State or Jurisdiction*] shall report results of the life-cycle cost analysis in a manner freely accessible to the public upon receipt or completion of the report identifying the lowest life-cycle cost option.

SECTION 3: This act becomes effective [Effective Date].

Tab 4 - Determining the Design Values for Base Aggregate and Subgrade Soil Strength[1]

For the design of concrete pavements, the modulus of subgrade reaction (k) is typically used as the measure of base and soil strength and is determined using the field plate-bearing test. However, this field test procedure is not widely preformed; therefore, other strength tests are run with the results correlated to the k-value for input into the design method. Correlations for k can also be determined based on soil type, drainage conditions, and frost conditions at the site. Further discussion on strength value correlations can be found later in this tab.

When a base course is used under the pavement, the k-value on top of the base is used to determine the effective modulus of soil reaction (k_{eff}) which considers both the strength of the underlying subgrade soil together with the base strength. The plate-bearing test may be run on top of the base, or more typically, strength correlations and weighted calculations may be used to determine the effective modulus of soil reaction.

The subgrade strength value used to correlate to the k-value may be determined either by testing the soil in the laboratory (i.e. California Bearing Ratio, CBR or resilient modulus, Mr), testing in place (i.e. estimating CBR from Dynamic Cone Penetrometer, DCP or backcalculating modulus from Falling Weight Deflectometer deflection data), or by correlating strength to another physical property of the soil (i.e. estimating CBR from Plasticity Index). However, it should be noted that the final concrete pavement slab thickness is typically not very sensitive to subgrade/base strength, which means that a conservative ‘guess’ may not impact the design result significantly; however, a geotechnical investigation prior to construction of a project is highly recommended.

Geotechnical Investigations

Subgrade suitability is typically based on test data from a soil sampling and testing plan that includes:

- Classification (Gradation, Atterberg Limits, etc.)
- Depth to Bedrock
- Depth to Water Table
- Potential for Compaction
- Presence of Weak or Soft Layers or Organics
- Susceptibility to Frost Action or Excessive Swell
- Soil Strength Characteristics

A geotechnical engineering report generally will include the:

[1] Additional information regarding subgrade and base properties for design and constructions may be found in *ACPA Technical Series EB204P, “Subgrades and Subbases for Concrete Pavements” online at http://www.acpa.org/free-downloads/*

- Borings Logs;
- Standard Penetration Test (SPT) blows/ft data;
- Material Descriptions;
- Atterberg Limits (LL, PL, PI);
- Moisture-Density Compaction Curves for Predominant Soil Types;
- % Swell (freeze and/or moisture related); and
- Subgrade Strength Characterization.

Geotechnical drilling along the roadway limits is generally used to obtain the needed soil samples. Drilling requirements are based upon the project type and situation but may include:

Geotechnical Drilling (New Pavements)
- Drilling depth should be a minimum of 5 feet below final top of subgrade elevation;
- For high plasticity soils (PI > 25), increase drilling depth to 10 to 15 feet;
- Spacing for boring will be a function of roadway type and soil conditions but drilling every 250 to 500 linear feet alternating between centerline and left and right roadbeds is normally acceptable for street and roads but in no case should exceed 1,000 linear feet;
- Materials for strength testing must be representative of the predominant subgrade soil supporting the pavement structure;
- Drilling may require larger augers at some boring locations for more soil to be sampled as per the requirements of the laboratory testing plan.

Geotechnical Drilling (Existing Pavements)
- Obtain existing pavement thicknesses;
- Spacing as stated above;
- Drilling depths as stated above;
- Materials for soil strength as stated above;
- Consider test pits if full depth reclamation will be used for pavement rehabilitation.

The two primary sampling techniques used in pavement material analysis are disturbed and undisturbed. Each is descriptive of the amount of disruption of the soil matrix from its natural or in situ state.

Disturbed samples are frequently referred to as bulk samples. The materials are generally collected with a power auger with helical flights that raise the materials to the surface so they can be collected. This method is efficient, since a great amount of materials can be collected in a short amount of time.

Undisturbed samples are not requested frequently. The advantage of having these samples is being able to test the material with (relatively) little disturbance, at the moisture content and density at which it was extracted.

Geotechnical engineering firms providing services should be accredited, qualified, and in compliance with the requirements of the following:

- ASTM D3740 Standard Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
- ASTM E329 Standard Specification for Agencies Engaged in Construction Inspection and/or Testing

Testing firms should have accreditation by the American Association of State Highway and Transportation Officials (AASHTO) or similar. Accredited test procedures for geotechnical testing should include:

- ASTM D422 Test Method for Particle-Size Analysis of Soils
- ASTM D558 Test Methods for Moisture-Density Relations of Soil-Cement Mixtures
- ASTM D698 Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3))
- ASTM D854 Test Method for Specific Gravity of Soil Solids by Water Pycnometer
- ASTM D 1140 Amount of Material in Soils Finer than No. 200 Sieve
- ASTM D1557 Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))
- ASTM D1883 Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils
- ASTM D2166 Test Method for Unconfined Compressive Strength of Cohesive Soil
- ASTM D 2216 Water (Moisture) Content of Soil and Rock
- ASTM D2435 Test Method for One-Dimensional Consolidation Properties of Soils
- ASTM D 2487 Classification of Soils for Engineering Purposes
- ASTM D2850 Test Method for Unconsolidated, Undrained Compressive Strength of Cohesive Soils in Triaxial Compression
- ASTM D2938 Test Method for Unconfined Compressive Strength of Intact Rock Core Specimens
- ASTM D4318 Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

Upon completion of the field investigation and laboratory testing program, the geotechnical engineer will typically compile, evaluate, and interpret the data and perform engineering analyses for the design of pavement foundation layers. In addition, the geotechnical engineer may produce a report that presents the subsurface information obtained from the site investigations and may also provide specific pavement section design and construction recommendations. The report should be signed by an engineer who is licensed in the state where the project is located.

Since the scope, site conditions, and design/construction requirements of each project are unique, the specific contents of a geotechnical design report must be tailored for each project. The report should identify subsurface soil and rock conditions and provide recommended design parameters for each of these units. This requires a summary and analysis of all factual data to justify the recommended index and design properties.

Groundwater conditions are particularly important for both design and construction; therefore, they need to be carefully assessed and described. For every project, the subsurface conditions encountered in the site investigation need to be compared with the geologic setting to better understand the nature of the deposits and to predict the degree of variability between borings.

Recommended Test Methods for Determining Soil Strength Values

Laboratory testing of the base and/or soil provides many advantages to the designer which includes a more accurate determination of the strength of the material, quantification of the stress dependency of the material (as is the case with resilient modulus testing), and an indication of the effect that moisture has on the material. The following paragraphs provide basic guidance on the test methods typically employed to determine base and subgrade strength values for use in design.

California Bearing Ratio (CBR)

The laboratory CBR should be measured using *ASTM D 1883 Standard Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils* or similar. Specimens should be prepared at the optimum water content and to 95% of the maximum dry density as determined using ASTM D698 or D1557, depending on the material type and road classification. It is recommended to test the sample after soaking for 96 hours in accordance with the procedure.

Resilient Modulus (M_r)

The resilient modulus is a basic subgrade soil stiffness/strength characterization commonly used in structural design of pavements. Resilient modulus is a measure of the elastic response of a soil (e.g., how well a soil can return to its original shape and size after being stressed) under repeated loading. The resilient modulus of the soils should be determined from the repeated load triaxial test following the AASHTO T 307 procedure entitled *Standard Method of Test for Determining the Resilient Modulus of Soils and Aggregate Materials* or the procedure outlined in the report for *NCHRP Project 1-28A Harmonized Test Methods for Laboratory Determination of Resilient Modulus for Flexible Pavement Design*. The resilient modulus constitutive equation recommended for use in establishing the stress response should follow the form presented in *NCHRP Project 1-28A*. The form of the equation is as follows:

$$M_r = k_1 \cdot p_a \cdot \left(\frac{\theta - 3k_6}{p_a}\right)^{k_2} \cdot \left(\frac{\tau_{oct}}{p_a} + k_7\right)^{k_3}$$

$k_1, k_2 \geq 0$

$k_3, k_6 \leq 0$

$k_7 \geq 1$

where:

M_r = resilient modulus, psi
θ = bulk stress: $\theta = \sigma_1 + \sigma_2 + \sigma_3$
τ_{oct} = octahedral shear stress, psi: $\tau_{oct} = \frac{1}{3} \cdot \sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_1 - \sigma_3)^2 + (\sigma_2 - \sigma_2)^2}$
σ_1, σ_2, σ_3 = principal stresses, psi
k_i = regression constants
p_a = atmospheric pressure (14.7 psi)

Assign initial values of zero (0) for k_6 and one (1) for k_7 and restrain all remaining regression constants according to the model conditions as shown above.

If the AASHTO T 307 procedure is utilized to determine the subgrade resilient modulus the following nonlinear relationship between the soil resilient modulus and the stress state of the soil may alternatively be used (although the NCHRP 1-28A relationship can be used instead if desired):

$$M_r = k_1 \sigma_d^{k_2} \sigma_3^{k_5}$$

where:
M_r = resilient modulus of the soil, psi
k_1, k_2, and k_3 = regression coefficients
σ_d = deviator stress, psi
σ_3 = confining pressure, psi

The pavement designer should determine the design resilient modulus of the soil at the in-situ stress state using an iterative procedure, regardless of the resilient modulus test method that is used. Seasonal variation of the design resilient modulus may also be considered by assuming the following:

- 4 months of the year the modulus will be as determined at the optimum moisture content.
- 3 months of the year the soil will be considered saturated and the modulus will be reduced 33%.
- 5 months of the year the soil will be considered dry and the modulus will be increased by 25%.

<u>The number of months and moisture conditions should be modified to more closely represent local conditions if they differ from the recommendations above.</u>

Backcalculated Modulus From Falling Weight Deflectometer (FWD) Deflection Data
In some situations, it may be possible to backcalculate the subgrade soil modulus from FWD data. As described by the Washington State Department of Transportation, the FWD (Falling Weight Deflectometer) is a non-destructive testing device that is used to complete structural testing to determine pavement structural capacity. It may be used for flexible, composite and rigid pavement structures.

The FWD is a device capable of applying dynamic loads to the pavement surface, similar in magnitude and duration to that of a single heavy moving wheel load. The response of the pavement system is measured in terms of vertical deformation, or deflection, over a given area using seismometers. The use of a FWD enables the pavement analyst to determine a deflection basin caused by a controlled load. These results make it possible to treat pavement structures in the same manner as other civil engineering structures by using mechanistically based design and evaluation methods.

FWD generated data, combined with layer thickness, can be used to obtain the "in-situ" resilient elastic modulus of a pavement structure if the deflection basins (or bowls) adhere to a shape that is consistent with linear elastic analysis. The pavement analyst uses this information in a structural analysis to determine the bearing capacity, estimate expected life, and calculate overlay requirements over a desired design life.

If FWD data is to be used to determine a design modulus value, it is recommended to use the procedures detailed in the following publication and the related design pamphlets:

Analyses Relating to Pavement Material Characterizations and Their Effects on Pavement Performance, United States Department of Transportation, Federal Highway Administration, Contract No. DTFH61-95-C-00029, September 1996. http://www.fhwa.dot.gov/pavement/pub_details.cfm?id=205

Determining Subgrade and Base Strength In-Situ with the Dynamic Cone Penetrometer

The dynamic cone penetrometer (DCP) is a low-cost alternative for determination of pavement layer properties. The DCP may be used to evaluate subgrade strength prior to paving or may be used to assess the properties of unbound materials in an existing pavement structure. It may also be used to assess construction quality for acceptance. The DCP is easy to operate and data analysis is straightforward.

In-situ strength testing using the DCP should be conducted following the procedures and correlations found in *ASTM D6951 / D6951M-09, Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications*. Determining the percent compaction of soils or base at the time of construction should be governed by *ASTM D7380-08, Standard Test Method for Soil Compaction Determination at Shallow Depths Using 5-lb (2.3 kg) Dynamic Cone Penetrometer*.

Subgrade and Base Strength Correlations

Figure 2-1 in ACI 325.12R presents approximate interrelationships of soil classifications and bearing values, including the k-value, for various soil types. In addition, the graphs shown in Figures 1 and 2 in this tab provide correlations that may be used to correlate CBR with the resilient modulus of the soil and the resilient modulus with the modulus of subgrade reaction, k. To determine the resilient modulus (M_r) of the subgrade/base from the CBR in Figure 1, the correlation equation in the AASHTO Mechanistic-Empirical Pavement Design Guide (MEPDG) is recommended. This equation is shown below:

$$Mr = 2,555 \times CBR^{0.64}$$

The other equation, which is published in the *1993 AASHTO Guide for the Design of Pavement Structures*, may be used but is generally considered less accurate at CBR strength values greater than about 5 percent.

Another method that can be used to convert CBR and R-value data to resilient modulus can be found as a web application on the ACPA website. As noted on the ACPA webpage: “This web applet, based on the conversion factors included in *NCHRP Report 128 Evaluation of AASHTO Interim Guide for the Design of Pavement Structures* allows users to quickly estimate the Subgrade Resilient Modulus (MRSG) from either a California Bearing Ratio (CBR) or Resistance Value (R-value) measurement. The conversion from resilient modulus of the subgrade to k-value was updated in the fall of 2011 to better reflect published test results; the constant conversion factor of 19.4 as suggested in the AASHTO Guide for Design of Pavement Structures 1993 is no longer used.” The web app may be found at:
http://apps.acpa.org/applibrary/SubgradeResilientModulus/

Other Subgrade Conditions That May Affect Long-Term Concrete Pavement Performance
Appendix B of ACI 325.12R covers some topics related to subgrade strength values. However, further consideration should be given to the following:

1. Subgrade Soil Stabilization for Increased Strength and Reduced Expansion of Problem Soils
2. Expansive Soils and How to Mitigate
3. Frost Susceptible Soils and How to Mitigate
4. Pumping from Fine-Grained Soils and Construction Details and Methods that Reduce Risks
5. Obtaining Subgrade Support Uniformity for Long-Term Performance

A better understanding of the topics listed above will provide the designer with the background necessary to sufficiently design the subgrade with the goal of achieving long term concrete pavement performance. A review of ACI 325.12R Appendix B as well as the information provided herein is recommended.

Pavement Design on Expansive Soils
Several areas throughout the country will have roadways directly over expansive subgrade soils. It is expected that designers consider the harmful effects of swell when developing pavement sections over expansive soils.

The 1993 AASHTO procedure includes provisions to account for roadbed swelling through a reduction in serviceability or ride quality over time as the roadbed swells. The 1993 AASHTO Guide states on page II-10, “If…roadbed swelling…can lead to a significant loss in serviceability or ride quality during the analysis period, then it should be considered in the design analysis for all pavement structural types…” The intent of this portion of the AASHTO design procedure is to take into consideration what will happen to the pavement section if underlying expansive soils are wetted to a point where they will swell due to exposure to water. In many soils, additional pavement structure may be sufficient and cost effective to reduce the affect of swell due to expansive soils. Therefore, it is recommended that pavement designers utilize this procedure to reduce the effect of soil induced swell on pavement performance.

In deep, highly expansive soils, other mitigation techniques, like over excavation and select fill replacement may also need to be considered in the pavement design to further reduce the potential for underlying clay soils to swell and cause damage to the pavement section. Additionally, other design features should be considered to protect the underlying expansive clays from being wetted by transient ground water.

The estimated Potential Vertical Rise (PVR) for roadways should be determined using an appropriate procedure (one such example is the empirical procedure Texas Department of Transportation (TxDOT) Method Tex-124-E, *Method for Determining the Potential Vertical Rise (PVR)*. An appropriate surcharge load, active zone, and moisture conditions should be considered in estimating the PVR values. Boring depths shall be sufficient to determine the active zone for the expansive soil. Other methods for determining swell may be utilized if proven in the local jurisdiction.

Options to Reduce the Effect of Soil Heave From Moisture or Frost on Pavements

Provided pavement sections are sufficiently designed and constructed to perform in the native soil environments, pavements constructed over highly expansive clays require significant routine maintenance to correct pavement roughness caused by underlying soil swelling. Swell can be reduced through various measures but cannot be totally eliminated without full removal of the problematic soil in the first place. Measures that are acceptable for reducing swell under concrete pavements include the following:

- Chemical Injection of Soil
- Soil Treatment with Lime or Cement
- Removal and Replacement of High PI Soils
- Drains or Barriers to Collect or Inhibit Moisture Infiltration

<u>Chemical Injection</u>

Chemical stabilization/injection techniques are used to treat expansive clay soils. The method involves the injection of potassium based chemical(s) into the soil to supply cations to the clay and neutralize the clay's imbalanced electrical charge. Some methods consists of drilling one to two inch diameter holes in the soil to depths ranging from one to ten feet on a grid (a 2 x 2 foot grid is typical). Chemical injection is completed using high injection pressures of about 200 to 300 psi and is injected through the access holes for a period of time. This injection time may vary depending on the soil conditions and project requirements (a few hours to several days may be needed).

Chemical stabilization is best utilized on soils that are in an in-situ condition that is dryer than the optimum moisture content of the questionable soil as well as soils that have cracks and fissures and/or a soil matrix that is “open” or in other words allows the pressure injected chemicals to easily permeate the soil matrix. Non-fissured soils can be chemically treated given ample time and high enough pressures for the chemical to permeate the soil.

Soil Treatment

Soil treatment with lime or cement is typically used to reduce the swelling potential of the upper portion of the pavement subgrade. Lime or cement and water are mixed with the top 6 to 12 inches (or possibly more) of the subgrade and allowed to mellow or cure for a period of time. After curing the treated soil mixture is compacted to form a strong soil matrix that can improve pavement performance and reduce soil heave.

It is recommended that lime be placed in slurry form only, unless a safety and containment plan is in place for dry lime application.

To include a lime stabilized layer as part of the structural pavement system or when attempting to increase the k-value to reduce concrete thickness, the application rate of lime should be determined based on laboratory testing and shall be the lowest percentage of lime that provides:

- a pH of 12.4 or the highest pH achieved in accordance with ASTM D6276 *Standard Test Method for Using pH to Estimate the Soil-Lime Proportion Requirement for Soil Stabilization*,
- a PI of less than 20 in accordance with ASTM D4318 *Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils*,
- an unconfined compressive strength (UCS) at 7-days of at least 160 psi in accordance with ASTM D5102 *Standard Test Methods for Unconfined Compressive Strength of Compacted Soil-Lime Mixtures (Procedure B) (*In addition, curing should occur for 7 days at 40C and specimens should be subjected to 24-hr capillary soak prior to testing*)*, and
- [*Optional Criteria for Expansive Soils*] a three dimensional expansion of less than 1% (or maybe 2%).

For construction verification the following shall be conducted in the field:

- After initial mixing the soil-lime mixture shall mellow for a period of two to three (2 – 3) days. Maintain moisture during mellowing;
- After mellowing and final mixing, the pulverization shall be checked using the following criteria (remove non-slaking aggregates retained on the ¾ inch sieve from the sample):
  - Minimum passing 1 ¾” sieve 100
  - Minimum passing ¾” sieve 85
  - Minimum passing No. 4 sieve 60
- Sample soil-lime mixture for determination of MDD. In the laboratory, mold specimens to 95% of MDD at optimum moisture content and verify UCS to be at least 160 psi in accordance with procedure outlined above for mixture design.
- Compact and check field density (minimum of 95% of MDD required);

- Cure for an additional 2 to 5 days (total mellowing and curing time should total at least 5 days).
- Verify depth of lime stabilized layer to depth as noted on plan to within +/- 1.0 inches.

Removal and Replacement

Removal of highly expansive soils and replacement with lower PI soil or select fill significantly reduces the potential for vertical rise or heave of soils underlying a pavement. The amount of soil to remove and replace is dependent upon the acceptable amount of swell, the PI of the natural soil, the available moisture, and the overburden pressure from the overlying pavement. Removal and replacement can be a very effective method for minimizing heave but can be labor intensive and cause complications in construction depending on the job site conditions. However, the resulting cost savings to future maintenance can make this technique cost effective over the life cycle of the pavement. With highly expansive clays removal of up to 5 or 6 feet or more of the subgrade and replacement with a non-expansive select fill typically would reduce the PVR to acceptable levels.

Drains and Moisture Barriers

Capturing water infiltration via French drains, pavement edge drains, or inhibiting water through the use of vertical moisture barriers would reduce the potential for heave since one important component of the heaving mechanism, water, would be reduced.

Further information regarding soil improvement for pavement applications may be found at:

Geotech Solutions for Soil Improvement SHRP2 2014

Guidance for Improving Foundation Layers to Increase Pavement Performance on Local Roads

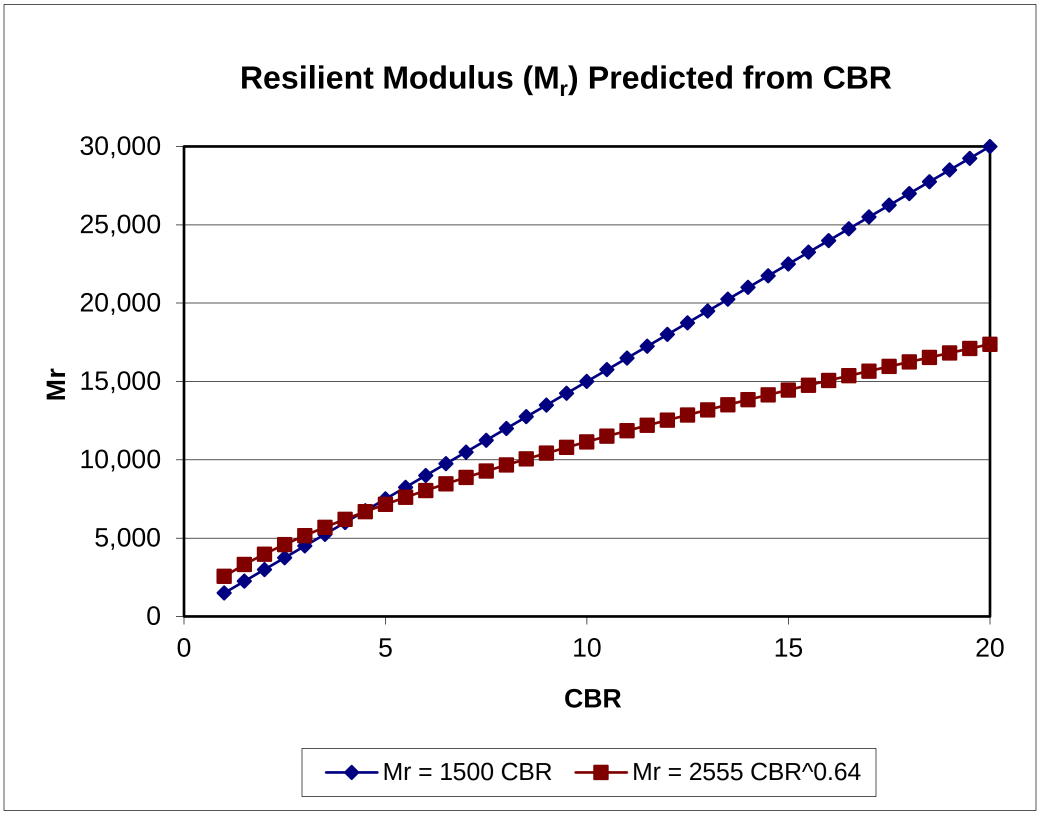


Figure 1. Resilient Modulus (M_r) of Subgrade or Base as a Function of California Bearing Ratio (CBR) Using AASHTO 1993 and ME Models.

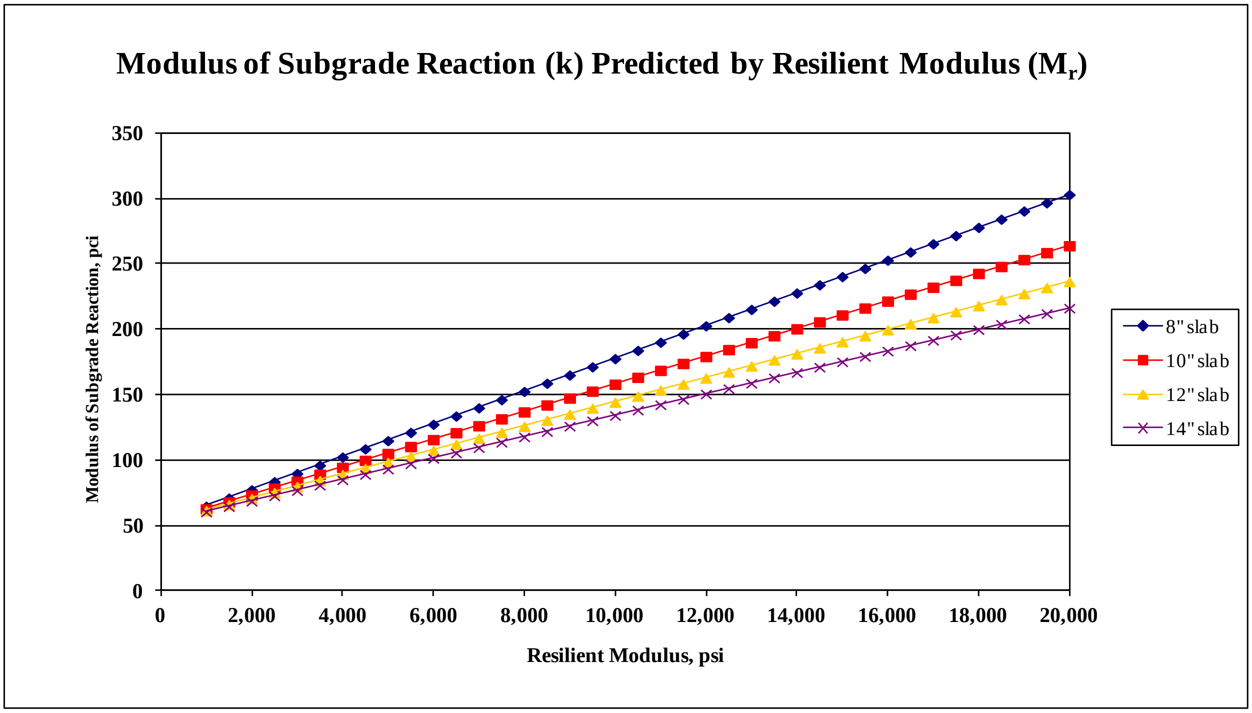


Figure 2. Modulus of Subgrade Reaction (k) of Subgrade or Base as a Function of Resilient Modulus (M_r) Utilizing Equivalent Deflection Analysis.

Tab 5 - Traffic Conditions

To determine the pavement thickness, the designer needs to know the types of vehicles that will use the pavement (such as passenger cars, light trucks, heavy trucks, and school or commuter buses), the number of trips for each vehicle type, vehicular loads, and the daily volume or total volume anticipated for the facility over the design life. It is important to note that although cars do some damage to pavements, heavy vehicles or trucks do the most damage and therefore must be accounted for as accurately as possible both initially and over the design life of the pavement.

For streets and roads as well as parking lots, heavy vehicle traffic will typically include buses, 2 or 3 axle delivery trucks, construction vehicles like dump trucks or concrete trucks, trash pick-up trucks, and semi tractor-trailer rigs. Generally, these vehicles will fall into Classifications 4 through 9 in the FHWA vehicle classification definitions (see Tab 5a).

Converting the traffic stream into a usable number or set of values for use in a pavement design method is typically called traffic characterization. Each design method will indicate the form of the traffic characterization needed for the design. There are many ways to characterize traffic and may consist of one of the following characterizations depending on the design method:

- Average Daily Truck Traffic (ADTT)
- ADTT with Axle Load Spectra
- Average Daily Traffic (ADT) with % Trucks
- Equivalent Single Axle Loads (ESALs)

The definitions for these traffic terms are:

Average Daily Truck Traffic (ADTT) - The average daily number of trucks (FHWA vehicle classes 4-13) expected over the day.
ADTT with Axle Load Spectra – The total axle applications within each load interval for single, tandem, and tridem axles.
Average Daily Traffic - The average daily number of vehicles (FHWA vehicle classes 1-13) expected over the day.
Percent Trucks - The percent of trucks (FHWA vehicle classes 4-13) in the average daily traffic stream that are expected over the day.
*Equivalent Single Axle Load*s - The effect on pavement performance of any combination of axle loads of varying magnitude equated to the number of 18,000-lb. single-axle loads that are required to produce an equivalent effect.

When specific traffic information is unknown, vehicular estimates may be made based on the street class (Residential, Collector, Arterial, etc.) that is being designed.

Parking Lots and Service Roads

Table 5.1 which is taken from ACI 330R classifies traffic in terms of four categories defined as A, B, C, and D where A is for car parking areas, B is for shopping center drives and delivery lanes, C is for bus (commuter and school) parking and lanes, and D is for truck parking. 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 is the same as Category B, except that the heaviest axle loads have been eliminated. Category D consists only of tractor semitrailer trucks with total gross weights of 80 kips (80,000 lbs). The typical axle weight ranges for each category are as follows:

Table 5.1. Category and Axle Load Weights (Table 3.3 from ACI 330R-08)

Category	Weight Range, kips	
	Single Axles	Tandem Axles
A	4 – 16	4 – 32
B	4 – 22	4 – 36
C	8 – 26	8 – 44
D	16	32

Tab 5b contains various heavy vehicles that commonly use parking lots as well as entrance and exit drives. The distributed axle weights, both loaded and unloaded, are shown as well as the estimated damage and Equivalent Single Axle Load (ESAL) factors so that comparisons may be made with other common design procedures.

Streets/Roads and Industrial Areas

As discussed in ACI 325.12R, the determination of a design thickness requires some knowledge of the range and distribution of traffic loads expected to be applied to the pavement over the design period. Although accurate traffic predictions are difficult to achieve, the designer should obtain some information regarding the types of trucks that will use the pavement, the number of each truck type, truck loads, and the daily volume anticipated over the design life. Passenger cars and pickup trucks typically cause little or no distress on concrete pavements and can be excluded from the design traffic.

The heaviest axle loads control concrete pavement thickness design and resulting pavement performance. Documented traffic data may contain some inaccuracies because the number and the magnitude of the heaviest axle load groups may not have been recorded. A few very heavy axle loads can play a critical role in the cracking and faulting performance of thin concrete pavements. The design engineer should determine the number and types of trucks that can use the facility in the future, particularly in regard to garbage trucks, concrete trucks, construction vehicles, or other heavy traffic that may have load exemptions within a certain travel radius.

The design engineer also can derive the gross and axle weights of the trucks, which can be done by assuming the loaded axles conform to state legal load limits, such as 18 kip for single axle, and 34 kip for tandem axle. Overloaded vehicles should be more carefully determined. These can then be projected into the future by forecasting the growth curve of the facilities to be serviced by the new pavement. The forecast can be based on curves constructed to parallel the trends in area population, utility growth, driver or vehicle registration, or commercial developments.

Items to consider when predicting traffic include:

- Traffic volumes (ADT and ADTT) are usually expressed as the sum of two-directional flow and should be divided by two to determine a design value;
- Traffic flow for two-lane roadways seldom exceeds 1,500 vehicles per hour per lane, including passenger cars, and may be less than ½ this value in rolling terrain or where roadside interference exists; and
- Where traffic is carried in one direction in multiple lanes, 75 to 95% of the trucks, depending on traffic, will travel in the lane abutting the right shoulder.

In the absence of detailed traffic data, pavement designs may be based upon street classifications or roadway use. The street classifications outlined in Table 5.2 may or may not correspond to the classifications used in any metropolitan area. They are given to indicate, generally, the volumes and axle weights of traffic using streets. The values are reasonable but should be tempered with knowledge of local traffic patterns.

Table 5.2—Street Classification (Table 3.1 from ACI 325.12R-02)

		Heavy commercial vehicles (two-axle, six-tire, and heavier)	
Street classification	**VPD or ADT, two-way**	**%**	**No. per day**
Light residential	200	1 to 2	2 to 4
Residential	200 to 1000	1 to 5	10 to 50
Collector	1000 to 8000	3 to 5	50 to 500
Minor arterial	4000 to 15,000	10	300 to 600
Major arterial	4000 to 30,000	15 to 20	700 to 1500
Business	11,000 to 17,000	4 to 7	400 to 700
Industrial	2000 to 4000	15 to 20	300 to 800

Table 5.3 Street Classifications and Typical Range of Concrete Slab Thicknesses (Not to be used for design).

Street Class	Description	Two-way Average Daily Traffic (ADT)	Two-way Average Daily Truck Traffic (ADTT)	Typical Range of Slab Thickness
Light Residential	Short streets in subdivisions and similar residential areas – often not through-streets.	Less than 200	2-4	4.0 - 5.0 in. (100-125 mm)
Residential	Through-streets in subdivisions and similar residential areas that occasionally carry a heavy vehicle (truck or bus).	200-1,000	10-50	5.0 - 7.0 in. (125-175 mm)
Collector	Streets that collect traffic from several residential subdivisions, and that may serve buses and trucks.	1,000-8,000	50-500	5.5 - 9.0 in. (135-225 mm)
Business	Streets that provide access to shopping and urban central business districts.	11,000-17,000	400-700	6.0 - 9.0 in. (150-225 mm)
Industrial	Streets that provide access to industrial areas or parks, and typically carry heavier trucks than the business class.	2,000-4,000	300-800	7.0 - 10.5 in. (175-260 mm)
Arterial	Streets that serve traffic from major expressways and carry traffic through metropolitan areas. Truck and bus routes are primarily on these roads.	4,000-15,000 (minor) 4,000-30,000 (major)	300-600 700-1,500	6.0 - 9.0 in. (150-225 mm) 7.0 - 11.0 in. (175-275 mm)

Tab 5a - FHWA Vehicle Classes with Definitions

1. **Motorcycles** -- All two or three-wheeled motorized vehicles. Typical vehicles in this category have saddle type seats and are steered by handlebars rather than steering wheels. This category includes motorcycles, motor scooters, mopeds, motor-powered bicycles, and three-wheel motorcycles.
2. **Passenger Cars** -- All sedans, coupes, and station wagons manufactured primarily for the purpose of carrying passengers and including those passenger cars pulling recreational or other light trailers.
3. **Other Two-Axle, Four-Tire Single Unit Vehicles** -- All two-axle, four-tire, vehicles, other than passenger cars. Included in this classification are pickups, panels, vans, and other vehicles such as campers, motor homes, ambulances, hearses, carryalls, and minibuses. Other two-axle, four-tire single-unit vehicles pulling recreational or other light trailers are included in this classification. Because automatic vehicle classifiers have difficulty distinguishing class 3 from class 2, these two classes may be combined into class 2.
4. **Buses** -- All vehicles manufactured as traditional passenger-carrying buses with two axles and six tires or three or more axles. This category includes only traditional buses (including school buses) functioning as passenger-carrying vehicles. Modified buses should be considered to be a truck and should be appropriately classified.
5. **Two-Axle, Six-Tire, Single-Unit Trucks**[1] -- All vehicles on a single frame including trucks, camping and recreational vehicles, motor homes, etc., with two axles and dual rear wheels.
6. **Three-Axle Single-Unit Trucks** -- All vehicles on a single frame including trucks, camping and recreational vehicles, motor homes, etc., with three axles.
7. **Four or More Axle Single-Unit Trucks** -- All trucks on a single frame with four or more axles.
8. **Four or Fewer Axle Single-Trailer Trucks** -- All vehicles with four or fewer axles consisting of two units, one of which is a tractor or straight truck power unit.
9. **Five-Axle Single-Trailer Trucks** -- All five-axle vehicles consisting of two units, one of which is a tractor or straight truck power unit.
10. **Six or More Axle Single-Trailer Trucks** -- All vehicles with six or more axles consisting of two units, one of which is a tractor or straight truck power unit.
11. **Five or fewer Axle Multi-Trailer Trucks** -- All vehicles with five or fewer axles consisting of three or more units, one of which is a tractor or straight truck power unit.
12. **Six-Axle Multi-Trailer Trucks** -- All six-axle vehicles consisting of three or more units, one of which is a tractor or straight truck power unit.
13. **Seven or More Axle Multi-Trailer Trucks** -- All vehicles with seven or more axles consisting of three or more units, one of which is a tractor or straight truck power unit.

[1] NOTE: In reporting information on trucks (Classes 5-13) the following criteria should be used:
- Truck tractor units traveling without a trailer will be considered single-unit trucks.
- A truck tractor unit pulling other such units in a "saddle mount" configuration will be considered one single-unit truck and will be defined only by the axles on the pulling unit.
- Vehicles are defined by the number of axles in contact with the road. Therefore, "floating" axles are counted only when in the down position.
- The term "trailer" includes both semi- and full trailers.

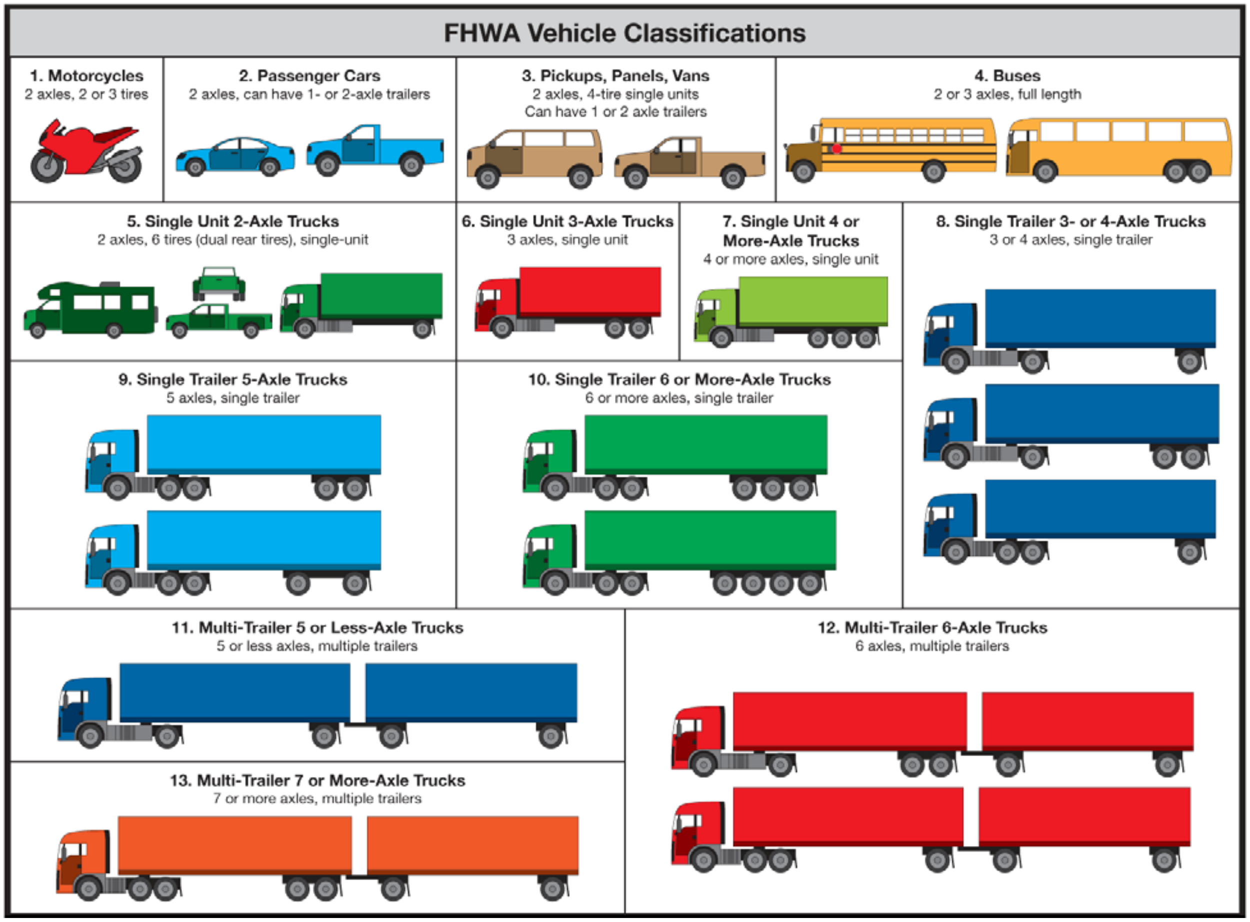


Figure 1. Graphical Reference to FHWA Vehicle Classifications. ***(Source: TxDOT Traffic Recorder Instruction Manual, February 2012, Copyright © 2012 by Texas Department of Transportation)***

Tab 5b – Truck Axle Weights and ESAL Factors for Common Heavy Vehicles

Vehicle Types

Concrete Truck

	Steering Single Axle	Drive Tandem Axle (Unloaded)	Trailer Tridem Axle (Loaded)	
Weight Distribution	15%	85%	85%	

Total Weight (Loaded) = 65,000.0 lbs.
Total Weight (Unloaded) = 25,000.0 lbs.

Axle Weights (lbs)	Steering	Drive	Trailer	
Loaded	9,750.0		55,250.0	
Unloaded	3,750.0	21,250.0		

Damage Factors (based on 18 kip ESALs)	Steering	Drive	Trailer	ESAL Factor
Loaded	0.086	0.000	1.755	1.841
Unloaded	0.002	0.153	0.000	0.154

Garbage Truck

	Steering Single Axle	Drive Tandem Axle
Weight Distribution	15%	85%

Total Weight (Loaded) = 50,000.0 lbs.
Total Weight (Unloaded) = 20,000.0 lbs.

Axle Weights (lbs)	Steering	Drive	
Loaded	7,500.0	42,500.0	
Unloaded	3,000.0	17,000.0	

Damage Factors (based on 18 kip ESALs)	Steering	Drive	ESAL Factor
Loaded	0.030	2.441	2.472
Unloaded	0.001	0.063	0.063

School Bus (Blue Bird)

	Steering Single Axle	Drive Single Axle (Dual Wheel)
Weight Distribution	36%	64%

Total Weight (Loaded) = 31,000.0 lbs.
Total Weight (Unloaded) = 19,500.0 lbs.

Axle Weights (lbs)	Steering	Drive
Loaded	11,160.0	19,840.0
Unloaded	7,020.0	12,480.0

Damage Factors (based on 18 kip ESALs)	Steering	Drive	ESAL Factor
Loaded	0.148	1.476	1.624
Unloaded	0.023	0.231	0.254

City Transportation Bus

New Flyer 40-ft Low Floor

	Steering Single Axle	Drive Single Axle (Dual Wheel)
Weight Distribution	35%	65%

Total Weight (Loaded) = 31,500.0 lbs.
Total Weight (Unloaded) = 21,500.0 lbs.

Axle Weights (lbs)	Steering	Drive
Loaded	11,025.0	20,475.0
Unloaded	7,525.0	13,975.0

Damage Factors (based on 18 kip ESALs)	Steering	Drive	ESAL Factor
Loaded	0.141	1.674	1.815
Unloaded	0.031	0.363	0.394

NABI 40-ft Low Floor

18-Wheel Tractor-Trailer

	Steering Single Axle	Drive Tandem Axle	Trailer Tandem Axle
Weight Distribution	15.00%	42.50%	42.50%

Total Weight (Loaded) = 80,000.0 lbs.
Total Weight (Unloaded) = 32,000.0 lbs.

Axle Weights (lbs)	Steering	Drive	Trailer
Loaded	12,000.0	34,000.0	34,000.0
Unloaded	4,800.0	13,600.0	13,600.0

Damage Factors (based on 18 kip ESALs)	Steering	Drive	Trailer	ESAL Factor
Loaded	0.198	1.000	1.000	2.198
Unloaded	0.005	0.026	0.026	0.056

legal U.S. weight per axle is: STEER 12,000 lbs DRIVES 34,000 lbs TRAILER 34,000 lbs

Tab 6 – Rigid Pavement Design Optimization

Simply designing a rigid pavement and accepting the answer without considering several important ancillary conditions is short-sided and may cause the concrete cross section to be expensive and uncompetitive. Optimizing the design will enable the designer to develop pavement sections that are truly applicable to the project conditions.

Design optimization for the various rigid pavement types – conventional, roller compacted, and pervious concrete – may share many of the same considerations. These may include avoiding overdesign by using the appropriate thickness design methods, refining design inputs to match the specific project requirements and conditions, maximizing maintenance methods and timing so as not to allow the pavement to become too distressed, and conducting multiple life-cycle cost analyses during the design phase to find the lowest cost alternative that meets the project requirements.

Other optimization considerations are specific to the rigid pavement type. For example, evaluating the transverse joint spacing so that the joints are placed at the optimal distance is important for conventional and pervious concrete whereas simply determining if joints are necessary is a consideration for roller compacted concrete. For pervious concrete, an important consideration may be the depth of a base layer to either meet the hydraulic or traffic loading needs of the pavement.

Specific details that can be optimized in a conventional concrete pavement design can include several items and requires asking the questions associated with each item as listed below:

- Base:
  - What conditions exist that would require a base under the rigid pavement?
  - If a base is required, what type is appropriate and how thick should it be?
  - If a bound, treated, modified, or stabilized base is used, what strength is needed?
- Reinforcing Steel:
  - What conditions are present where steel reinforcement would improve performance?
  - If steel is needed, what size, dimension, and quantity are needed?
- Load Transfer Condition:
  - Are dowels needed to improve load transfer efficiency?
  - If dowels are needed, what size, shape, and dimensions are needed?
- Joint Sealing:
  - Are there environmental or loading conditions present that require joints to be sealed?
  - If joints are to be sealed, what type of sealant is best for the project?

The important aspect to remember is to ask is whether each detail is needed or pertinent to the project being designed and if so, how can the costs be minimized while still meeting the project objectives? The answer to each of the questions listed above will be the driving forces behind whether the detail should or should not be included in the design. The following paragraphs delve deeper in to the questions above and help to answer them.

Bases

For most concrete pavement design procedures, the overall concrete slab thickness is not significantly affected by the inclusion of a base layer below the concrete slab. For example, a 6-inch aggregate base, in most cases, will not reduce the concrete slab thickness enough to substantially reduce the initial cost of the pavement. Typically, bases are needed under a concrete pavement when one or more situations occur. These include:

- heavy traffic loads and frequency,
- subgrade pumping (erosion) potential,
- water availability like a high water table or standing water near the pavement,
- risk of deep frost penetration/heave,
- risk of heave from expansive soils,
- project timing or phasing requires a temporary drivable surface, or
- an adequate paving surface is needed.

Bases under pervious concrete pavement may be used to hold water over a low permeability soil or if there is a possibility that a freeze event may occur at some point during its performance life when water could be in the pervious concrete layer. If one or more of the conditions above do exist, it is important to select the correct base. Many times, local conditions will dictate which base is more viable from a performance and/or economic standpoint. Some of the available base types are shown in the list below:

- Granular (Crushed Stone)
- Treated Aggregate (Cement, Lime, Fly Ash, or Combination as well as Bituminous)
- Recycled (Concrete or Asphalt)
- Permeable With or Without Drainage System

If local or project conditions exist where a base does not make sense, there are other options available to improve concrete pavement performance. Subgrade soil stabilization with cement, lime, fly ash, or a combination of materials is a very good option in terms of performance and economics. Laboratory mixture designs to determine the optimum amount of stabilizer as well as the required depth from the pavement design needs to be completed.

Other options like soil mixing and improving subsurface drainage are other options that can be considered based upon the project conditions and may alleviate performance challenges. More information on subgrade and base design is contained in *Tab 4 - Determining the Design Values for Base Aggregate and Subgrade Soil Strength*.

Reinforcing Steel

Long-term performance history of jointed concrete pavements with steel has been marginal and therefore jointed, reinforced concrete pavement (JRCP) is no longer recommended except in specific circumstances. When we consider that steel does not contribute to the load carrying capacity of the pavement and was used primarily to keep cracks tight (which we can do with appropriate joint spacing) adding steel in normal circumstances does not add value to the pavement. It is recommended to use steel only when random cracking may occur due to frost heave or if expansive soils are present and moisture cannot be controlled.

CRCP is concrete pavement reinforced with continuous steel bars throughout its length and is found on some interstates and highways (in a limited number of states) carrying significant volumes of trucks and passenger vehicles. Its design eliminates the need for transverse joints (other than at bridges and other structures) and keep cracks tight, resulting in a continuous, smooth riding surface that is very low maintenance. With the potential to accommodate any level of traffic, under climatic extremes, CRCP has the potential to be used in low volume situations but will need to be assessed for each project and used in the correct situation.

Dowels

In low volume traffic situations or when there are few trucks present, there is no need to add dowels at saw-cut or construction joints on concrete pavement. The only time dowels may be needed is when the number of trucks exceeds 200 per day *(this number may be changed depending on local conditions and experience)* or if there are weak subgrade conditions that extend deep below the pavement. Other times dowels may be needed include concrete mixtures that have proven poor aggregate interlock. If one of these conditions exists and dowels are needed on thin pavements, those less than 8 inches in thickness, plate dowels may be used.

Information about jointing, dowels, and the use plate dowels are found in the references listed below:

CPTech Center Guide for Optimum Joint Performance of Concrete Pavements 2012
CPTech Center Guide to Dowel Load Transfer Systems for Jointed Concrete Pavements 2011
ACPA RT 10.01 - Plate Dowels 2010

Joint Sealing

Typically joint seals are not needed in low volume traffic/truck situations. However, before making a decision several questions should be asked and include:

- Will the Joint Sealant be Maintained Over Time?
- Is There Water or Wind Blown Material Present?
- Is Subgrade Likely to Pump?
- Is There Risk of Joints Opening (i.e. Expansive Subgrade)?

If these risks can be minimized, joint sealing may not be necessary. If joint sealing is considered, information contained in *Joint Movement Estimator for Designing Transverse Joint Seal Installations* from the Seal No Seal Group is useful in selecting the joint seal type and joint reservoir design.

Tab 7 – Materials and Construction Specifications

There are different ways an owner can specify how to manufacture, deliver, and construct rigid pavement layers. Some materials and construction specifications prescribe very clearly the acceptable means and methods of production and construction while others simply state what the performance requirements for the material should be and allow the material producer and construction contractor to figure out how to produce and construct the material (within certain boundary conditions).

The specification becomes the general "agreement" or "rules" between the parties (the owner and the construction contractor) for building the pavement. The risk that each party undertakes is an inherent part of the specification. A specification where the means and methods are heavily dictated by the owner agency, the agency bears almost all of the risk when something goes wrong. On the contrary, a performance specification places most of the risk on the producer and contractor. There are specifications where the balance of risk is more equally shared between the owner and contractor. These specifications are sometimes considered a hybrid because they may contain elements of both a prescriptive as well as a performance type specification. The various types of specifications that are utilized for pavement production and construction typically include:

- Method or Prescriptive
- End Result
- Quality Control/Quality Acceptance (QC/QA) (also called Quality Assurance or QA)
- Performance Related (PRS)
- Performance Based
- Warranty

Most of these specifications are defined and discussed by the American Association of State Highway and Transportation Officials (AASHTO) in the document entitled *"Major Types of Transportation Construction Specifications: A Guideline to Understanding Their Evolution and Application"* which was developed by the AASHTO Highway Subcommittee on Construction Quality Construction Task Force in August 2003 and provides a good overview of each of the specification types and the historical experience in the U.S.

Recommended Specifications for Use on Streets and Local Roads

Guide or example specifications for various rigid pavement types that are used to construct streets and local roads may be found in the references listed below. These include specifications for conventional concrete, roller compacted concrete, pervious concrete, concrete overlays, full depth reclamation with cement, and soil cement. An example specification from Wisconsin specifically related to joint sealing is also included as reference.

Conventional Jointed Plain Concrete Pavement
NRMCA PCC SLR Materials and Construction Specification 2012

Roller-Compacted Concrete Pavement
ACPA RCC Guide Specification Roller-Compacted Concrete Pavements as Exposed Wearing Surface 2014

Pervious Concrete Pavement
ACI 522.1-13 Specification for Pervious Concrete Pavement

Bonded or Unbonded Concrete Pavement Overlays
CPTech Center Guide to Concrete Overlays 2014
SUDAS Jointing Concrete Overlays 2013

Full Depth Reclamation With Cement
CP Tech Center Guide to Full-Depth Reclamation (FDR) with Cement 2017

Concrete Pavement Joint Sealing
Wisconsin Concrete Pavement Association Joint Sealing Specification 2009

HIPERPAV (for construction phase assessment of early age behavior of conventional concrete)
Another important consideration for concrete paving is understanding the early age behavior of concrete mixtures and how the component properties will affect this behavior. A program called HIPERPAV was developed to help understand early age behavior of conventional concrete paving materials. With HIPERPAV, you can input everything you know about a concrete project – mix design, joint design, subbase type, curing method, weather conditions, sawcut timing, everything – and accurately predict the stress and strength behavior of the concrete over the first critical 72 hours.

The HIPERPAVE software can be downloaded at http://www.hiperpav.com/ and the following document links are provided for ready reference:

HIPERPAVE Overview
HIPERPAVE Volume I Overview 2005
HIPERPAVE Volume II Users Guide 2005
HIPERPAVE Volume III Technical Background 2005

Tab 8 – Construction Details

The proper development and implementation of construction details plays a critical role in the performance of a pavement as well as the economic viability of the pavement cross section. Details convey to the contractor and other job personnel certain expectations about the construction process. Details also become a part of the contractual agreement between the owner and the contractor so their importance cannot be understated.

Included within this guide are various details related to rigid pavements. Primarily these details include joints, drainage structures, curbing, driveways, sidewalks, and overlays for conventional concrete as well as some details for pervious concrete. These details may be obtained from the Ready Mixed Concrete Research and Education Foundation website here.

Tab 9 – Concrete Mixtures

Conventional Concrete Paving Mixtures

The design of a conventional concrete mixture suitable for paving includes the desired outcomes of production, construction, service life, economy and sustainability. Material selection and mixture proportioning are the means of obtaining the goals of the mixture design, and must consider materials suitability and availability in relation with the proposed production technology and construction constraints.

Concrete paving mixtures have purposes and desired characteristics that are different from other types of mixtures, such as structural or mass concrete. Trial mixture proportions are for concrete consisting of normal aggregates and concrete with workability suitable for usual pavement construction. A suitable method provides an initial approximation of proportions intended to be analyzed to assess their performance potential for mixing, transporting, placing, consolidating, screeding, finishing, texturing, strength, durability, abrasion resistance, skid resistance, smoothness, and volume stability. The mixture should be checked for incompatibilities of materials in given construction environments. Resulting proportions should be checked by preparing and analyzing trial mixtures in the laboratory and then in the field and adjusting as necessary to produce the desired concrete characteristics.

ACI 211 provides an in-depth discussion of concrete mixture characteristics and technology; however, concepts specific to paving mixtures are not fully developed in the 211 document. With this in mind, the ACI 325 committee has developed a mixture and proportioning document entitled "*Guide for Design and Proportioning of Concrete Mixtures for Pavements*" to specifically address the concrete paving mixture. This Guide is currently unpublished but is in the review and voting process with an anticipated publication date in 2015.

Until such time as the ACI 325 document is available, it is recommended that concrete paving mixtures be designed using local, proven mix design methods or by following the recommendations in the Integrated Materials and Construction Practices for Concrete Pavement: A State-of-the-Practice Manual, specifically Chapter 6.

COMPASS

Optimizing concrete mixtures specifically for the locally available materials and environment is another key consideration in conventional concrete mixture design. COMPASS is an available tool that allows mix designers to assess material properties in light of the local conditions. As reported in the FHWA MAP Brief 1-1:

> *The industry needs a concrete mixture optimization tool that can isolate properties of interest and simplify the approach to the mixture proportioning process based on site-specific conditions. In response to this need, the Federal Highway Administration (FHWA)*

developed the Concrete Mixture Performance Analysis System (COMPASS), a windows-based application system that uses a proven statistical optimization approach and includes many practical features and analysis techniques to help users optimize concrete mixtures.

With COMPASS, a user can optimize the performance of a concrete mixture in a particular environment by properly selecting material constituents, such as types of aggregates, cementitious materials, and admixtures, that will benefit properties identified as important to a particular environment, project type, and degree of importance of the project.

The user can also determine the appropriate gradation and material constituent proportions that will enhance the performance of a mixture. The user can then take the guidance offered by COMPASS and apply it to the optimization of mixture proportions.

The COMPASS tool can be downloaded at http://www.pccmix.com/download-compass/ and the COMPASS Users Guide provides background information and details about the software.

Mixture Design Resources for Other Cement Based Paving Materials
Mixture design procedures for other rigid paving materials may be found in:

Roller Compacted Concrete (RCC)
CPTech Center RCC Pavement Report 2010

Pervious Concrete
CPTech Center Pervious Mixture Design 2011
NRMCA Pervious Concrete Mixture Proportioning Guideline and Software 2009

Concrete Overlays
CPTech Center Guide for Concrete Overlays 2014

Full Depth Reclamation (FDR)
Guide to Full-Depth Reclamation (FDR) with Cement

Tab 10 - Construction Inspection of Rigid Pavements

The construction inspection process, for all rigid pavement types, is an essential element for ensuring quality and thus achieving long-term pavement performance goals. For inspection to be effective, it is imperative that inspectors and testing technicians are thoroughly familiar with the specifications and techniques applying to the work. Before construction begins, all phases of the work should be reviewed and all members of the crew should be familiar with the duties to which they are to be assigned.

Advanced planning and organization of the engineering and inspection teams will do much to eliminate the confusion and improper construction sometimes found during the first day's work. All inspection equipment and testing tools should be on hand in advance of paving, and demonstrations should be made to acquaint Inspectors with their proper use. The Engineer should make certain that all Inspectors are instructed in the proper methods of keeping notes, records and diaries. Accurate records of construction progress and test results are absolutely essential in evaluating pavement performance through the years.

Recommended Inspection Guidelines for Use on Streets and Local Roads

General guidelines for concrete pavement inspection are provided below (page 3) for conventional concrete pavement construction for streets and local roads (based on procedures from TxDOT, MnDOT, and CALTRANS). Keep in mind that inspection and acceptance procedures should be modified to address the size of the job and use of the roadway. The procedures and recommendations contained herein are guidelines only and the project engineer should decide as to what is necessary for each project.

The supporting references contain documents that provide additional information related to conventional concrete as well as inspection and testing of other cement based or rigid pavement materials like pervious and roller compacted concrete, full depth reclamation, and also ancillary items like joint sealing, pavement markings, and pre-construction meetings.

Conventional Jointed Plain Concrete Pavement (additional References)
FHWA Field Reference Manual for Quality Concrete Pavements 2012
IMCP for Concrete Pavement Chapters 8, 9, & 10 2007
CPTech Center Concrete Paving Reference 2006
CPTech Center Construction Basics Tech Note 2006

Roller-Compacted Concrete Pavement
LTAP Roller Compacted Concrete Manual 2010
CPTech Center RCC Report Section 10 2010

Pervious Concrete Pavement
NRMCA Pervious Concrete Contractor Certification 2010
ACI 522.1-13 Specification for Pervious Concrete Pavement

Bonded or Unbonded Concrete Pavement Overlays
CPTech Center Guide for Concrete Overlays 2014

Full Depth Reclamation With Cement
Full Depth Reclamation Inspection Checklist 2013

Concrete Pavement Joint Sealing
Joint Sealing Portland Cement Concrete Pavements Checklist 2002

Pavement Markings
TxDOT Pavement Marking Handbook 2004

Pre-Construction Meeting
NRMCA Concrete In Practice Series 32p: Concrete Pre-Construction Meeting 2000
ACPA Concrete Pavement Field Reference: Pre-Paving (EB237) 2008

Construction Inspection of Conventional Concrete Pavement[1]

Definitions

The first priority of an inspector should be a thorough understanding of the terminology used in specifications, plans, contracts, and submittals. Typically the materials and construction specification includes a list of definitions that may be referenced. In the case that the list is limited or is not part of the specification, the following list is offered to familiarize the inspector with material terms that may be encountered when reviewing concrete mixture designs or related field and laboratory testing data.

1. **Accelerating Admixture:** A chemical admixture that shortens the amount of time necessary for setting. Early age strength development may also be enhanced.
2. **Admixture Materials:** Materials incorporated in a concrete mix design in addition to cement, supplementary cementitious material (SCM), coarse aggregate, fine aggregate and water that are used to enhance specific properties of the mix. Admixture materials typically include chemical admixtures such as lithium nitrate, and air-entraining admixtures.
3. **Air Entraining Admixture:** An admixture material that causes microscopic air bubbles (generally less than 1 mm) to be formed within the cementitious material matrix of concrete. Entrained air enhances workability and improves freeze-thaw resistance.
4. **Alkali Silica Reactivity (ASR):** Reaction between reactive components of aggregate, amorphous and cryptocrystalline silica, and alkalis in the pore solution of concrete. ASR is an expansive reaction that can cause deterioration of concrete.
5. **ASR Inhibiting Admixtures:** A chemical admixture, that is typically lithium based, used to control alkali silica reactivity (ASR).
6. **Binary Mix:** A mixture of two cementitious materials, typically portland cement and one SCM.
7. **Blended Cement:** A combination of portland cement and one or more SCM, the combining being done prior to delivery to a concrete batch plant. This may include a combination of Type II or Type V cement and SCM produced either by intergrinding (grinding two or more components together) portland cement clinker and SCM, by blending portland cement and either finely ground granulated blast furnace slag or finely divided pozzolan, or a combination of intergrinding and blending. These blended cements are classified as Type IS (MS), portland blast-furnace slag cement, or Type IP (MS), portland-pozzolan cement, with (MS) representing moderate sulfate resistance.
8. **Cementitious Materials:** Generally includes portland cement, ground granulated blast furnace slag, fly ash and ultra fine fly ash, raw or calcined natural pozzolans, metakaolin, silica fume, and rice hull ash, or a combination of any of these materials. All are materials that exhibit binding properties and characteristics like portland cement.

[1] Utilize the following inspection procedures as a guide and modify per local codes, regulations, and specifications. Supporting information regarding construction inspection of conventional concrete pavement may be found in the references.

9. **Chemical Admixture:** Admixtures that fall under the category of ASTM Designation C 494 are considered chemical admixtures. This includes water reducing, retarding, water reducing and retarding, shrinkage reducing and accelerating, viscosity modifying, and ASR mitigation admixtures.
10. **Class F Fly Ash:** A pozzolan, used as an SCM, which is created as a byproduct of burning coal in power plants.
11. **Coarse Aggregate:** The larger rock in concrete that typically consists of gravel, crushed gravel, crushed rock, reclaimed aggregate, crushed air-cooled iron blast furnace slag, or a combination thereof. Coarse aggregate is the portion of the aggregate retained on the #4 sieve.
12. **Concrete:** A mixture of cementitious material, water, fine aggregate, and coarse aggregate combined that hardens to a rock-like mass. Admixture materials may also be included.
13. **Curing:** Maintaining freshly placed concrete under moisture and temperature conditions for a period of time after placement so the concrete can sufficiently gain its desired properties. Curing assures satisfactory hydration of the cement and hardening of the mix.
14. **Fine Aggregate:** The fine aggregate in concrete consists of natural sand, sand manufactured from larger aggregate, or a combination thereof. Fine aggregate is the portion of the aggregate passing the #4 sieve.
15. **Lithium Nitrate:** Lithium Nitrate ($LiNO_3$) is a chemical that can arrest active ASR in lightly damaged concrete or prevent ASR from occurring when added as an admixture to fresh concrete.
16. **Metakaolin:** A very finely ground natural pozzolan that is used as an SCM and is derived from the calcination of high-purity kaolin clay.
17. **Natural Pozzolan:** A naturally occurring material that is typically processed by heat treatment and/or grinding. Natural pozzolans include diatomaceous earth, opaline cherts, tuffs, volcanic ash, pumicite, calcined clay (including metakaolin) and calcined shale.
18. **Portland Cement:** A hydraulic calcium silicate with one or more forms of calcium sulfate in a powder form, that reacts chemically with water to bind materials, such as aggregate, together to form concrete. There are five basic types of Portland cement:
    a. Type I General purpose cement.
    b. Type II Provides moderate sulfate resistance.
    c. Type III Used when high early strength is required.
    d. Type IV Used when low heat of hydration is required.
    e. Type V Used when high sulfate resistance is required.
19. **Pozzolan:** A finely divided material that reacts with calcium hydroxide to produce materials exhibiting cementitious properties. Silica fume, fly ash, and natural pozzolan are all pozzolans.
20. **Reclaimed Aggregate:** Aggregate that has been recovered from plastic concrete by washing away the cementitious material.
21. **Recycled Aggregate:** Aggregate that is formed by crushing, sizing, and screening an existing, hardened concrete surface or structure.
22. **Retarding Admixture:** A chemical admixture that delays the setting and hardening of concrete.
23. **Shrinkage Reducing Admixture:** A chemical admixture that reduces the amount of drying shrinkage in concrete and is typically used in areas where cracks must be minimized for durability reasons.

24. **Silica Fume:** A very fine pozzolan that is created as a byproduct in the arc furnaces of the silicon and ferrosilicon metals industries.
25. **Slag:** A glassy, granular material used as an SCM that is created as a byproduct of iron smelting that has been ground into a powder. May also be referred to as Ground Granulated Blast Furnace Slag (GGBFS).
26. **Supplementary Cementitious Materials (SCM's):** Materials that on their own or when combined with portland or blended cements exhibit cementitious properties. These materials are naturally occurring, manufactured, or by-products of industrial processes. Typical SCM's are slag, fly ash, silica fume, and natural pozzolans such as calcined shale, calcined clay, and metakaolin.
27. **Ternary Mix:** A concrete mixture containing three cementitious materials, typically portland cement and two SCM's.
28. **Water Reducing Admixture:** A chemical admixture that allows for a reduction in the amount of water required to produce concrete with a certain slump. Less water in the mix reduces the water-cement ratio for higher strength, and may reduce the cement content for lower cost, or increases slump or penetration in a concrete mix to improve workability.

Safety

As with all construction jobs, personnel safety is critical during the construction process. The Minnesota Department of Transportation lists the following safety items as part of the inspector's responsibility.

1. Be responsible for your own safety and the safety of your co-workers. Safety is everyone's responsibility. Remember, no job or task is so important that we cannot take the time to do it safely!
2. Monitor contractor operations for hazardous exposures to agency employees, contractor employees and/or the public. Take prompt corrective action to have unsafe behaviors, unsafe conditions and/or imminent danger situations corrected immediately.
3. Promptly report all motor vehicle accidents and/or personal injuries to your supervisor.
4. Appropriate personal protective equipment (PPE) must be worn whenever hazards cannot be removed and/or projects have designated specific PPE as being required. PPE includes, but is not limited to: hard hats, high visibility vests, safety foot wear, eye and hearing protection.
5. Walk clear of operating mobile equipment. Always stay in the operator's site. Before approaching equipment, make and maintain visual contact with the operator.
6. Accessible areas within the swing radius of the rear of the rotating super structure of a crane must be barricaded.
7. Appropriate fall protection must be worn when exposed to an unprotected fall exposure of six (6) feet or greater. While working over water, a life vest is also required.
8. Excavations greater than five (5) feet in depth must have a protective system such as adequate sloping, trench box and/or shoring.
9. Do not enter confined spaces unless properly trained and provided with proper monitoring and retrieval equipment.

10. Temporary electricity used on-site must be provided with ground-fault circuit interrupters or assured equipment grounding conductor program must be implemented to protect employees from ground-fault hazards.
11. Do not wear loose clothing or jewelry or loose long hair that may get caught on corners, protrusions or in moving machinery.
12. Wear work clothes that provide protection against the natural elements.
13. Avoid misunderstandings where safety is concerned – discuss questions or concerns with your supervisor or the project manager before you act.

The NRMCA has an online safety series for ready mix plant operations and transportation professionals that can be accessed at http://www.nrmca.org/operations/SAFETY/safety_series.htm. In addition, the ACPA has a safety training course for contractors that may be accessed at http://www.acpa.org/self-paced-online-courses/.

Concrete Pavement Inspection Process

Quality Control Plan and Pre-Paving Meeting

Quality Control Plan: The contractor should prepare a plan addressing the elements that affect the quality of the pavement and submit about 14 days prior to commencement of concrete paving or as specified in the construction specification. The Quality Control plan should also address the conduct of acceptance testing. The plan should address at a minimum the following:

1. Introduction with Project Description and Key Contact Information
2. Organizational Chart Delineating the Flow of Responsibility
3. Duties and Responsibilities of Project Personnel
4. Pre-Paving Meeting Agenda
5. Inspections and Submittals
6. Process Control Testing Plan and Submittals
7. Contractor Acceptance Testing Plan and Submittals
8. Deficiencies Reporting
9. Conflict Resolution
10. Defective Pavement Repair
11. Changes To The QC Plan During Work
12. Supporting Information as Needed

Subgrade Preparation

The subgrade should be shaped and thoroughly compacted. Special attention should be directed to see that all parts of the subgrade are firm and unyielding. Soft spots should be removed and backfilled with suitable material. The subgrade should be prepared to a width that will accommodate the paving equipment without visible distortion. The subgrade must be trimmed to the proper subgrade elevation and shape. After trimming, the subgrade shall be thoroughly wetted and compacted to achieve a dense unyielding surface. The subgrade must be kept in this condition until the concrete is placed.

The elevation of the subgrade should be checked either by stretching a stringline between the control wires and measuring down to the surface or by another method that provides for a satisfactory check. Extra checks should be made through crown and super transitions to be sure proper adjustments were made in the machine through this area and that no high spots exist.
If control stakes have not been set for previous operations, they need to be installed at this time. If the control stakes have previously been set, the installation of the wire shall be checked to verify that it is set to the proper line and grade. This is especially important if the wire is offset from its original position.

Equipment

Before paving operations begin, the Inspector should check to see that all the required paving equipment is on the project, it meets the requirements of the specifications, is in good working order, and is properly adjusted.

Inspection of Mixer: The following instructions apply primarily to portable mixing plants set up specifically for the project. An inspection should be made of the mixing drum, to see that the mixing blades are not excessively worn. A worn blade will show wear at the center of the blade, while the ends receive very little wear. Since new mixing blades are generally straight, the amount of wear can be determined by use of a stringline or straightedge. Blades worn more than ¾ inch must be removed and new ones installed. Make sure the interior of the drum and the blades are clean, and that accumulations of hardened mortar are all removed.

The batch counter, or timer, should be checked to see that a batch receives the full specified period of mixing before the first part of the batch emerges from the discharge gate. The water meter should be checked for calibration to ensure that the indicated quantity of water is delivered into the mixing drum. By diverting the discharge water into a suitable container and weighing the quantity delivered, the accuracy of the meter can be checked. This check of the calibration should be made at a minimum of three different settings of the meter control, covering a somewhat wider range than that expected to be used on the job. If the quantity of water delivered does not check with the setting on the gauge, a curve should be plotted, showing actual quantity delivered for a given gauge setting. The Inspector should check to see that no water valves or lines are leaking, resulting in loss of control of water content of the mix and should make sure that no other means are available for the mixer operator to add unauthorized water.

A careful inspection of the mixer prior to beginning of work will pay dividends in better control of the mix once the job is underway.

Inspection of Batch Trucks: Nonagitating trucks are permitted to haul plant mixed concrete provided the concrete is delivered and discharged within 45 minutes after the introduction of mixing water to cement and aggregates, and the concrete is in a workable condition when placed. The trucks shall be inspected for tightness and ability to dump or empty. If square cornered truck beds are used, corners should be baffled to prevent bridging and hanging-up of concrete.

Inspection of Paver: The slip form paving equipment must be self-propelled and capable of placing, spreading, consolidating, screeding, and finishing the freshly placed concrete to the proper pavement elevation and cross-section within the specified tolerances. Sliding forms on the paver must be rigid to prevent spreading of the forms. The paving equipment must finish the surface in a manner which will minimize hand finishing.

Slip form pavers contain various combinations of all or some of the following components: auger spreader, spud vibrators, oscillating screeds, tamping bars, and pan floats. The equipment should be checked for calibration and satisfactory operation in accordance with the manufacturer's manual before paving is allowed to proceed.

Critical features include, checking all screeds with a stringline to ensure a true plane or crown, checking the height of the finished pavement elevation, checking vibrating frequency of the vibrators and screeds, checking the feelers or sensors for sensitivity, and the related stringline for tightness to ensure adequate control of line and grade. The paver should be checked to see that it can accomplish the desired crown break section and any transition adjustments required from this section to a one plane section.

If it is necessary to stop the forward movement of the paver, the vibratory and tamping elements should also be immediately stopped. No tractive force should be applied to the machine except that which is controlled from the machine.

Inspection of Miscellaneous Tools and Equipment: The power saws shall be checked to see that they are in proper running order and adjustment to the crown of the roadway and the required depth. Extra blades shall be on hand and sufficient lighting to operate at night. The curing compound applicator shall be checked to see that it is capable of applying the curing compound as specified at a uniform rate.

<u>Mixing Operations</u>

Batching and Mixing: It is essential that careful, diligent inspection of the mixing of the concrete be maintained. A great many features of the work require constant attention in order that properly mixed concrete of uniform consistency will be placed on the subgrade. The concrete must be properly mixed in order that the pavement will have the desired characteristics of strength and durability. So that concrete may be finished uniformly and result in a smooth profile, it is essential that the mix be of uniform consistency.

Several items of work that the Inspector must watch are listed below:

1. The addition of water during the mixing period is of utmost importance. Every effort should be made to see that the total water content of the mix remains uniform. Variations in water content result in variations in the strength and shrinkage characteristics of the separate batches. Over-watered batches will cause difficulties in finishing, edge slump, and also will result in random cracks due to excessive shrinkage. If variations occur in slump, look for:

    a. variation in the moisture content of the aggregates,
    b. leakage of water from the discharge valve into the drum,
    c. variations in batch sizes due to errors in weighing or spillage, or
    d. non-uniformity in grading in each size of aggregate.

2. If an air-entraining agent is added at the mixer, checks need to be made of the quantity added to each batch by the automatic dispenser. Tests for air content of the mix should be made with the air meter. The automatic dispensers have been known to malfunction, resulting in an excess of air entrained in the mixture, or no air entrained at all. For this reason, occasional checks should be made to see that the dispenser is functioning properly by comparing the amount of air-entraining agent used against the number of batches mixed.

3. Speed of the mixing drum in RPM's should be checked when the mixer is in operation. Specifications typically require that the drum shall revolve at the speed shown on the manufacturer's name plate.

4. Occasional checks should be made of the mixing time. Once the mixing timer is set and locked, it must not be changed except on order of the Engineer.

5. Check to see that the concrete is well mixed with no segregation when emptied from the mixer.

6. The Inspector should make daily inspections of the mixer for wear of mixing blades, and to see that hardened concrete is not allowed to accumulate on the blades or sides of the drum. Proper mixing is dependent upon a clean drum with full-sized, clean mixing blades.

<u>Transporting</u>

The trucks transporting the concrete are to conform to the posted local load limits. If the trucks travel on or off the edge of existing pavement, see that the edge of the pavement is protected from damage by the trucks. See that there is no segregation in the concrete when it is discharged from the truck and that the complete batch is discharged. See that the trucks are properly cleaned at the end of each day's operation.

Paving

Preparation: Ahead of the paving operation, the subgrade must be properly prepared with some type of "fixed" control template to accommodate the width of the paver. The subgrade must be properly dampened so as to have no water demand from the mix, but, also, the concrete must not be placed on subgrade on which pools of water have formed. If concrete is delivered by trucks on the grade, subgrade disturbance should be kept at a minimum.

A very important factor in obtaining a superior product with slip form paving is uniformity of operation. The Engineer should ensure that the plant, mixing facilities and hauling units are in quality and quantity balance to supply the paver with an adequate quantity of concrete for continuous operation at the recommended speed, without sacrificing uniform slump. Considerable pavement roughness can be attributed to spasmodic operation, and this should be held to a minimum.

It is very important that uniform consistency of the concrete be maintained. The current requirements for water/cement ratio and edge slump are intended to control consistency.

Placing: As paving progresses, the Inspector should be alert to the wire position just ahead of the machine, since the most precisely set control can be disturbed by workers or equipment hitting it. If you notice anyone or anything bumping, touching, leaning on or otherwise in contact with the control wire, notify the Contractor immediately. It is much easier to correct a misaligned control wire than repair the pavement after it has been placed.

The unconsolidated concrete in front of the paver should be kept well distributed by spreading or by dumping. As the truck or mixer discharges the mix onto the grade in front of the paver, the forces delivered to the machine should be held to a minimum, with all systems functioning as designed.

If the paver is not moving, the vibration should be off. When vibration is in progress, it is important that the concrete becomes uniformly plastic for the full slab width as it passes through the vibration area. A lack of consolidation at one position on the machine could cause a potential fracture line parallel to the direction of movement and also a rough and uneven finished surface. The machine should always operate with a full head of material in front of it to prevent an abrupt reduction in slab thickness.

It is possible that experimentation may be necessary at the beginning of paving. To start, no trailing forms should be used on the machine and all finishing equipment should be engaged. This could then be modified if problems occur. One of the prime contributors to edge slump is high slump concrete. This should not be tolerated. Another is tie bar insertion for abutting lanes, which should be installed ahead of the final finishing.

Edge slump of the unsupported sides behind the paver is one of the major problems to be combated on slip form paving. The surface should be immediately straight edged by the Contractor and methods corrected to deliver a consistently true edge. Trailing forms can be used to give support beyond the length of the paver, but this may not be the answer. It is possible that more damage than good is done by trailing forms in some cases, by drag resistance pulling down the edge, or by mechanical vibration transmitted through the paver linkage to the form. This comment is also applicable to a trailing finisher. Remember that the concrete is between the moving forms only a few minutes and does not take its initial set until long after the forms leave it.

If water is added to the surface from a spray bar at the rear of the machine it should be in the form of a fine fog spray to avoid washing of the surface and extreme care must be exercised to see that the amount of water added is held to a bare minimum. Addition of excessive amounts of water during finishing will weaken the surface of the concrete and may result in hair checking or scaling of the pavement surface at an early date. If a considerable amount of water is continually required to finish the concrete, it may be better to add more water to the concrete mix to reduce the need for spraying water on the surface. Rain on a green unformed slab can cause disastrous edge slump and erosion. The Contractor should be encouraged to halt operations previous to this circumstance, and should be prepared to protect the pavement at all times.

Although the paver template was established true “dry,” soon after paving starts, and periodically thereafter, the slab template should be checked by stretching a line over the wires (transverse) and measuring down to see that the machine has not changed due to the concrete support. This check should also be made through curves and transitions to ensure that the proper section adjustments are being made. Behind the paver, a grout rod 4-inch to 6-inch aluminum pipe is dragged parallel to and at a skew with the pavement to heal minor faults in the surface. This may be replaced with other methods at the Contractor’s discretion.

The slip form paver behaves similarly to an asphalt paver with the front probe approximately 3/16-inch higher than the rear. This will probably vary with the machine, due to mass distribution, etc. Slope of less than this produces an unstable characteristic and an undulating profile, slopes in excess of the correct one cause the machine to repeatedly build up and then slump down. If the symptoms occur, this is one place to check. The machine also has about ¾-inch convergence in the sides, to encourage stability. Hand finishing, water adding, and other surface manipulation should be kept at a minimum.

Installing Tie and Dowel Bars: Tie and dowel bars must be installed where specified in the Plans. Tie bars must be placed so that equal lengths of the bars project into the two lanes of adjoining pavement. When paving two or more lanes at a time, the tie bars are placed at the juncture of the lanes by mechanical means. The Inspector must be alert to see that the bars are set at the proper spacing and depth and are properly centered between the two lanes.

When placing tie/dowel bars in the edge of a slab, the ends of the bars projecting from the forms should be protected against disturbance that might destroy the bond between the concrete and steel. The bars already in place shall be bent to lie close to the slab to permit preparation of the subgrade of the adjoining lane, and carefully straightened to their proper position before placement of concrete.

Finishing: Finish all concrete pavements with approved self-propelled equipment. Use power-driven spreaders, power-driven vibrators, power-driven strike-off, and screed, or approved alternate equipment. Use the transverse finishing equipment to compact and strike off the concrete to the required section and grade without surface voids. Use float equipment for final finishing. Use concrete with a consistency that allows completion of all finishing operations without addition of water to the surface. Use the minimal amount of water fog mist necessary to maintain a moist surface. Reduce fogging if float or straightedge operations result in excess slurry. Perform sufficient checks with long-handled 10 foot and 15 foot straightedges on the plastic concrete to ensure that the final surface is within the tolerances specified.

In general, the paving contractor is responsible only for the pavement placed by them. This includes the smoothness of the pavement on both sides of any and all joints constructed. On the other hand, the Contractor would not be responsible for pavement placed by another contractor or if the work abuts a bridge or approach slab constructed on a separate contract. When leaving or approaching such joints, the center of the profiler will be started or stopped on the pavement to be profiled at a point approximately 15 feet from the joint. The remaining areas that are un-profiled would be checked for smoothness with the 10-foot straightedge in accordance with current practices used on bridge decks.

Since the primary goal is to obtain a smooth pavement, it would be advisable to run the profiler over the joints at the beginning and end of the project, as well as any intermediate joints as described above, and exclude these readings from the profile index. Should these areas meet straightedge tolerances, but not that for the profiler, the consideration should be given to grinding which would be performed at the agency’s expense.

Pavement smoothness should be checked following the placing of the concrete to determine whether the equipment and methods used by the contractor are producing a pavement meeting the smoothness required by the specifications.

Grinding depths should be limited to ⅜ inch. If the specifications cannot be met with this, the section should be removed. Low areas which grinding cannot feasibly remedy shall be sandblasted, filled with epoxy bonded mortar and textured by grinding. The epoxy bonding agent shall meet the requirements of the Standard Specifications for Type II epoxy. Areas which exhibit improperly finished surfaces and would require extensive patching should be removed at the Engineer’s discretion.

Curing: Immediately following final finishing of the concrete, or after free water leaves the surfaces, the curing compound should be applied. The purpose of curing, whatever method is used, is to prevent the loss of moisture required to hydrate the cement so that the concrete will gain its proper strength and durability. It is essential that a complete coverage of curing compound be applied to seal the exposed surface of the pavement.

On most paving work, specifications will call for machine application of the curing compound. It should be seen that the spray nozzle is adequately protected from the wind by shielding so that the compound is not blown off the pavement surface. The Inspector shall check to see that the specified rate of coverage is obtained.

The efficiency of the curing compound in preventing escape of moisture from the concrete is dependent upon the thickness of the membrane. For this reason, it is essential that the compound be evenly applied over the exposed surface at a rate of application not less than that specified. The curing membrane must be protected from damage by foot traffic or equipment. There is a certain amount of foot traffic required in sawing joints, operating the profiler and other operations. This traffic should be held to a minimum, and if damage from undue scuffing or other causes does occur, the area shall be re-sprayed with the required amount of curing compound. Care must be exercised so that curing compound is not sprayed into saw cuts, as the joint sealing compound will not adhere to the concrete in the joints if the curing compound is present.

When pavement is being constructed in early spring or late fall, the Engineer must be alert to predictions of freezing weather, and see that the Contractor is prepared to protect the fresh concrete from freezing. When special protection against freezing is required, the protective earth covering must be placed against the sides of steel forms, if used, as well as on the surface of the pavement, since steel offers poor insulation to the change in temperature.

Joints

Contraction Joints: As concrete cures and hardens, a change in volume occurs due to loss of moisture and cooling. This shrinkage results in tensile stresses being set up in the pavement, causing cracks to develop. History has shown that transverse cracks will develop at about 15-foot intervals along the length of a slab, and that a slab wider than 15 feet may crack longitudinally.

The purpose of contraction joints is to control the cracking of the concrete, thereby preventing ragged random cracks that spall and require expensive maintenance. Good construction of these joints is of the utmost importance, and inspection of this work is one of the most important phases of the Engineer's duties. Contraction joints are weakened planes that collect the cracking into a controlled joint. These joints are made by sawing and pouring hot or cold filler into the joint. The purpose is to create a maintainable joint in the slab and cause the crack to form along the plane of the joint. This type of joint is constructed by sawing a groove in the hardened concrete to create a plane of weakness along which the crack will form. The saw cuts are made with the circular saw blades edged with abrasives or diamonds.

On full width construction, a gang sawing machine using several blades simultaneously is generally used to saw the transverse joints. When the gang sawing machine is used, the Inspector must see that the individual blades are properly aligned and set to cut the required depth. It is necessary to control the time of sawing transverse joints very carefully, so that sawing may be done when concrete has hardened as much as possible without delaying so long as to allow development of random cracks. It is impossible to state a sawing schedule that will be ideal for every job, since curing conditions vary a great deal from job to job. Some generalizations can be made concerning sawing, but the Engineers on each job must determine from experience the most suitable schedule for that job.

It is desirable to delay sawing as long as possible to allow the concrete to gain enough strength to resist raveling adjacent to the saw cut. Sawing green concrete produces excessive wear on the saw blades, and causes washing, raveling, and other structural damages to the concrete near the joint. However, it may be necessary to make some early cuts to control cracking.

In general, a program of sawing control joints should be followed, sawing every fifth joint, not to exceed 64 feet, as soon as the concrete hardens sufficiently to resist excessive raveling. The time of beginning sawing may vary from about 6 hours on hot, dry days to as long as 18 hours when the weather is cool and the humidity high. The Inspector must use good judgment in controlling the sawing sequence. Sawing of the intermediate joints should follow the sawing of the control joints. It will usually be found possible to delay sawing of the final joints until the day following placement of the concrete (see the Standard Specifications and Plans).

By observing the frequency of cracking and opening of joints the next day, it will be possible to lay out a sawing schedule that will give best results. If only the control joints are cracked, the sawing of the intermediate joints can be delayed further, given fairly constant weather conditions. Sawing of the longitudinal joints on full width pavement should be completed similarly to the transverse control joint. The Engineer should mark off the locations of the transverse joints and should check frequently to see that the specified depth of cut is sawed. If sawing will be done at night, the Inspector should be equipped with a good flashlight to properly examine the condition of saw cuts and to watch for random cracks. When paving a lane adjacent to a previously paved slab, an early morning examination of joints in the existing lane will show the joints that are open and working. These locations should be marked for sawing control joints in the second lane. Friction at the construction joint and the tie bars will transmit stresses to the new slab and may cause random cracking to occur. For the same reason, uncontrolled cracks in the first lane should be matched with a control joint in the second. In addition, a bond breaker, such as a small piece of roofing felt, may be placed over each working joint to prevent uncontrolled migration of the crack into the adjacent slab.

Construction Joints: A construction joint shall be made at the end of each day's paving by placing a header board transversely across the pavement. Uncapped dowel bars should be installed in the joint, seeing that the dowels are parallel with the centerline and profile of the pavement. The ends of the dowels projecting from the header should be protected so that they will not be disturbed or moved from their correct positions. Upon beginning paving the following day, any broken curing seal on the end of the previous day's work must be re-sprayed with curing compound. In addition, the exposed dowel bars shall be "greased" to allow for future slab movement.

Sealing Sawed Contraction Joints: Prior to opening of the pavement to traffic, sawed joints must be sealed with an approved type of filler material. Before application of the filler material, the joints must be thoroughly clean and dry. In most cases, it will be necessary to clean the saw cut with a carborundum blade saw and remove dirt and dust with a jet of compressed air. It is important that the saw cut be completely filled to between ¼ inch and ⅝ inch below the top surface of the concrete with the filler material. The Inspector can check this by probing the joint after sealing with a stiff wire and watching for sagging of the filler below the top of the joint.

<u>Miscellaneous Items</u>

Thickness: The standard specification outlines procedures for thickness determinations and provides penalties when prescribed tolerances are exceeded. Before final payment, the thickness tests will have to be made in order to determine the quantities.

Opening to Traffic: During the curing period designated for the concrete mix, the pavement must be properly barricaded to close it to all traffic. If necessary, the Contractor may be required to furnish a person to prevent traffic from using the pavement. When the pavement has developed the minimum allowable compressive strength designated by the specifications, as determined from cylinders made at the time of placement, it may be opened to traffic. The pavement should be cleaned either by brooming or a pickup sweeper prior to opening.

Concrete Paving Checklist[2]

1. **Review Plans and Specifications.**
    a. Examine the Plans and make notes of any questions that you have. If there is a conflict, the Plans will govern over Standard Specifications or Supplemental Specifications.
        i. Notes.
        ii. Read the General Notes to determine details that are project specific and not included in the specifications that apply to concrete paving. Plan notes supersede specifications if there is a conflict.
    b. Estimate of Quantities.
        i. Find out what quantities are for the concrete paving (doweled, non-reinforced, high early strength, fully reinforced, etc.).
    c. Detail Sheets.

[2] Based on North Dakota DOT Checklist.

   i. Go through detail sheets and find detail sheets that pertain to concrete paving such as paving transitions, valley gutters, manhole box outs, manhole reinforcement, intersection details, driveway details, etc.

d. Typical Sections.
   i. Note Sta's of each proposed cross section.
   ii. Note where each transition is.
   iii. Insure the typical sections and transitions match up with the paving layouts.
e. Removal section.
   i. See what concrete pavements need to be removed.
f. Plan and Profile.
   i. Check pavement widths, locations of transitions, end points of concrete paving, or any alignment changes.
g. Paving Layout.
   i. Note joint spacing and types of joints required on layout sheets.
   ii. Insure doweled joints are not interlocked together. (Doweled on two different sides)
h. Standard Details.
   i. Review all standard detail drawings required with Concrete Paving.
      1. Longitudinal joint details, transverse contraction joint details, transverse construction joint, concrete driveway, floating manhole casting for reinforcement details, or transverse expansion joint detail.
i. Standard Specifications.
   i. Review the Standard Specifications to refresh knowledge of requirements for the work.
   ii. Often another specification will be referenced within a specification to save duplication. The reference specification becomes part of the specification referencing it. Materials specifications pertaining to the work will also be referenced.
j. Proposal.
   i. Look at Supplemental Specifications to be aware if any specification updates from the Standard Specifications have been made. Supplemental Specifications will govern over the Standard Specifications.
   ii. Examine the proposal to find Special Provisions regarding Concrete Paving. Special Provisions are specific to the project and cover items and conditions that are not included in the Standard Specifications. Special Provisions govern over Plans, Supplemental Specifications and Standard Specifications.
k. Check the quantities of the bid items involved in the work. Plans are generally accurate but errors do happen and it is much better to find them early to avoid problems.
   i. Organize calculations to identify where materials are placed.
l. Prepare any necessary field books to document the work.
   i. Include:
      1. Location

2. Date installed
3. Pay item
4. Quantity (LF or SY)
5. Date paid
6. Calculations (if needed)

ii. Each main pay item should have a field book.

1. Can set up each sheet for mainline paving Sta to Sta. Include the date and any measurements taken to get quantity.

iii. Ask for prior year's field books and ask for past inspectors input on what to improve to make field book more complete.

m. Organize the documentation required for materials acceptance.

i. Determine what materials are accepted by certification and which need sampling or testing.

ii. Prepare a list of materials that are accepted by certification and a testing and sampling frequency for materials that require them.

1. Coarse Aggregates
2. Fine Aggregates
3. Concrete Mixture (Note type and job strength)
4. The frequency varies for testing of each of these materials. Look up each one and figure for what type of work the contractor is doing.

2. Prior to the start of Concrete Paving.

a. Job site.

i. Get survey done for exact locations of offsets with elevations.

1. Find Sta, offset, and elevations to insure they match the plans.
2. If they are different than the plans make necessary changes to the plans to insure elevations are correct for end sections and inlets.
3. Check elevations of cross sections with the slope staking reports to see if changes are needed.
4. Insure the contractor and the surveyors are on the same page with elevations and offsets so no confusion arises.
5. Double check a few points on the string line to insure elevations are correct.

ii. Check stockpiles.

1. Identify type of material and location of materials needed for improvements.
2. Dowel bars, baskets, and tie bars. Insure correct sizes are installed.

b. Supplier.

i. Do you need materials samples from the supplier?

ii. Do you have the required spec sheets from the supplier for materials used in the PCC?

iii. Has the rock and sand materials passed the prior gradation tests?

   iv. Have the materials tester performed all gradations and/or concrete tests needed prior to actually placing the concrete.
   v. Insure all needed trial batches are complete before actual paving begins.

c. Have surveyor install all hubs needed for Concrete Paving.
   i. Get together with contractor and surveyor to find out what way to have surveyor stake the required improvements so the contractor can construct improvements correctly and accurately.(offsets and markings)
   ii. Check elevations and locations of hubs to make sure they match the plans.
   iii. Make sure contractor and yourself can double checks hubs to insure correct elevations are used.
   iv. Have surveyor check the grade of gravel to insure the gravel trimming elevations are correct.

d. Reinforcement (If used).
   i. Insure correct diameters and lengths of reinforcement are installed.
   ii. Check to insure all reinforcement is placed correctly and accurately.
      1. Insure all doweled baskets are installed in the correct location and secured correctly. (If automatic dowel bar inserter is used, insure the bars are getting installed correctly while paving)
      2. Insure tie bars are installed in the correct locations and held in place correctly.
   iii. Insure the reinforcement is within +/- 1 inch in vertical placement and +/- 3 inches in horizontal placement or as shown in the specifications.
   iv. Insure all reinforcement doesn't move during the paving operation.

e. Depth checks.
   i. Install depth checks to get quick checks on the pavement depth while contractor is paving. (If contractor doesn't install themselves)
      1. Record these locations and check depths during the paving operation.
   ii. If contractor installs the depth checks note location and record the depths as the contractor makes the depth check during the paving operation.

f. Forms.
   i. Insure all forms are placed correctly and securely if used.
   ii. Make sure all necessary tie bars or dowels are placed inside the forms. (if needed along curb & gutter or another slab)
   iii. Insure all keyways are built into the forms if required.

g. Grade.
   i. Ensure grade is thoroughly compacted. (no soft spots)
   ii. Make sure adequate moisture is in grade. (If too dry add moisture if too wet have contractor dry grade or remove wet material and replace with dryer material)

3. Concrete Paving Construction.

a. Review and understand standard details, notes, and plan detail sheets.

b. Batching concrete.
    i. Insure the batch plant has the correct mix design.
        1. Size and batch determined.
        2. Mix design proportions adjusted for desired air content.
    ii. Insure all scales checked and calibrated.
        1. Water meter checked for accuracy.
    iii. Whether by weight or volume insure that the batch plant adds all materials correctly.
    iv. Have contractor check the batching operation as directed by the engineer.
    v. Should be constant testing and checking of moisture contents of aggregates.

c. Delivery.
    i. Read up on the delivery section of the specification.
    ii. Insure batch trucks adequate for size of batch.
    iii. Insure there is not spillage or contamination while loading.
    iv. Insure concrete is mixed to the specifications of the job.
    v. Don't allow water to be added to mixer truck after 60 minutes or as shown in the specification.
    vi. Insure the concrete is discharged from the truck in the allotted timeframe (typically 60 to 90 minutes depending on ambient air temp and type of delivery method).

d. Placement of Concrete.
    i. Dumped directly by trucks.
        1. Insure trucks don't destroy grade.
        2. Insure the trucks have adequate ground to dump from before concrete is delivered.
        3. Make sure reinforcement is in place and won't be disturbed by trucks.
        4. Insure trucks are not blocking traffic for significant periods during dumping. (aren't backing up traffic)
    ii. Pump truck.
        1. Insure truck can reach the required locations.
        2. Watch out for overhead utilities (telephone or electrical wires, traffic lights, etc.)
        3. Insure the base plates to level the truck are on solid ground.
    iii. Concrete spreader.
        1. Used to get concrete in front of paver when reinforcement is set in place.
        2. Insure there is enough room for spreader and concrete trucks (especially if there is any vehicle traffic in area).

e. Vibration.
    i. Paving machine.
        1. Are all vibrators working properly?
        2. Is machine moving at a steady rate to avoid over vibration?
        3. When operator stops machine make sure he stops the vibrators.

4. Insure that the machine is releasing entrapped air by looking into the machine where the vibrators are located.
5. To insure over vibration doesn't occur make sure the paver moves at a decent speed that correlates to the vibrator frequency.

ii. Hand pours.

1. Ensure proper vibration is occurring by watching the internal vibrator spud release air bubbles from the concrete (for and held vibrator operated by laborer).
2. Watch to see the area of influence from the vibration and insure the entire area receives proper vibration.
3. Make sure vibrator operator doesn't drag the vibrator through the concrete (should insert and remove in each location).
4. Assure the vibrator operator can keep up to the paving operation.
5. Ensure vibration is releasing air bubbles as concrete can have as much as 20% entrapped air.
6. Make sure proper vibration occurs around any boxed our manholes or other fixtures in the roadway.

f. Screeding Concrete.

i. Concrete screeding is leveling and smoothing the top layer of concrete so the concrete is the same height as the forms, or guides.
ii. Insure contractor uses an adequate straight edge to screed concrete.
iii. If paving machine is used ensure machine is full of concrete and is leveling off concrete to a smooth surface.
iv. If burlap is dragged behind paving machine make sure it is damp but not soaked with water. (should not leave water bubbles after it passes)
v. Hand screeds include: power screed, truss screed, roller screed, laser screed (all mechanical), or simple straight edge (2x4 lumber or steel/aluminum straightedge; non-mechanical).
vi. Mechanical screeds do add external surface vibration to the concrete as well (although internal spud vibrators should be used as well).
vii. If hand screeds are used insure screed is running on the forms or pavement on both sides of the screed to achieve a level surface.

g. Finishing Concrete.

i. Ensure contractor uses proper floating equipment to smooth out concrete.
ii. Ensure contractor <u>does not add water</u> to aid in finishing surface.
iii. Contractor should use a long handled float to remove any noticeable bumps and fills holes and low spots.
iv. Ensure the contractor uses proper edging tools to edge the concrete to give a nice edge so the concrete doesn't spall or tear along the edges.
v. After surface is smoothed over texture needs to be added to the surface of the concrete.

vi. To add texture contractor should pull; burlap, turf drag, or a coarse broom over the surface of the concrete to give the required texture to aid stopping in wet weather.
vii. The amount of texture required depends mostly on the speed in the area and if stopping is required.

h. Curing Concrete.
   i. Contractor must cure concrete shortly after texturing the concrete.
   ii. If liquid membrane is used ensure contractor covers the entire exposed area with an adequate application rate.
   iii. If forms are removed shortly after initial set a layer of curing compound should be sprayed on the newly exposed surfaces.
   iv. If wet cure is used insure contractor lays burlap down as soon as it will not damage the new concrete.
   v. The burlap should then be misted with water immediately to ensure burlap doesn't remove moisture from the concrete.
   vi. Burlap should be kept moist for as many days as the plans specify.
   vii. Contractor needs to water burlap as many times a day as necessary to insure burlap is kept moist (all 24 hours of the day as well).
   viii. If insulation blankets are needed it is preferred to use a liquid membrane cure first then lay the insulation blankets to protect concrete from freezing.

i. Sawing and Sealing Joints.
   i. The contractor should have all joints marked so to insure adequate joint spacing and line up joints directly over dowel (if used).
   ii. All joints should be sawed to the required depth once the concrete has adequate strength to hold equipment without any damage to the concrete. (No raveling should occur)
   iii. All joints should be sawed within 24 hours to prevent uncontrolled cracking.
   iv. After sawing joints should be inspected to insure no spalling has occurred. (If spalls are greater than 1/4" in depth the spall should be corrected with an epoxy mortar patch)
   v. Joints should then all be sealed with a silicone sealant or preformed elastomeric compression joint seal after saw cutting.

j. Surface Tolerance.
   i. After concrete has reached a sufficient strength test the pavement surface with a 10 foot straightedge.
   ii. If needed on job use a profilograph to test the profile index of the roadway.
   iii. If needed contractor needs to grind all areas that do not meet the required profile index. This is at the contractor's expense.
   iv. If used in the set of plans a unit price adjustment will be used to adjust the $/SY of concrete installed on the project.

k. Post construction.
   i. Fill out daily diary.

1. Equipment used for the work.
2. Labor force to complete the work.
3. What contractor completed during the day.
    a. Include all locations of where work was completed.
    b. Include pay items installed, with their respective quantities.
    c. Note any problems or delays that happened during day.
    d. Note any changes to plans that were required during construction.

ii. Fill out field books.

1. Fill out each field book with dates to show what pay items were completed for the day.
2. Note any specs required per pay item. (date stamped, grade, tickets, type of concrete, etc.)
3. Note any changes in location, grade, or elevations.

iii. Fill out pay quantity report.

1. Include location, pay item, quantity, and calculations if needed.
2. Note what field book is needed to find the information on the pay item.

iv. Open to traffic once the cylinder breaks have reached the required psi strength.

Tab 11 – Maintenance and Rehabilitation

Conventional Concrete Pavement

Concrete pavements are typically designed to last for up to 40 years and many times are in service for 50 years or more. Within this timeframe, it is expected that some periodic maintenance will be needed and at other times more significant rehabilitation activities will be required. The type and amount of maintenance and rehabilitation (M&R) will be a function of the environmental conditions, roadway classification, the type and frequency of vehicular traffic, the surface materials used, and the condition of the roadway that is acceptable to the owner.

In general respects, maintenance activities are those repairs that correct minor deficiencies in the pavement that reduce ride quality or adversely affect drainage or allow intrusion of water. These activities will typically include:

- Diamond Grinding
- Joint Seal Repair or Resealing
- Crack Sealing
- Slab Stabilization
- Partial Depth Repair

Rehabilitation activities include those repairs that restore or increase the structural capacity (i.e. load/traffic carrying capacity) of the pavement. These activities may include:

- Bonded or Unbonded Concrete Overlay
- Asphalt Concrete Overlays
- Crack Stitching
- Full-Depth Repair
- Dowel Bar Retrofit

Maintenance and Rehabilitation References

Evaluating in-service pavements is an important part of determining whether maintenance or rehabilitation is required and when the activities should be conducted. There are various means of evaluating pavements and they include conducting distress surveys as well as conducting non-destructive and/or destructive tests. Several references listed below describe how, when, and why M&R is to be conducted.

Conventional Jointed Plain Concrete Pavement
Guide for Repair of Concrete Pavements 2008
CPTech Center Concrete Pavement Preservation Guide 2014
Municipal CPR Best Practices Manual 2006

CPTP Tech Brief on PCC Pavement Rehabilitation 2005
NCHRP Rehabilitation Strategies for Highway Pavements 2001
Guide for Conducting Forensic Investigations of Pavements NCHRP Rpt 747 2012
Concrete Pavement Repair For City Streets Fact Sheet
Early Opening to Traffic PCC for Rehabilitation 2005

Roller-Compacted Concrete Pavement

Maintenance and rehabilitation activities for roller compacted concrete (RCC) pavement will be similar to those used for jointed plain concrete pavement (JPCP) placed with conventional concrete. However, the timing, frequency, and specific methods will be a function of the use of the pavement, whether joints were sawcut at construction, and the wearing surface of the RCC pavement (i.e. an exposed RCC riding surface or an asphalt surface placed as an overlay of the RCC). If asphalt concrete is the wearing surface, M&R techniques applicable to asphalt overlays will apply.

Basic maintenance guidelines for RCC pavements are provided in ACI 327R-14: Guide to Roller-Compacted Concrete Pavements 2014.

Pervious Concrete Pavement

Maintenance of pervious concrete is typically related to restoring permeability of the pavement from clogging caused by large and small sediments and other debris. Full-depth patching is another M&R strategy than may be employed to correct localized raveling, cracking, and loss of strength.

Specific methods for cleaning pervious concrete may be found NRMCA's Pervious Maintenance Operations Guide.

Bonded or Unbonded Concrete Pavement Overlays

Maintenance and rehabilitation of in-service bonded and unbonded concrete overlays will be similar to conventional concrete pavement. However, selecting which type of overlay is an appropriate rehabilitation alternative of an existing conventional concrete, hot-mix asphalt, or composite pavement requires a data gathering and analysis process.

The University of Pittsburg has developed guidelines to assist engineers with determining whether an existing asphalt pavement is appropriate for a bonded concrete overlay. Guidelines for Bonded Concrete Overlays of Asphalt: Beginning with Project Selection and Ending with Construction published in 2013 by the university is a good starting place when evaluating the possible concrete overlay options of an existing asphalt pavement.

Maintenance and Rehabilitation Techniques

Guides for other M&R techniques have been published by various organizations and a few are listed below. One of the most effective and least costly methods of restoring rideability is diamond grinding. The International Grooving and Grinding Association (IGGA) has numerous fact sheets, research reports and specifications that can be referenced for not only surface restoration by diamond grinding but also joint repair, reducing tire-pavement noise, partial and full-depth repair, and other concrete repair strategies. Their website can be accessed at http://igga.net/.

CPTech Center Guide for Partial Depth Repair of Concrete Pavements 2012
Full-Depth Repairs for Concrete Pavements 2012
SHRP2 R-05 Precast Concrete Panels for Rehabilitation of JPCP 2013
Precast Concrete Pavement System Model Construction specification 2014
Evaluation of Dowel Bar Retrofits for Local Road Pavements
Materials and Procedures for Repair of Joint Seals in Portland Cement Concrete Pavements - Manual of Practice

Maintenance and Rehabilitation Checklists
FHWA Diamond Grinding of Portland Cement Concrete Pavements Checklist 2005
FHWA Dowel Bar Retrofit for Portland Cement Concrete Pavements Checklist 2005
FHWA Full-Depth Repair of Portland Cement Concrete Pavements Checklist 2005
FHWA Partial-Depth Repair of Portland Cement Concrete Pavements Checklist 2005
Joint Sealing Checklist

Tab 12 – Sustainability

More and more engineers and designers are being asked to consider and quantify how building, using, and maintaining infrastructure impacts the environment, economy, and society. Certainly this is true of pavement designers, contractors, and material producers. Currently, there are many rating systems available with the goal of "measuring" or "scoring" transportation infrastructure in terms of its sustainability or environmental impact. Figure 1 denotes many of these rating systems.

Rigid or cement based pavements have many attributes that can contribute towards meeting higher sustainability ratings within these systems. Attributes of concrete pavement that make it a sustainable choice include:

- Long-Term Durability
- High Reflectivity w/Reduced Lighting Demand
- High Albedo Potentially Reducing the Urban Heat Island Affect
- Ability to be Recycled as Aggregate Base or Concrete Aggregate
- Can Incorporate Supplementary Cementitious Materials like Fly Ash and Slag
- Potential to Use Recycled Water During Manufacturing Phase
- High Stiffness Resulting in Lower Fuel Use and Harmful Emissions During the Use Phase

All of these attributes, and more, make rigid or cement based materials a good choice when considering sustainability goals. There are several references available that delve significantly deeper on this discussion and includes:

Sustainable Concrete Pavements (CPTech Center 2012)
The Sustainability of Concrete Pavements (NRMCA CSR03 2011)
Pavement Environmental Life Cycle Analysis (MIT CSHub 2013)
Pavement Vehicle Interaction - Deflection Induced (MIT CSHub 2013)
Pavement Vehicle Interaction - Roughness Induced (MIT CSHub 2013)
Green Roadways: Environmentally and Economically Sustainable Concrete Pavements (ACPA SR385 2011)

Tab 13 – Certifications for Construction and Production

Working with companies and individuals that have invested in the appropriate certifications and accreditations will significantly increase the potential for meeting specification requirements and quality goals for cement based paving. The National Ready Mixed Concrete Association (NRMCA) and other organizations offer certification and accreditation programs for producers, contractors, and testing agencies. In developing specifications, agencies should consider including certification and accreditation requirements for production facilities, delivery trucks, producer personnel, material testing laboratories, testing personnel, and their own testing and inspection personnel. The following is a list of some of the certifications and accreditations that are available and may be referenced in a materials and construction specification.

NRMCA Plant Certifications:

- Quality: Plant and Truck Certification and/or Quality Certification Program
- Environmental Stewardship: Green-Star Certification Program
- Sustainability: Sustainable Concrete Plant Certification

NRMCA Personnel Certifications:

- Concrete Exterior Flatwork Finisher Program
- Certified Concrete Sales Professional (CCSP)
- Certified Sustainability Professional
- Concrete Delivery Professional Certification
- Concrete Field Testing Technician Grade II
- Concrete Green Building Certification
- Concrete Sustainability Professional Certification
- Concrete Technologist Level 2 “Technical Short Course”
- Concrete Technologist Level 3
- Concrete Technologist Level 4 “Durability Course”
- Effective RMC Supervisor Certification
- Environmental Professional Certification for the Ready Mixed Concrete Industry
- Fleet Manager Certification
- NRMCA Safety Certification
- OSHA 10-Hour Safety Certification for General Industry
- Pervious Contractor Certification
- Plant Manager Certification
- Sales Manager Certification

NRMCA Product Certifications:

- NRMCA Certified Environmental Product Declaration

Testing Agency Qualifications (ASTM and AASHTO):

- ASTM C1077 and ASTM E329 for quality assurance testing indicated
- Concrete Mixture Design: CCRL AASHTO Accreditation Program (AAP)

Testing Personnel Certifications:

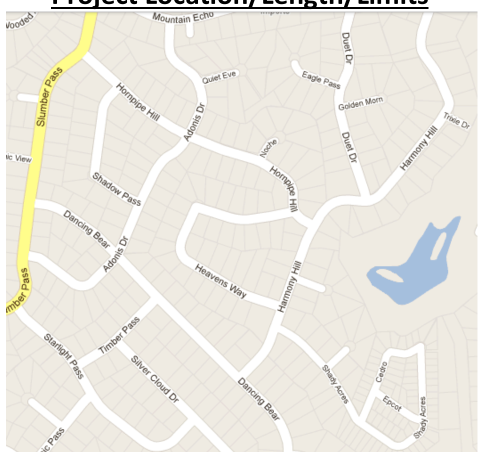
- Field: ACI Concrete Field Testing Technician Grade 1 (according to ACI CP-1)
- Laboratory Technician: ACI certified Concrete Strength Testing Technician or Concrete Laboratory Testing Technician - Level I
- Laboratory Supervisor: ACI certified Concrete Laboratory Testing Technician - Level II

Tab 14 – Example Concrete Pavement Design Report

Concrete Pavement Design Report:

Example Street Design
Your Town, State

<u>Project Location/Length/Limits</u>



<u>Project Owner</u>
Public Works Department
100 1st Street
Town, State 00000-0000
(123) 456-7890

<u>Civil Engineer</u>
Civil Engineer, Inc.
200 2nd Street, Suite 200
Town, State 00000-0000
(987) 654-3210

<u>Geotechnical Engineer</u>
Geotechnical Engineer, Inc.
300 3rd Street
Town, State 00000-0000
(800) 123-4567

Disclaimer

The information contained herein is provided for use by professional personnel who are competent to evaluate the significance and limitations of the information provided and who will accept total responsibility for the application of this information. The project Engineer of Record shall be responsible for the review and acceptance of the design recommendations. The recommendations reflect the judgment of [Your Company] which believes the recommendations are accurate.

DATE

Mr. John Smith, P.E.
Civil Engineer, Inc.
200 2nd Street, Suite 200
Town, State 00000-0000

RE: Concrete Pavement Design Report
Example Street Design
Your Town, State

Mr. Smith:

[Insert Company Name Here] is pleased to provide this concrete pavement design proposal for the subject project. Specific information used to develop this alternative design was gathered from the Geotechnical Engineering Report (Project No. 1000-15-100) dated January 1, 2015. This proposal demonstrates that based upon a Life-Cycle Cost Analysis (LCCA) the concrete pavement provides the lowest cost to the owner over the life of the pavement.

This document is intended for the specific project noted above. It is not to be used, in whole or in part, for construction, bidding, or permitting purposes unless the project engineer of record strictly complies with the laws and acts of engineering practice within the state upon which the project is to be constructed.

Please contact us if you desire further assistance regarding this project.

Sincerely,
[Insert Your Company Name Here]

Your Signature

[Engineer's Name], P.E.
[Title]

Concrete Pavement Design Report
Example Street Design
Your Town, State

Summary

Project Description

Approximately 1 mile of roadway will be constructed in a new subdivision in Your Town, State. The subdivision is being platted and developed by New Development, LLC and includes 150 lots situated on primarily residential streets.

Subgrade Foundation Soils

On-site soils primarily consist of CH fine-grained dark-brown clays with a California Bearing Ratio of approximately 2.0. During construction the subgrade should be prepared in accordance with *Section 3.1 Subgrade Preparation* from the *NRMCA Guide Specification for Materials and Construction of Jointed Unreinforced Concrete Pavement for Streets and Local Roads*.

Traffic Conditions

The roadway for this design is classified as a residential collector with approximately 20 trucks per day (two-way, all lanes) with no growth anticipated over the 20 design period.

Concrete Pavement Recommendation

Proposed Portland Cement Concrete Thickness	**5.0 inches** (1" Nom. Max., 4,000 psi, 5% Air Content)
Subbase	4.0" (as a construction platform)
Maximum Transverse Joint Spacing	10.0 feet
Maximum Longitudinal Joint Spacing	12.0 feet
Concrete Curb and Gutter	Required
Dowel Bars	Not Required

Life-Cycle Cost Analysis (LCCA)

An equivalent asphalt pavement design was also completed so that the owner can assess the net present cost of both pavement types over a 30 year life-cycle period. A life-cycle cost analysis (LCCA) was conducted for both the asphalt and concrete pavement options and the results are shown as follows:

30 year concrete pavement life-cycle costs:	$502,404
30 year asphalt pavement life-cycle costs:	$590,066

Detailed Report

Project Description

Approximately 1 mile of roadway will be constructed in a new subdivision in Your Town, State. The subdivision is being platted and developed by New Development, LLC and includes 150 lots situated on primarily residential streets. Design approval and oversight is provided by the County Department of Development Services Division. Changes in grade on the order of 5 feet or less are anticipated.

Subgrade Pavement Foundation Soils

Soils encountered in the upper 10 feet of the borings drilled for the geotechnical engineering report include fine-grained soils of soft to very stiff dark brown fat clay (CH) and elastic silt (MH) with varying amounts of sand and gravel. Uncorrected SPT N-values for these soils ranged from 3 blows per foot (bpf) to 7 bpf, with an average of 5 bpf. Engineering properties of the encountered soils were measured and reported in the geotechnical engineering report as shown in the table below.

Samples	Liquid Limit	Plasticity Index	Max. Dry Density (pcf)	Opt. Moisture (%)	CBR (%)
1 – 4	58 – 79	33 – 51	88.2 – 101.7	19.2 – 31.4	2.0 – 2.8

Modulus of Subgrade Reaction

For rigid pavement design, concrete slab support is characterized by the modulus of subgrade/subbase reaction, otherwise known as the k-value with units typically shown as psi/in. An effective k-value, which proportionally considers the stiffness contribution of both the subgrade and subbase at the point immediately below the slab, is used in the design when a subbase is utilized.

For this design a CBR value of 2.5% is assumed which is based upon the geotechnical engineering test data. This equates to a resilient modulus value ranging from 3,500 to 4,500 psi or a k-value range of approximately 85 - 100 psi/in. The subgrade should be prepared in accordance with *Section 3.1 Subgrade Preparation* from the *NRMCA Guide Specification for Materials and Construction of Jointed Unreinforced Concrete Pavement for Streets and Local Roads*.

Subbases: Guidance Concerning the Use of Subbases in Concrete Pavement Design

In most situations, the overall concrete slab thickness is not significantly affected by the inclusion of a subbase layer below the concrete slab. Typically, subbases are needed under a concrete pavement when there are heavy loads, subgrade pumping potential, water availability to the subbase and/or subgrade, risk of deep frost penetration/heave, and/or the existence of expansive clay soils. Additionally, a subbase may be used as a construction platform under certain conditions.

For this project, a 4-inch subbase is recommended to be placed prior to construction of the concrete pavement. The subbase is not included in the k-value determination for the subsurface support of the concrete slab for this project. The subbase will only be used as a construction platform during concrete placement; however, the subbase will provide some measure of pumping resistance when the pavement is in use. The subbase material may be gravel, aggregate, non-plastic soil, or treated soil. During construction the subgrade should be prepared in accordance with *Section 3.1 Subgrade*

Preparation from the *NRMCA Guide Specification for Materials and Construction of Jointed Unreinforced Concrete Pavement for Streets and Local Roads*.

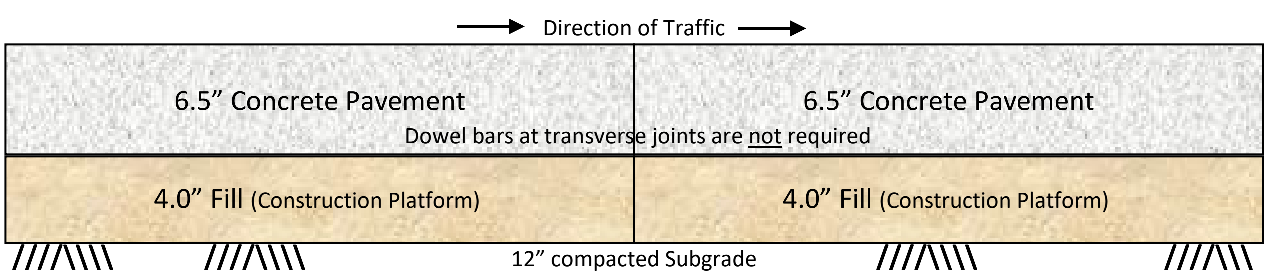
Concrete Pavement Recommendation

For the purposes of this report the ACPA StreetPave v12 pavement design software has been used to determine an acceptable concrete pavement cross section. Based on the StreetPave v12 software the following inputs were used to determine the required concrete pavement thickness:

Design Period	20 years
Roadbed Soil Resilient Modulus	3,500 psi (CBR ≈ 2.5)
Percent of Concrete Slabs Cracked at End of Design Life	25%
Reliability	75%
Reinforcing Steel (Transverse/Longitudinal)	None
Minimum 28-Day Flexural Strength	600 psi (≈ 4,000 psi Compressive)
Modulus of Elasticity (E)	4,050,000 psi
Edge Support Condition	Supported w/Curb and Gutter
Traffic Category	Residential
Average Daily Truck Traffic (two-way, all lanes)	20 trucks per day
Annual Traffic Growth Rate (Simple)	0%

The recommended pavement cross section as determined by StreetPave v12 and the recommended construction details are as follows (see Appendix A for the StreetPave program output for further details):

Concrete Pavement Thickness	**5.0 inches** [1]
Subbase[2]	4.0 inches (as a construction platform)
Maximum Transverse Joint Spacing	10.0 feet
Maximum Longitudinal Joint Spacing	12.0 feet
Tied Concrete Shoulder	Required[3]
Dowel Bars	Not Required
Subgrade Preparation	Scarify and Recompact top 12 inches to 95% of MDD @ Opt. Moist. (ASTM D698)

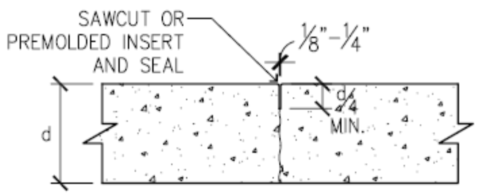


[1]All concrete pavement should conform to ACI 301 (1” Nom. Max., 4,000 psi (min.), 5% air) placed in accordance with the *NRMCA Guide Specification for Materials and Construction of Jointed Unreinforced Concrete Pavement for Streets and Local Roads* or similar.
[2] Subbase material may be gravel, aggregate, non-plastic soil, or treated soil.
[3] May be integral or placed independently and tied.

Suggested Concrete Pavement Details

A proper jointing plan is integral to the overall long-term performance of the concrete pavement. In particular, proper jointing through intersections and a functional transition joint between existing pavement and the new concrete are important for good performance. Intersection and other joint details should be in accordance with *American Concrete Pavement Association* (ACPA) publication TB019P entitled *Concrete Intersections: A Guide for Design and Construction*. Additional jointing information may be found in *American Concrete Institute* publication ACI 325.12R-02 entitled *Guide for Design of Jointed Concrete Pavements for Streets and Local Roads*.

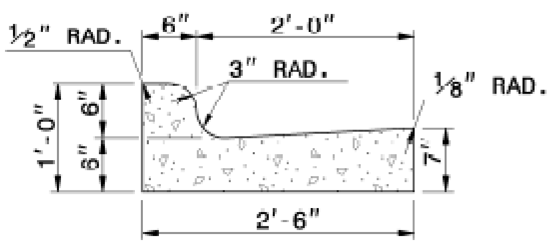
The following transverse joint detail is recommended for the proposed pavement cross section:



PLAIN PAVEMENT
CONTROL JOINT, UNDOWELED

If the full width of pavement is paved together, longitudinal joints shall be sawcut to a minimum depth of 1/4 the concrete slab thickness and sealed with no tie bars required. If each pavement lane is paved independently the pavement lanes may be tied with 24 inch long 5/8 inch diameter Grade 60 deformed steel bars placed on 30 inch centers. Local experience may indicate that tie bars are not required with the confinement provided by the curb and gutter.

When a curb and gutter is required, the suggested curb detail shown below is a standard curb design and may be used on this project. Curbs and gutters may be formed monolithically with the pavement at the same thickness or may be poured independently. If placed independently, the curb and gutter should be tied to the pavement to reduce separation.



2'-6" CURB AND GUTTER

Suggested Materials and Construction Specification

NRMCA has developed a reference specification entitled *Guide Specification for Materials and Construction of Jointed Unreinforced Concrete Pavement for Streets and Local Roads* (see Appendix B) to define material and construction requirements, criteria, and expectations of material suppliers and construction contractors. This guide specification may be used for materials and construction control on this project; however, prior to use, the guide specification should be thoroughly reviewed by the Project

Engineer of Record for applicability to the specific project and local conditions. It is intended that the language contained within the guide specification will be modified, as necessary, to fit within the project contractual conditions and local preferences and that the referenced test methods will be modified accordingly.

Maintenance and Rehabilitation of Concrete Pavements

The pavement design assumes that approximately 25% of the slabs at the end of the design life will have a transverse crack across the entire pavement width. This is a typical design scenario and generally these cracks do not require significant maintenance other than sealing which may be at the discretion of the owner or maintenance engineer. Due to the potentially expansive nature of the subgrade on this project it is assumed that some longitudinal cracks may develop over time which will require partial depth repair. In addition, it is assumed that due to the potentially expansive subgrade some slabs will move sufficiently to cause faulting at some of the transverse joints which will require diamond grinding of the joints to restore smoothness. Maintenance and concrete pavement restoration techniques can be found in ACPA publication *Concrete Paving Technology: The Concrete Pavement Restoration Guide – Procedures for Preserving Concrete Pavements*.

Life-Cycle Cost Analysis (LCCA)

As per the Federal Highway Administration, LCCA is an analysis technique that builds on the well-founded principles of economic analysis to evaluate the over-all-long-term economic efficiency between competing alternative investment options. It does not address equity issues. It generally incorporates initial and discounted future agency, user, and other relevant costs over the life of alternative investments. It attempts to identify the best value (the lowest long-term cost that satisfies the performance objective being sought) for investment expenditures.

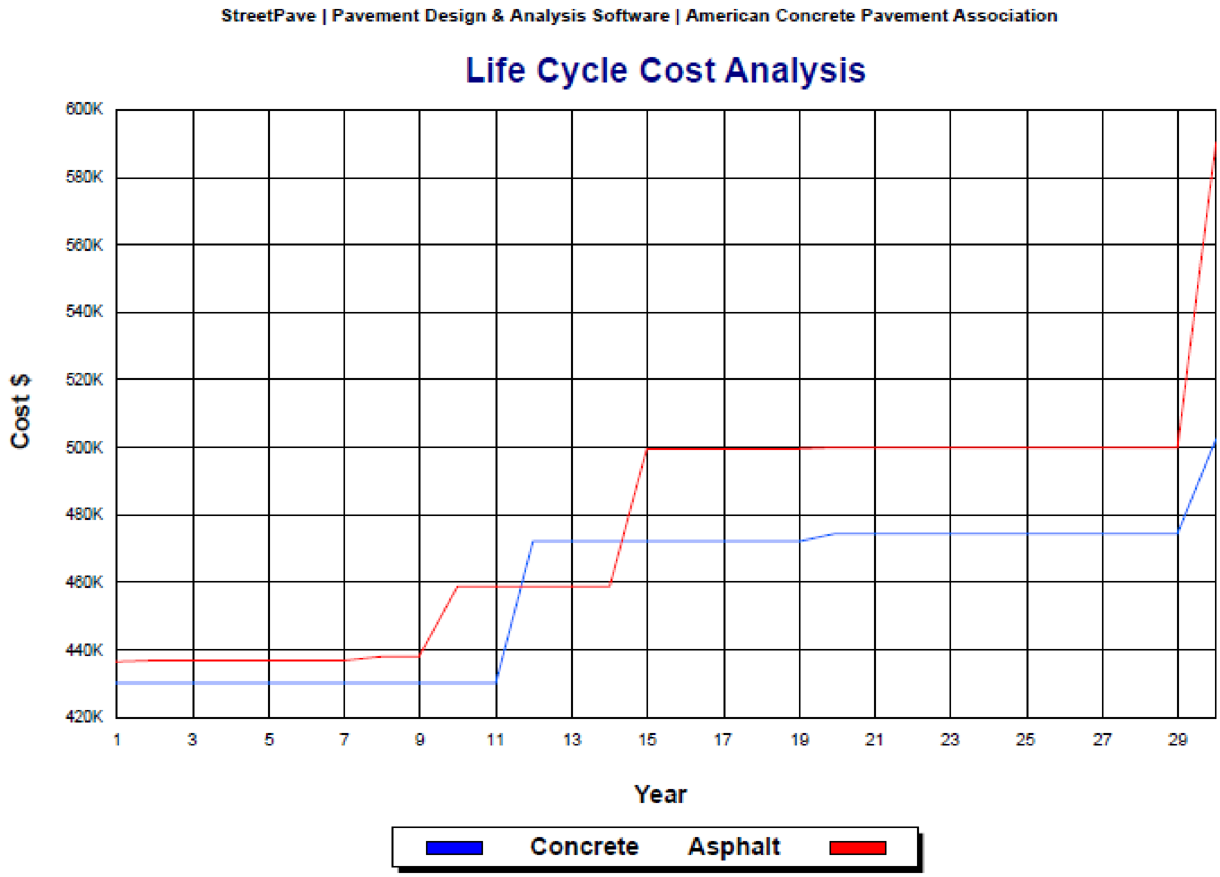
For comparison purposes the StreetPave v12 LCCA module was utilized to provide an assessment of the proposed concrete pavement alternative relative to an equivalent asphalt pavement design over a 30 year life cycle analysis period. The initial costs as well as the maintenance and rehabilitation costs were considered in the analysis and typical maintenance and rehabilitation schedules were assigned for each pavement type. A 30 to 50 year analysis period is typical for life cycle cost analysis (which is different from the 20 year analysis period used for this project's thickness design) and is used to reflect long-term cost differences between alternatives. FHWA typically recommends a 30 to 35 year life cycle analysis period.

The cost information used in the LCCA comes from multiple sources and includes average national data from RSMeans, DOT historical data, and a national pavement rehabilitation study conducted by the Texas Transportation Institute. The maintenance schedules indicate that partial depth repairs for concrete pavement will be conducted at years 12 and 30 and diamond grinding will occur at year 20. For the asphalt surfaced pavement crack sealing is to occur at years 2, 8, and 20 while sealing will occur at years 10 and 15. A mill and overlay will be required at year 30 (see Appendix A for LCCA details).

Based upon the LCCA, the net present cost for the two pavement designs over 30 years is as follows:

Concrete Pavement	$502,404
Asphalt Pavement	$590,066

The following graph demonstrates the total agency cost over the 30 year period.



Appendix A - StreetPave v12 Output

StreetPave 12

Report for Concrete Pavement Design

Project Name:	Example Pavement Design
Route:	Your Street
Location:	Your Town
Project Description:	This is an example design for demonstration and ed
Owner/Agency:	Public Works Department
Design Engineer:	Brian Killingsworth, PE (TX)

Recommended Concrete Pavement Design

Min. Required Thickness =	5 in
Design Thickness =	5.00 in
Max. Joint Spacing =	10 ft
Failure Controlled By =	Cracking

Rounding Considerations:

Thickness Adjustment	Thickness (in.)	Reliability at Specified Design Life (%)	Theoretical Life at Specified Reliability (yrs)
Rounded-Down	4.50	99.9	2
None (As-Designed)	5	75	20
Rounded-Up (Recommended)	5.00	99.9	20

Inputs

Design Life: 20 years

Reliability

Reliability:	75 %
Percent of Slabs Cracked at End of Design Life:	25 %

Traffic

Traffic Category:	Residential
Direction Distribution:	50
Design Lane Distribution:	100
Trucks per Day (two-way, at time of construction):	20 per day
Truck Traffic Growth:	0 % per year
Rigid ESALs =	25,797

American Concrete Pavement Association

www.acpa.org || apps.acpa.org

PAVE AHEAD
DURABLE. SUSTAINABLE. CONCRETE.

Support Conditions

Subgrade

CBR (California Bearing Ratio)	2.5	
Calculated Resilient Modulus of the Subgrade	3,635	psi

Subbase

Top Layer:	Not Selected	Modulus:	0	psi
		Thickness :	0	in
Layer 2:	Not Selected	Modulus:	0	psi
		Thickness:	0	in
Layer 3:	Not Selected	Modulus:	0	psi
		Thickness:	0	in

Composite Modulus of Subgrade Reaction (k-Value):

k = 89 psi/in

Concrete Properties

28-Day Flexural Strength (MR):	600	psi
Macrofibers in Concrete?	No	
Residual Strength:	N/A	%
Modulus of Elasticity (E):	4,050,000	psi

Modulus of Elasticity (E) = 6750 x MR

Design Features

Load Transfer Devices (Dowel Bars)?	No
Diameter =	NA
Edge Support Provided? (e.g., tied concrete shoulder, curb and gutter, or widened lane)	Yes

Fatigue & Erosion Calculations

Traffic Category: Residential			Cracking Analysis			Faulting Analysis		
Axle Load, kips	Axles per 1000 Trucks	Expected Repetitions	Stress Ratio	Allowable Repetitions	Fatigue Consumed	Power	Allowable Repetitions	Erosion Consumed
				Single Axles				
22	0.96	70	0.861	245	28.6	52.359	36345	0.19
20	4.23	309	0.787	824	37.51	43.272	63037	0.49
18	15.81	1155	0.713	4301	26.85	35.051	117847	0.98
16	38.02	2777	0.638	44361	6.26	27.695	245451	1.13
14	56.11	4099	0.563	1386116	0.3	21.204	608041	0.67
12	124	9058	0.487	298277919	0	15.579	2114302	0.43
10	204.96	14972	0.41	unlimited	0	10.819	22317774	0.07
8	483.1	35290	0.333	unlimited	0	6.925	unlimited	0
6	732.28	53493	0.254	unlimited	0	3.895	unlimited	0
4	1693.31	123696	0.173	unlimited	0	1.732	unlimited	0
				Tandem Axles				
36	4.19	306	0.597	248014	0.12	38.254	90646	0.34
32	69.59	5084	0.534	7927405	0.06	30.226	185911	2.73
28	68.48	5002	0.471	unlimited	0	23.142	446434	1.12
24	39.18	2862	0.408	unlimited	0	17.002	1436547	0.2
20	57.1	4171	0.343	unlimited	0	11.807	10420041	0.04
16	75.02	5480	0.278	unlimited	0	7.556	unlimited	0
12	139.3	10176	0.212	unlimited	0	4.251	unlimited	0
8	85.59	6252	0.145	unlimited	0	1.889	unlimited	0
4	31.9	2330	0.076	unlimited	0	0.472	unlimited	0
0	0	0	0	unlimited	0	0	unlimited	0
				Tridem Axles				
52	0	0	0.538	6095629	0	290.824	273	0
46	0	0	0.48	582534385	0	227.583	561	0
40	0	0	0.421	unlimited	0	172.085	1258	0
34	0	0	0.361	unlimited	0	124.332	3171	0
28	0	0	0.301	unlimited	0	84.322	9453	0
22	0	0	0.24	unlimited	0	52.056	36953	0
16	0	0	0.178	unlimited	0	27.534	250110	0
10	0	0	0.114	unlimited	0	10.755	23726154	0
4	0	0	0.048	unlimited	0	1.721	unlimited	0
0	0	0	0	unlimited	0	0	unlimited	0
			Total Fatigue Used %:		99.71	Total Erosion Used %:		8.4

Report for Asphalt Pavement Design

Project Name:	Example Pavement Design
Route:	Your Street
Location:	Your Town
Project Description:	This is an example design for demonstration and ed
Owner/Agency:	Public Works Department
Design Engineer:	Brian Killingsworth, PE (TX)

Recommended Asphalt Pavement Design

Min. Required Asphalt Thickness = 4.67 in

Inputs

Design Life: 20 years

<u>Traffic</u>

Traffic Category: Residential

Total Number of Lanes: 2

Direction Distribution: 50

Design Lane Distribution: 100

ADTT: 20 per day
(average daily truck traffic, two-way, all lanes)

Truck Traffic Growth: 0 % per year

Flexible ESALs = 18,915

Axle Load, kips	Axles per 1000 Trucks
Single Axles	
22	0.96
20	4.23
18	15.81
16	38.02
14	56.11
12	124
10	204.96
8	483.1
6	732.28
4	1693.31
Tandem Axles	
36	4.19
32	69.59
28	68.48
24	39.18
20	57.1
16	75.02
12	139.3
8	85.59
4	31.9
0	0
Tridem Axles	
52	0
46	0
40	0
34	0
28	0
22	0
16	0
10	0
4	0
0	0

Support Conditions

Subgrade:

M_{RSG} [user-entered] = 4,118.00 psi M_{RSG} [design] = 2,703.33 psi

M_{RSG} [design] = M_{RSG} [user-entered] * (1-ZR*COV)

Where:

ZR = standard normal variate, calculated from user-entered reliability (R)

COV = coefficient of variation typical of the project type and soils for the project

Coefficient of Variation = 38 %

Subbase: 12 inch Granular Base

Reliability

Specified Reliability = 75 %

StreetPave 12

Life Cycle Cost Analysis

Project Name:	Example Pavement Design
Route:	Your Street
Location:	Your Town
Project Description:	This is an example design for demonstration and ed
Owner/Agency:	Public Works Department
Design Engineer:	Brian Killingsworth, PE (TX)

Initial Cost

Concrete Pavement Details

Project Length:	1.0	miles	
Lane Width:	15	feet	
Design Thickness:	5	in.	*StreetPave Recommended Value
Subbase Thickness:	0	in.	
Composite Subbase Density:	120	lb/CF	

Cost Inputs

Concrete Pavement (material):	$ 140.00	/ CY
Concrete Placement (cure,saw,seal):	$ 5.00	/ SY
Aggregate Base:	$ 12.00	/ ton

Calculated Initial Cost for Concrete =	$430,222
Calculated Initial Cost for Aggregate Base =	$0
Total Initial Cost for Concrete Pavement Design =	**$430,222**

Asphalt Pavement Details

Project Length:	1.0	miles
Number of Lanes:	2	
Lane Width:	15	feet
Design Thickness	5	in.
Surface Coarse Thickness:	2.0	in.
Remaining Base Thickness:	3	in.
Aggregate Base Thickness:	12	
Surface Course Density:	145	lb/CF
Base Density:	140	lb/CF
Aggregate Base Density:	120	lb/CF

Cost Inputs

Asphalt Surface Course:	$70.00	/ ton
Asphalt Base:	$68.00	/ ton
Aggregate Base:	$12.00	/ ton

Calculated Initial Cost for Asphalt Surface Course =	$133,980
Calculated Initial Cost for Asphalt Base =	$188,496
Calculated Initial Cost for Aggregate Base =	$114,048
Total Initial Cost for Asphalt Pavement =	**$436,524**

Maintenance Costs

Concrete Cost Inputs

Concrete Annual Maintenance:	$ 0.00	/ / SY	Partial-Depth Repairs:	$ 125.00	/ / SY
Joint Sealant:	$ 0	/ lf	Diamond Grinding:	$ 2.25	/ / SY
Full-Depth Repairs:	$ 90.00	/ / SY			

Concrete Maintenance Schedule with Associated Costs

Year	Item	Available Quantity	Amount	Units	Present Value Cost
12	Partial-Depth Repairs	2.5	440	SY	$41,865
20	Diamond Grinding	10	1760	SY	$2,513
30	Partial-Depth Repairs	2.5	440	SY	$27,803

Asphalt Cost Inputs

Asphalt Annual Maintenance:	$ 0.15	/ / SY	Chip Seal:	$ 1.50	/ / SY
Crack Sealing:	$ 1.25	/ lf	Seal Coat:	$ 3.25	/ / SY
Milling:	$ 2.50	/ / CY			

Asphalt Maintenance Schedule with Associated Costs

Year	Item	Amount	Units	Present Value Cost
2	Rout and Seal Cracks	317	lf	$379
8	Rout and Seal Cracks	950	lf	$990
10	Seal Coat	17600	SY	$21,030
15	Chip Seal	17600	SY	$40,669
20	Rout and Seal Cracks	634	lf	$503
30	Mill and Asphalt Overlay	2	in.	$89,971

Cummulative Costs (includes initial costs and present value maintenance costs)

Year	Concrete	Asphalt
1	$430,222	$436,524
2	$430,222	$436,903
3	$430,222	$436,903
4	$430,222	$436,903
5	$430,222	$436,903
6	$430,222	$436,903
7	$430,222	$436,903
8	$430,222	$437,893
9	$430,222	$437,893
10	$430,222	$458,923
11	$430,222	$458,923
12	$472,088	$458,923
13	$472,088	$458,923
14	$472,088	$458,923
15	$472,088	$499,592
16	$472,088	$499,592
17	$472,088	$499,592
18	$472,088	$499,592
19	$472,088	$499,592
20	$474,601	$500,095
21	$474,601	$500,095
22	$474,601	$500,095
23	$474,601	$500,095
24	$474,601	$500,095
25	$474,601	$500,095
26	$474,601	$500,095
27	$474,601	$500,095
28	$474,601	$500,095
29	$474,601	$500,095
30	$502,404	$590,066

Appendix B – NRMCA Guide Specification for Materials and Construction of Concrete Pavement for Streets and Local Roads

Guide Specification for Materials and Construction of Jointed Concrete Pavement for Streets and Local Roads

April 2012

National Ready Mixed Concrete Association • 900 Spring Street, Silver Spring, MD 20910 • 888-84-NRMCA • www.nrmca.org

Disclaimer

The information contained herein is provided for use by professional personnel who are competent to evaluate the significance and limitations of the information provided and who will accept total responsibility for the application of this information. The project Engineer of Record is responsible for the review and acceptance of the materials and construction specifications. The recommended specification requirements, criteria, and language herein reflect the professional knowledge and experience of the National Ready Mixed Concrete Association (NRMCA). However, NRMCA makes no representations or warranties concerning the fitness of this information for any particular application or installation and DISCLAIMS any and all RESPONSIBILITY and LIABILITY for the accuracy of and the application of the information provided to the full extent of the law.

Introduction

The following specification has been developed for use by owners and their design consultants to define material and construction requirements, criteria, and expectations of material suppliers and construction contractors. The definitions, test methods, and quality requirements are considered current state of the practice for the industry at the time of publication. This document is a recommended guide specification and has not been developed through a consensus process typical of industry standards that can be referenced. It should not be incorporated by reference in project specifications or contract documents.

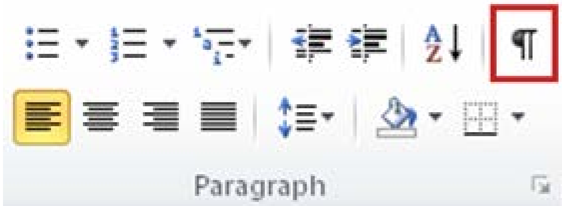
Jointed unreinforced streets and local roads may be designed using various methods; however, NRMCA recommends using the American Concrete Institute (ACI) procedure 325.12R-02 *Guide for the Design of Jointed Concrete Pavements for Street and Local Roads* (www.concrete.org) or the American Concrete Pavement Association's *StreetPave Software* (http://www.acpa.org/) both of which specifically address the unique conditions inherent to streets and local roads and provide optimized concrete pavement thicknesses for city, municipal, county, and state roadways.

Notes to Specifier

1. Prior to use on a project, this guide specification should be thoroughly reviewed by the Project Engineer of Record for applicability to the specific project and local conditions. It is intended that the language contained herein will be modified, as necessary, to fit within the project contractual conditions and local preferences and that the referenced test methods will be modified accordingly.

2. All references to NRMCA on the cover page and in the main document header should be removed prior to incorporation into the final project specifications by the Engineer of Record or their representative.

3. The specification includes hidden text throughout which provides guidance to the specifier regarding the applicability or use of a section/subsection. Hidden text may be shown or hidden with the use of the Show/Hide button to see notes about optional language and what should be removed from the specification if it is not applicable. Hidden text is indicated as blue text. The hidden text should not be shown in the final project specification. The Show/Hide button in Microsoft Word is highlighted below. Print options can suppress printing of hidden text.



4. There are several locations where the engineer of record needs to input information specific to the project for which this specification is being issued. Without modifying these locations, this specification is incomplete. Locations identified as <**bold text**> indicate required information to be completed by the specifier. Locations identified as [**bold text]** generally indicate choices between one or more options to be selected by the specifier. The specifier is responsible for removing or inserting these for the final project specification. The engineer can also add other clauses as is typical for local practice and standard of care.

5. NRMCA requests feedback regarding this guide specification in terms of clarity of the language, constructability, and specification criteria/parameters. Feedback may be emailed to Publications@nrmca.org. Please include the specification title, revision number, and section/subsection number pertinent to your comment(s).

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SECTION 32 13 13.51 – CONCRETE PAVEMENT FOR STREET AND LOCAL ROAD APPLICATIONS

PART 1 - GENERAL

1.0 PROJECT IDENTIFICATION

A. This specification is to be used for concrete pavement materials and construction associated with <**insert project name and location**>.

1.1 RELATED DOCUMENTS

A. Drawings and general provisions of the Contract, including General and Supplementary Conditions, apply to this Section.

1.2 SUMMARY

A. This Section covers the requirements for the construction of unreinforced concrete pavements, with or without subbases, and may also include attached or integral curbs.

B. Related Sections may include the following:

1. Division 03 Section “Concrete Slip Forming” for pavement construction.
2. Division 03 Section “Concrete Reinforcing” for dowel and tie bars.
3. Division 03 Section “Concrete Curing” for concrete pavement and curb curing.
4. Division 31 Section “Base Courses” for subgrade soil stabilization and subbases.
5. Division 32 Section “Curbs, Gutters, Sidewalks, and Driveways” for attached curbs, gutters, and intersecting driveways.

1.3 DEFINITIONS

A. <u>Accepted:</u> determined to be satisfactory to the engineer.

B. <u>Cementitious Materials:</u> Portland cement alone or in combination with one or more of the following: blended hydraulic cement, fly ash and other pozzolans, slag cement, and silica fume; subject to compliance with requirements.

C. <u>Cold Weather:</u> a period when for more than three successive days the average daily outdoor temperature drops below 40°F (5°C). The average daily temperature is the average of the highest and lowest temperature during the period from midnight to midnight. When temperatures above 50°F (10°C) occur during more than half of any 24 h duration, the period shall no longer be regarded as cold weather.

D. <u>Construction Joint:</u> a joint constructed from two separate placements where the first has undergone final setting before the next placement.

E. Contraction Joint: formed, sawed, or tooled groove in a concrete structure to create a weakened plane and regulate the location of cracking resulting from the dimensional change of different parts of the structure.

F. Contractor: the person, firm, or entity under contract for construction of the Work.

G. Contract Documents: a set of documents supplied by Owner to Contractor as the basis for construction; these documents contain contract forms, contract conditions, specifications, drawings, addenda, and contract changes.

H. Dowel Bars: steel pins, commonly plain round steel bars that extend into adjoining portions of a concrete construction, as at a joint in a pavement slab, to transfer shear loads.

I. Engineer: the engineer or engineering firm issuing Contract Documents or administering Work under the contract documents, or both.

J. Exposure Conditions:

1. Negligible: absence of exposure to freezing and thawing or to deicing agents.
2. Moderate: exposure to a climate where the concrete will not be in a saturated condition when exposed to freezing and will not be exposed to deicing agents or other aggressive chemicals.
3. Severe: exposure to deicing chemicals or other aggressive agents or where the concrete can become saturated by continual contact with moisture or free water before freezing.

K. Free Edge: the edge of pavement abutting an isolation joint or the edge of the pavement against which no concrete is placed.

L. High-Early-Strength Concrete: concrete that, through the use of additional cement, high-early-strength cement, or admixtures, has accelerated early-age strength development.

M. Hot Weather: any combination of the following conditions that tend to impair the quality of freshly mixed or hardened concrete by accelerating the rate of moisture loss and rate of cement hydration, or otherwise resulting in detrimental results.

1. high ambient temperature above 90ºF (32ºC);
2. high concrete temperature;
3. low relative humidity;
4. wind velocity; and
5. solar radiation.

N. Isolation Joint: a separation between adjoining parts of a concrete structure, usually a vertical plane, at a designed location such as to interfere least with performance of the structure, yet such as to allow relative movement in three directions and avoid formation of cracks elsewhere in the concrete and through which all or part of the bonded reinforcement is interrupted.

O. Owner: the corporation, association, partnership, individual, public body, or authority for whom the work is constructed.

P. Panel: an individual concrete slab bordered by joints or slab edges.

Q. Project Drawings: graphic presentation of project requirements.

R. Project Specifications: the written document that details requirements for Work in accordance with service parameters and other specific criteria.

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

T. Subgrade: the soil prepared and compacted to support the pavement system.

U. Tie Bar: a reinforcing bar, commonly a deformed steel bar intended to transmit tension, compression, or shear through a construction joint.

V. Tolerances: the permitted deviation from a specified dimension, location, or quantity. Plus (+) tolerance increases the amount or dimension to which it applies or raises a level alignment. Minus (-) tolerance decreases the amount or dimension to which it applies or lowers a level alignment. Where only one signed tolerance is specified (+ or -), there is no limit in the other direction.

W. Unreinforced Concrete Pavement: concrete pavement that does not contain distributed deformed steel reinforcing bars or welded wire fabric. Pavement may include dowel bars at the joints (construction and possibly contraction joints) and tie bars in some locations.

X. Water/Cementitious Ratio (*w/cm*): the ratio of the mass of water, exclusive only of that absorbed by the aggregates, to the mass of cementitious material (hydraulic) in concrete, stated as a decimal.

Y. Work: the entire construction or separately identifiable parts thereof required to be furnished under the Contract Documents.

1.4 REFERENCED STANDARDS AND MANUALS

A. All standards and manuals referenced herein shall be the latest versions or editions. Check with the reference organization for latest published version and utilize this version on the project.

1. AASHTO M182: Standard Specification for Burlap Cloth Made from Jute or Kenaf and Cotton Mats
2. ACI 301: Specifications for Structural Concrete
3. ACI 306.1: Standard Specification for Cold Weather Concreting
4. ACI 308.1: Standard Specification for Curing Concrete
5. ACI CP-1: Technical Workbook for ACI Certification of Concrete Field Testing Technician-Grade 1
6. ASTM A36/A36M: Standard Specification for Carbon Structural Steel
7. ASTM A615/A615M: Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
8. ASTM A775/A775M: Standard Specification for Epoxy-Coated Steel Reinforcing Bars
9. ASTM WK34874: New Specification for Epoxy-Coated Steel Dowels for Concrete Pavement
10. ASTM A820/A820M: Standard Specification for Steel Fibers for Fiber-Reinforced Concrete

11. ASTM C31/C31M: Standard Practice for Making and Curing Concrete Test Specimens in the Field
12. ASTM C33: Standard Specification for Concrete Aggregates
13. ASTM C39/C39M: Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens
14. ASTM C42/C42M: Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
15. ASTM C94/C94M: Standard Specification for Ready-Mixed Concrete
16. ASTM C136: Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates
17. ASTM C138/C138M: Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
18. ASTM C143/C143M: Standard Test Method for Slump of Hydraulic-Cement Concrete
19. ASTM C150: Standard Specification for Portland Cement
20. ASTM C171: Standard Specification for Sheet Materials for Curing Concrete
21. ASTM C172/C172 M: Standard Practice for Sampling Freshly Mixed Concrete
22. ASTM C173/C173M: Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method
23. ASTM C174/C174M: Standard Test Method for Measuring Thickness of Concrete Elements Using Drilled Concrete Cores
24. ASTM C231/C231M: Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method
25. ASTM C260/C260M: Standard Specification for Air-Entraining Admixtures for Concrete
26. ASTM C309: Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete
27. ASTM C494/C494M: Standard Specification for Chemical Admixtures for Concrete
28. ASTM C566: Standard Test Method for Total Evaporable Moisture Content of Aggregate by Drying
29. ASTM C595: Standard Specification for Blended Hydraulic Cements
30. ASTM C618: Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
31. ASTM C989: Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars
32. ASTM C1017/C1017M: Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete
33. ASTM C1064/C1064M: Standard Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete
34. ASTM C1074: Standard Practice for Estimating Concrete Strength by the Maturity Method
35. ASTM C1077: Standard Practice for Agencies Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Testing Agency Evaluation
36. ASTM C1116/C1116M: Standard Specification for Fiber-Reinforced Concrete
37. ASTM C1157: Standard Performance Specification for Hydraulic Cement
38. ASTM C1240: Standard Specification for Silica Fume Used in Cementitious Mixtures
39. ASTM C1260: Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)
40. ASTM C1293: Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction
41. ASTM C1567: Standard Test Method for Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method)

42. ASTM C1602/C1602M: Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete
43. ASTM D698: Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3 (600 kN-m/m^3))
44. ASTM D994/D994M: Standard Specification for Preformed Expansion Joint Filler for Concrete (Bituminous Type)
45. ASTM D1751: Standard Specification for Preformed Expansion Joint Filler for Concrete Paving and Structural Construction (Nonextruding and Resilient Bituminous Types)
46. ASTM D1752: Standard Specification for Preformed Sponge Rubber Cork and Recycled PVC Expansion Joint Fillers for Concrete Paving and Structural Construction
47. ASTM D2628: Standard Specification for Preformed Polychloroprene Elastomeric Joint Seals for Concrete Pavements
48. ASTM D3406: Standard Specification for Joint Sealant, Hot-Applied, Elastomeric-Type, for Portland Cement Concrete Pavements
49. ASTM D3963/D3963M: Standard Specification for Fabrication and Jobsite Handling of Epoxy-Coated Steel Reinforcing Bars
50. ASTM D5893/D 5893M: Standard Specification for Cold Applied, Single Component, Chemically Curing Silicone Joint Sealant for Portland Cement Concrete Pavements
51. ASTM E329: Standard Specification for Agencies Engaged in Construction Inspection, Testing, or Special Inspection
52. ASTM E548: Standard Guide for Proficiency Testing by Interlaboratory Comparisons
53. ASTM E950/E950M: Standard Test Method for Measuring the Longitudinal Profile of Traveled Surfaces with an Accelerometer Established Inertial Profiling Reference
54. ASTM E1980: Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low-Sloped Opaque Surfaces
55. CRSI's "Manual of Standard Practice," Latest Edition.
56. NRMCA QC 3 – Checklist for Certification of Ready Mixed Concrete Production Facilities, NRMCA, www.nrmca.org

1.5 SUBMITTALS

A. LEED Submittals: As required by the LEED for Neighborhood Development Rating System (Latest Edition).

1. Prerequisite 4 Construction Activity Pollution Prevention: Demonstrate conformance with the Erosion and Sediment Control Plan pertaining to wash water and other pollutants that may be part of concrete transport and delivery.

2. Credit 9 Heat Island Reduction: For products (cement and aggregate combined), evidentiary documentation that the Solar Reflectance Index (SRI) is at least 29 calculated using ASTM E1980. For standard grey concrete or concrete using white cement, no testing is required because they are deemed to comply with SRI 29 or greater in LEED.

3. Credit 15 Recycled Content in Infrastructure: For products having recycled content, documentation indicating percentages by weight of postconsumer and preconsumer recycled content.

B. Design Mixtures: For each concrete mixture proposed for the Work. Submit changes to design mixtures when characteristics of materials, project conditions, weather, test results, or other circumstances warrant adjustments. Only submit adjustments that involve changes in material sources or when the quantity of cementitious materials and aggregates vary by more than ±5% of that in the design mixtures or admixture quantities exceed the manufacturers recommended range

1. Indicate on delivery tickets of delivered batches of concrete amounts of mixing water withheld for addition at Project site.

C. Dowel and Tie Bar Steel Reinforcement Drawings: Drawings that detail placement. Include bar sizes, lengths, material, grade, and supports for concrete reinforcement.

D. Qualification Data: For each plant supplying, vehicle transporting, installer, laboratory, and technician involved in testing concrete for paving, submit documentation that the appropriate certifications have been obtained and are currently valid.

E. Material Certificates: For each of the following, signed by manufacturers:

1. Cementitious materials.
2. Admixtures.
3. Steel reinforcement and accessories.
4. Fiber reinforcement.
5. Curing compounds.
6. Joint filler.

F. Quality control plan as described in Section 1.6 and field quality-acceptance inspection and testing reports as described in Section 3.12.

G. Jointing Plan: If the contractor is responsible for the joint layout and plan, submit plan in accordance with and as described in Section 3.7.B.

1.6 QUALITY CONTROL PLAN

A. Quality Control Plan: Prepare a plan addressing the elements that affect the quality of the pavement. Submit this plan at least [**14**] **or** [**insert number of days**] days prior to commencement of concrete paving. The Quality Control plan should also address the conduct of acceptance testing. The plan should address at a minimum the following:

1. Introduction with Project Description and Key Contact Information
2. Organizational Chart Delineating the Flow of Responsibility
3. Duties and Responsibilities of Project Personnel
4. Pre-Paving Meeting Agenda[4]
5. Inspections and Submittals
6. Process Control Testing Plan and Submittals
7. Contractor Acceptance Testing Plan and Submittals
8. Deficiencies Reporting
9. Conflict Resolution
10. Defective Pavement Repair
11. Changes To The QC Plan During Work

[4] See NRMCA Concrete In Practice (CIP) Series 32 – Concrete Pre-Construction Conference for Recommended Pre-Paving Agenda Items (http://www.nrmca.org/aboutconcrete/cips/default.asp)

12. Supporting Information as Needed

1.7 QUALITY ASSURANCE

A. Installer Qualifications: A qualified installer who employs on project personnel qualified as ACI-certified Concrete Flatwork Technician and a supervisor who is an ACI-certified Concrete Flatwork Finisher.

B. Manufacturer Qualifications: A firm experienced in manufacturing ready-mixed concrete products and that complies with ASTM C94/C94M requirements for production facilities and equipment.

1. Manufacturer’s production facilities and delivery vehicles certified according to NRMCA's “Certification of Ready Mixed Concrete Production Facilities” **<optional: and “Sustainable Concrete Plant Certification Bronze level or higher.”>**

2. Personnel responsible for quality control/quality assurance of concrete, certified as NRMCA Concrete Technologist Level 2 or equivalent certification required by state highway agency in the jurisdiction of the Work.

C. Testing Agency Qualifications: An independent agency, complying with the requirements of ASTM C1077 and ASTM E329 for quality assurance testing indicated, or similar and acceptable to the Engineer.

1. Personnel conducting field tests shall be qualified as ACI Concrete Field Testing Technician, Grade 1, according to ACI CP-1 or an equivalent certification program. Equivalent certification programs shall include a component that evaluates performance of the test methods.

2. Personnel performing laboratory tests shall be ACI-certified Concrete Strength Testing Technician or Concrete Laboratory Testing Technician – Level I. Testing Agency laboratory supervisor shall be an ACI-certified Concrete Laboratory Testing Technician – Level II.

D. Source Limitations: Use the same source of cementitious materials, aggregates, chemical admixtures and other ingredients for concrete mixtures for the duration of the project, unless otherwise permitted.

E. Concrete Mixture Design: A qualified laboratory shall perform material evaluation tests and design concrete mixtures. The qualified laboratory can be the concrete supplier’s laboratory facility or an independent testing agency either of which shall be accredited for testing concrete mixtures and aggregates by the AASHTO Accreditation Program (AAP) or similar as accepted by the Engineer.

1.8 EQUIPMENT

A. Paving Equipment: Furnish the paving and finishing equipment applicable to the type of construction in this Work, as follows:

1. Slipform Machines: If slipforming, furnish machines capable of spreading, consolidating, screeding, and finishing the freshly placed concrete in one pass to provide a dense and homogeneous pavement requiring minimal hand finishing. Equip the paving machine with the following:

    a. Automatic controls to control line and grade from either or both sides of the machine, or from averaging-skis that reference the grade.
    b. Vibrators to consolidate the concrete for the full width and depth of the strip of pavement being placed.
    c. A positive interlock system to stop all vibration and tamping elements when forward motion of the machine stops.

2. Self-Propelled Form-Riding Machines: Where used, furnish mechanical, self-propelled spreading and finishing machines capable of consolidating and finishing the concrete with minimal hand finishing. Do not use machines that displace the fixed side forms. Furnish internal immersed tube or multiple spud vibrators. Attach vibrators to the spreader or finishing machine, or attach them on a separate carriage that precedes the finishing machine.

3. Manual Fixed-Form Paving Machines: Where needed, furnish spreading and finishing machines capable of consolidating and finishing concrete up to 8 in. (200 mm) thick.

B. Vibrators: Operate immersed vibrators at frequencies within 5,000- 8,000 vibrations/minute. Furnish a surface pan vibrator as an alternate to immersed tube or multiple spud vibrators for consolidation of 8 in. (200 mm) or thinner concrete slabs. Operate the surface pan vibrator at a frequency no less than 3,500 vibrations/minute. For construction of irregular areas, use handheld immersed vibrators. Operate the vibrator at a frequency in the range recommended by the manufacturer for the vibrator's head diameter.

C. Concrete Saws: Furnish concrete saws that are capable of sawing newly placed concrete for crack control on all concrete pavements included in the Work. Equip all saws with blade guards and guides or devices to control alignment and depth. Early entry saws may be used and shall provide a minimum sawcut depth of 1 in. (25mm) and contain a skid plate straddling the blade that exerts downward pressure on the surface of the concrete to prevent chipping or raveling of the sawcut.

D. Forms: When used, furnish straight, steel forms with a height equal to the nominal pavement thickness at the edge. For curved edges with radii less than 100 ft. (30 m), furnish flexible or curved forms. Conform to the following:

1. Use straight forms that are 10 ft. (3 m) minimum in length.
2. Use forms with a maximum top face deviation of 1/8 in. in 10 ft. (3 mm in 3 m).
3. Use forms with a maximum inside face deviation of 1/4 in. in 10 ft. (6 mm in 3 m).
4. Equip each form with devices to adequately secure the form to the subbase or subgrade, and to withstand operation of the paving equipment and pressure of the concrete.
5. Equip each form with devices to tightly join and lock each end to abutting form sections.

E. Joint Sealing: Furnish joint sealing equipment, if required, according to the sealant manufacturer's recommendations for the sealant specified in the Plans.

F. Finishing Tools: Furnish aluminum, magnesium or wooden hand finishing tools.

1.9 DELIVERY, STORAGE, AND HANDLING

A. Dowel and Tie Bar Steel Reinforcement: Deliver, store, and handle steel reinforcement to prevent bending and damage. Avoid damaging coatings, if used, on steel reinforcement.

PART 2 - PRODUCTS

2.1 CONCRETE MATERIALS

A. Comply with ASTM C94/C94M and the following requirements.

1. Cement: Conform to ASTM C150, C595 or C1157.

2. Supplementary Cementitious Materials (SCMs):

   a. Fly ash conforming to ASTM C618.
   b. Slag cement conforming to ASTM C989.
   c. Silica fume conforming to ASTM C1240.

3. Water: Conform to ASTM C1602/C1602M. Provide documentation required by ASTM C1602/C1602M when non-potable water is proposed for use.

4. Aggregates: Conform to ASTM C33.

5. Admixtures:

   a. Air-Entraining Admixture: Conform with ASTM C260/C260M.
   b. Chemical Admixtures: The following admixtures are permitted. Do not use calcium chloride or admixtures containing calcium chloride.

      1) Water-Reducing Admixture: ASTM C494/C494M, Type A.
      2) Retarding Admixture: ASTM C494/C494M, Type B.
      3) Water-Reducing and Retarding Admixture: ASTM C494/C494M, Type D.
      4) High-Range, Water-Reducing Admixture: ASTM C494/C494M, Type F.
      5) High-Range, Water-Reducing and Retarding Admixture: ASTM C494/C494M, Type G.
      6) Special Performance Admixture: ASTM C494/C494M, Type S.
      7) Plasticizing Admixture for flowing concrete: ASTM C1017/C1017M, Type I.
      8) Plasticizing and Retarding Admixture for flowing concrete: ASTM C1017/C1017M, Type II.

2.2 STEEL REINFORCEMENT

A. Dowel and Tie Reinforcing Bars: When used, dowel and tie bars shall comply with the sizes and grades as shown on the plans. If dowel and tie bar material requirements are not shown on plans, comply with ASTM A615, Grade 60 (Grade 420) and:

1. Dowel bars shall be plain bars cut true to length with ends square and free of burrs.
2. Epoxy-Coated Joint Dowel Bars shall comply with ASTM A775/A775M[5] epoxy coated.
3. Plate Dowels shall be manufactured from hot rolled steel plate meeting ASTM A36.
4. Tie bars shall be deformed bars.

B. Bar Supports: Dowel bar chairs or other devices for spacing, supporting, and fastening reinforcing bars in place. Manufacture bar supports from steel wire, plastic, or precast concrete according to CRSI's "Manual of Standard Practice," of greater compressive strength than concrete.

2.3 FIBER REINFORCEMENT

A. Carbon-Steel Fiber: Comply with ASTM A820, deformed, with a minimum of <**Insert dimension**> long, and an aspect ratio of <**Insert ratio**>.

B. Synthetic Fiber: Utilize [**Monofilament**] **or** [**fibrillated**] polypropylene fibers engineered and designed for use in concrete pavement, complying with ASTM C1116/C1116M, Type III, <**Insert dimensions**> long.

2.4 CURING MATERIALS

A. Liquid Membrane-Forming Compounds: Utilize a Membrane-Forming Curing Compound complying with ASTM C309, Type 2, Class A consisting of a waterborne, monomolecular film forming, manufactured for application to fresh concrete.

B. Absorptive Cover: If used, comply with AASHTO M182, Class 2, burlap cloth made from jute or kenaf, weighing approximately 9 oz/yd^2 (305 g/m^2) when dry.

C. Moisture-Retaining Cover: If used, comply with ASTM C171, polyethylene film or white burlap-polyethylene sheet.

2.5 JOINT AND SEALANT MATERIALS

A. Isolation Joint Materials: When used, comply with ASTM D994/D994M, D1751, or D1752, or as shown on plans.

B. Joint Sealing Materials: When used, comply with the following:

1. Hot-Poured Elastomeric Type; ASTM D3406

[5] ASTM Committee A01.05 is currently developing a revised specification for epoxy coated dowel bars entitled *ASTM WK34874: New Specification for Epoxy-Coated Steel Dowels for Concrete Pavement* to supplement or replace ASTM A775. Until such time as the new ASTM specification is complete ASTM A775 is acceptable.

2. Silicone Rubber Type (cold applied); ASTM D5893/D5893M
3. Single-Component Elastomeric Type (preformed); ASTM D2628

2.6 CONCRETE MIXTURES

A. Mixture Design: Prepare design mixtures for each type and strength of concrete required, proportioned on the basis of field test records or laboratory trial mixtures according to ACI 301. Use a qualified laboratory in accordance with Section 1.7.E for preparing and reporting proposed mixture designs when proposed mixtures are based on laboratory trial mixtures.

1. Supplementary Cementitious Materials (SCMs): For concrete that will be in a Severe Exposure Condition, limit percentage of supplementary cementitious materials, by weight of total cementitious materials, to a maximum quantity as follows:

a.	Fly Ash:	25 percent.
b.	Slag Cement:	50 percent.
c.	Silica Fume:	10 percent.
d.	Total of Fly Ash, Slag, and Silica Fume:	50 percent.[6]
e.	Total of Fly Ash and Silica Fume :	35 percent.[3]

2. Strength: Specified compressive strength shall be 4,000 psi (28 MPa) at 28 days, unless otherwise specified.

3. Total Air Content: Comply with Table 1, unless otherwise specified. The tolerance for air content shall be ±1.5%.

4. Aggregates: Nominal maximum aggregate size shall not exceed 1/3 of the specified pavement thickness.

   a. When required by the Engineer, provide results of aggregate tests for alkali silica reactivity in accordance with ASTM C1260.
   b. When ASTM C1260 expansion at 14 days measured on each source of aggregate exceeds 0.10%, provide test results with the aggregate and proposed combination of cementitious materials with an expansion that is less than or equal to 0.10% at 14 days, in accordance with ASTM C1567.

5. Slump: For pavements placed other than by using slipform equipment, nominal slump shall be 4 in. (100 mm) ±1 in. (25 mm), unless otherwise permitted. For pavements placed using slipform equipment the maximum slump shall be 2 in. (50 mm) +0 and –1-1/2 in. (40 mm), unless otherwise permitted.

B. Submit documentation for mixture proportions of concrete mixtures proposed for use in accordance with ACI 301 and Section 1.5.B herein.

[6] Fly ash and silica fume shall constitute no more than 25% and 10%, respectively, of the total weight of the cementitious materials.

Table 1. Required Total Air Content[1].

Nominal Maximum Aggregate Size, in. (mm)	Total Air Content, %[2]		
	Negligible Exposure	Moderate Exposure	Severe Exposure
3/8 (9.5)	N/A[3]	6.0	7.5
½ (12.5)		5.5	7.0
¾ (19.0)		5.0	6.0
1 (25.0)		4.5	6.0
1-1/2 (37.5)		4.5	5.5

Note 1: Measured in accordance with ASTM C173 or C231.
Note 2: Air content tolerance ± 1.5%
Note 3: Non-air entrained concrete, unless the concrete supplier chooses to entrain air in concrete mixtures.

PART 3 - EXECUTION

3.1 SUBGRADE/SUBBASE PREPARATION

A. Prepare subgrade/subbase as required by the plans. If not specified on the plans or related specification, compact a minimum depth of 6 in. of subgrade to a minimum of 95% of the maximum dry density as determined by ASTM D698 and within ± 2% of the optimum moisture content. Compact entire depth of subbase, if used, to a minimum of 98% of the maximum dry density as determined by ASTM D698 and within ± 2% of the optimum moisture content.

B. Construct subgrade/subbase to ensure that the required pavement thickness is obtained in all locations.

C. Re-grade and re-compact subgrade/subbase disturbed by concrete delivery vehicles or other construction equipment to the requirements of Section 3.1.A.

D. Do not use sand or loose material to obtain final subgrade or subbase elevation.

E. At the time of concrete paving the density and moisture of the subgrade or subbase, if used, shall be in the condition described in section 3.1.A. Test compaction and moisture levels at a minimum frequency of 1 test per [**500 yd^2 (420 m^3)**] **or** [**insert area**] per lift of compacted material.

3.2 SURFACE FIXTURES

A. Adjust manhole frames and other fixtures within area to be paved to conform to finished surface. Comply with plans for manhole adjustments and water fixture adjustments.

B. Clean outside of fixture to depth of pavement before concrete placement.

C. Construct boxouts if necessary for later adjustment of fixtures. Comply with plans for the size and shape of the boxout.

3.3 FORMWORK

A. Construct formwork so concrete pavement is of size, shape, alignment, elevation, and position indicated and so that the pavement is within the tolerance limits of Section 3.10 Tolerances.

B. Construct forms tight enough to prevent loss of concrete mortar.

C. Fabricate forms for easy removal without hammering or prying against concrete surfaces.

D. Clean forms and adjacent surfaces to receive concrete. Remove debris from forms just before placing concrete.

E. Retighten forms and bracing before placing concrete, as required, to prevent mortar leaks and maintain proper alignment.

F. Coat contact surfaces of forms with form-release agent, according to manufacturer's written instructions, before placing reinforcement, if used.

G. The edge of previously placed concrete may be used as a form. Do not apply form release agent to previously placed concrete, unless prevention of bond between the new and the old concrete is desired.

H. Formwork may be removed after cumulatively curing at not less than 50ºF (10ºC) for 24 hours after placing concrete, if concrete is hard enough to not be damaged by form-removal operations and curing and protection operations are maintained.

I. Clean and repair surfaces of forms to be reused in the Work. Damaged forms will not be acceptable. Apply new form-release agent.

J. When forms are reused, clean surfaces, remove fins and laitance, and tighten to close joints. Align and secure joints to avoid offsets.

3.4 STEEL REINFORCEMENT

A. Comply with CRSI’s “Manual of Standard Practice” for placing reinforcement.

B. Clean dowel and tie bar reinforcement of loose rust and mill scale, earth, ice, and other foreign materials.

C. Place joint reinforcement at locations indicated on project drawings. Align dowels exactly centered over the joint line.

D. Anchor dowel baskets securely into the subgrade. For paving lane widths greater than 12 ft (3.66 m), install a minimum of 4 stakes on the leave side of both basket legs.

E. Do not place bent dowel baskets. Do not leave bent dowel baskets in place.

F. At time of paving, make sure all dowels are parallel to the center line of the roadway, parallel to the base, baskets are properly pinned, and the center of each basket (i.e., the joint location) is clearly marked.

G. Place and align to meet the requirements of Section 3.10, Tolerances.

H. For epoxy-coated dowel bar reinforcement, if used, repair cut and damaged epoxy coatings with epoxy repair coating according to ASTM D3963/D3963M.

3.5 CONCRETE PLACEMENT

A. Measure, batch, mix, and deliver concrete according to ASTM C94/C94M, and ASTM C1116/C1116M when fibers are used, and furnish batch ticket information required by these specifications.

B. Before placing concrete, verify that installation of formwork, reinforcement, and embedded items is complete and that required inspections have been performed.

C. When placing and finishing fixed-form concrete pavement, comply with the following steps:

1. Deposit concrete directly from the transporting equipment onto the subgrade or subbase.
2. Do not place concrete on frozen subgrade or subbase.
3. Other methods of conveying the concrete may be used when specified or permitted by the Engineer.
4. Deposit concrete between the forms to a uniform height.
5. Consolidate concrete to remove voids and air pockets. Do not move concrete horizontally with a vibrator.
6. Strike off concrete between forms using a form riding paving machine, vibrating screed, or laser screed. Other strikeoff devices may be used, such as a highway straightedge or scraping straightedge, when approved by the Engineer.
7. Immediately after strikeoff and before bleed water appears on the surface, level concrete with a bullfloat.
8. Do not use steel trowels or power finishing equipment, unless otherwise specified or permitted.
9. Finish the pavement to the elevations, cross slope, and thickness specified in the project drawings and meet the requirements of Section 3.10, Tolerances.

D. When placing and finishing slipform concrete pavement, comply with the following steps:

1. Deposit and finish concrete in conformance with Section 3.5.C.
2. The slipform paver shall be operated with adherence to continuous forward movement as possible, and as such, all delivery and spreading of concrete shall be coordinated so as to provide uniform progress without stopping and starting the machine. Coordination with the concrete supplier is especially important to achieve the desired result.
3. Adjust the vibrator frequency for varying paver speeds and turn off vibrators when the paver stops.
4. When the slipform paver is to ride on the edge of a new concrete pavement, the concrete strengths of the riding surface shall be greater than 2,000 psi (14 MPa), determined by testing field cured specimens in accordance with ASTM C31 or maturity methods in accordance with ASTM C1074.
5. String lines or other means for setting grade should be checked frequently.

E. Edging:

1. Edge top surface edges to a radius of 1/8 in. (3 mm).
2. Do not tool edges if the joint is to be widened to provide a reservoir for joint sealant.

F. Final Surface Texture[7]: Complete final texturing as soon as possible after finishing, but before the concrete has attained its initial set.

1. Artificial Turf Drag:

   a. Drag artificial turf longitudinally along the concrete pavement surface after finishing. The turf shall be mounted on a work bridge or a moveable support system capable of varying the area of turf in contact with the pavement.
   b. The turf drag shall be a single piece of artificial turf of sufficient length to span the full width of the pavement being placed. The turf shall have a means to adjust the height and/or length so as to always maintain a minimum of 4 ft (1.2 m) longitudinal length of turf in contact with the concrete being placed. Where construction operations necessitate and with the approval of the Engineer, the length and width of the turf may be varied to accommodate specific applications.
   c. The turf used shall be an artificial grass type having a molded polyethylene pile face. The pile shall contain blades that are curled and/or fibrillated. The pile shall not contain straight, smooth monofilament blades. The pile shall include blade lengths of 0.6 to 1.3 in. (15 to 33 mm). The turf shall have a minimum weight of 60 oz/yd^2 (2,035 g/m^2). The backing shall be a strong, durable material not subject to rot, and shall be adequately bonded to withstand use as specified.
   d. Turf dragging operations should be delayed if there is excessive bleed water.
   e. Prevent the turf from getting plugged with grout or dragging larger aggregates or foreign materials by cleaning or replacing as necessary.
   f. Measures should be taken to ensure a surface of uniform appearance that is free from deep striations.
   g. Turf should be thoroughly cleaned or replaced at the end of each day's use. Damaged or worn turf should be repaired and/or replaced.
   h. When surface corrections for pavement smoothness are made in the hardened concrete, no additional texturing is required.

2. Broom Finish:

   a. Broom concrete surface with a steel or fiber broom to produce corrugations between 1/16 and 1/8 in. (2 and 3 mm) deep.
   b. Broom perpendicular to nearest edge of pavement. Broom all areas of a panel in the same direction.
   c. Use the same type and manufacture of broom for all paved surfaces to provide a consistent appearance.

3. Longitudinal Tining:

   a. Drag Pretexture: Pretexture the surface of the newly placed pavement in accordance with Section 3.F.1.

   b. Tining:

[7] See hidden text for important note regarding projects where pavement/tire noise reduction is important.

1) Place longitudinally tined grooves in the surface of the pavement while the concrete is plastic. The tining shall be done with a mechanical device such as a wire comb. The comb shall have a single row of tines that each has a nominal width of 5/64 to 1/8 in. (2 to 3 mm). The nominal spacing of the tines shall be 3/4 ± 1/8 in. (19 ± 3 mm) center-to-center. The nominal depth of tined groove in the plastic concrete shall be 1/8 ± 1/32 in. (3 ± 0.8 mm).
2) Longitudinal tining shall be accomplished by equipment with automated horizontal and vertical controls to ensure straight, uniform depth tined grooves. The texture geometry shall be the same as imparted throughout the length of the tining comb.
3) A 2 to 3 in. (51 to 76 mm) wide strip of pavement surface shall be protected from tining for the length of and centered about longitudinal joints.
4) The tining operation shall be done at such time and manner that the desired surface texture will be achieved while minimizing displacement of the larger aggregate particles and before the surface permanently sets.
5) Where abutting pavement is to be placed, the tining shall extend as close to the edge as possible without damaging the edge. If abutting pavement is not to be placed, the 6 in. (152 mm) area nearest the edge or 1 ft (305 mm) from the face of the curb shall not be tined.
6) Hand-operated tining equipment that produces an equivalent texture may be used only on small or irregularly shaped areas. Tines should be thoroughly cleaned at the end of each day’s use, and damaged or worn tines replaced.
7) When surface corrections for pavement smoothness are made in the hardened concrete, no additional texturing is required.

4. Transverse Tining:

a. Drag Pretexture: Pretexture the surface of the newly placed pavement in accordance with Section 3.F.1.

b. Tining:

1) Place transversely tined grooves in the surface of a pavement while the concrete is plastic. The tining shall be done with a mechanical device such as a wire comb. The comb shall have a single row of tines that each has a nominal width of 5/64 to 1/8 in. (2 to 3 mm). The nominal spacing of the tines shall be 3/4 ± 1/8 in. (19 ± 3 mm) center-to-center. The nominal depth of tined groove in the plastic concrete shall be 1/8 ± 1/32 in. (3 ± 0.8 mm).
2) Transverse tining shall be accomplished by equipment with automated horizontal and vertical controls to ensure straight, uniform depth tined grooves. The texture geometry shall be uniformly imparted throughout the length of the tining comb and between successive passes of the tining comb. Successive passes of the tining comb shall be overlapped the minimum necessary to attain a continuously textured surface.
3) The tining operation shall be done at such time and manner that the desired surface texture will be achieved while minimizing displacement of the larger aggregate particles and before the surface permanently sets.
4) Where abutting pavement is to be placed, the tining shall extend as close to the edge as possible without damaging the edge. If abutting pavement is not to be placed, the 6 in. (152 mm) area nearest the edge or 1 ft (305 mm) from the face of the curb shall not be tined.

5) Hand-operated tining equipment that produces an equivalent texture may be used only on small or irregularly shaped areas.
6) Tines should be thoroughly cleaned at the end of each day's use, and damaged or worn tines replaced.
7) When surface corrections for pavement smoothness are made in the hardened concrete, no additional texturing is required.

G. Cold-Weather Placement: Comply with ACI 306.1 and as follows. Protect concrete work from physical damage or reduced strength that could be caused by frost, initial freezing, freezing and thawing cycles, or low temperatures.

1. Concrete temperature as delivered and temperature of placed concrete shall be maintained within the temperature range required by ACI 301.
2. Do not use frozen materials or materials containing ice or snow. Do not place concrete on frozen subgrade or on subgrade containing frozen materials.
3. Do not use calcium chloride, salt, or other materials containing antifreeze agents or chemical accelerators, unless otherwise specified or permitted.

H. Hot-Weather Placement: Comply with ACI 301 and as follows:

1. Maintain concrete temperature below 95ºF (35ºC) at time of placement. Chilled mixing water or ice may be used to control temperature. Quantity of ice used shall be included in the total amount of mixing water. Using liquid nitrogen to cool concrete is Contractor's option.
2. Fog-spray forms, steel reinforcement, and subgrade just before placing concrete. Keep subgrade uniformly moist without standing water, soft spots, or dry areas.

3.6 CONCRETE PROTECTION AND CURING

A. Protect freshly placed concrete from damage due to rain. Have available, near the site of the work, materials for protection of the edges and surface of the concrete. Should any damage result, the Engineer will suspend operations until corrective action is taken and may require removal and replacement of the rain-damaged concrete.

B. Protect freshly placed concrete from premature drying and excessive cold or hot temperatures. Comply with ACI 306.1 for cold-weather protection and ACI 301 for hot-weather protection during curing.

C. Apply curing compound immediately after final surface texture has been obtained and water sheen has disappeared.

D. Apply membrane-forming curing compound to all exposed surfaces at a coverage rate of 180 ft^2/gal. (5 m^2/L).

E. When using liquid membrane-forming compounds, if the evaporation rate[8] during paving operations does not exceed 0.1 lb/ft^2/hr (0.49 kg/m^2/hr), then only 1 coat of membrane curing

[8] Unless an alternate technique is approved by the Engineer, evaporation rate shall be evaluated using the Menzel nomograph or its underlying equations. For more information, refer to the *Guide to Curing Concrete*, ACI 308R-01, ACI International, http://www.concrete.org.

compound at an individual application rate of 180 ft^2/gal. (5 m^2/L) is permissible. Do not allow the concrete surface to dry before applying the curing compound. Remove any standing pools of bleed water that may be present on the surface before applying the curing compound. Apply the first coat within 10 min. after completing texturing operations. If applicable, apply the second coat within 30 min. after completing texturing operations.

F. Maintain and promptly repair damage to curing materials on exposed surfaces of concrete pavement continuously for at least 3 curing days, or until the pavement is open to the traveling public, whichever occurs first. A curing day is defined as a 24-hr. period when either the temperature taken in the shade away from artificial heat is above 50°F (10°C) for at least 19 hr. or when the surface temperature of the concrete is maintained above 40°F (5°C) for 24 hr. Curing begins when the concrete curing system has been applied. Stop concrete paving if curing compound is not being applied promptly and maintained adequately.

G. Apply curing compound to pavement edges after forms, if used, have been removed.

H. Alternative curing methods may be used in accordance with this specification or with ACI 308.1 when acceptable to the Engineer.

3.7 JOINTS

A. Construct joints at the locations, depths, and with dimensions indicated on the project drawings or accepted drawings submitted by the contractor.

B. If jointing requirements are not indicated on the project drawings, the contractor shall submit drawings describing proposed jointing in accordance the requirements of 3.7.B.1 through 3.7.B.9. The contractor shall not proceed with work until the jointing requirements are accepted by the Engineer.

1. Indicate locations of contraction joints, construction joints, and isolation joints. Spacing between contraction joints shall conform to Table 2, unless otherwise permitted.
2. The larger dimension of a panel shall not exceed 125% of the smaller dimension.
3. The minimum angle between two intersecting joints shall be 80 degrees, unless otherwise specified or permitted.
4. Joints shall intersect pavement free edges at 90-degree angles and shall extend straight for a minimum of 1-1/2 ft (0.5 m) from the pavement edge, where possible.
5. Align joints of adjacent panels.
6. Align joints in integral curbs with joints in pavement.
7. Ensure joint depth and width dimensions are as specified.
8. Minimum contraction joint depth, using a conventional saw, hand tools, or inserts, shall be 1/4 of the pavement thickness. Minimum joint width for saw cutting is 1/8 in. (3 mm). When using an early-entry dry-cut saw, the depth of the cut shall be at least 1 in. (25 mm).
9. Use isolation joints only where pavement abuts buildings, foundations, existing pavements, manholes, and other fixed objects.

C. Construct contraction joints by saw-cutting concrete after concrete has hardened sufficiently to prevent aggregate being dislodged and soon enough to control pavement cracking. For conventional saws the start of the sawing window usually occurs between 8 and 12 hours after placement and between 1 and 4 hours for early entry saws. Discontinue sawing joint if a crack precedes the saw-cut. Resume sawing at the next joint location.

D. Extend isolation joints through the full depth of the pavement. Fill the entire isolation joint with isolation joint material, unless otherwise required by project drawings or by accepted jointing drawings submitted by the contractor (see Section 2.5 for material requirements).

Table 2. Spacing Between Contraction Joints.

Pavement Thickness, in. (mm)	Maximum Spacing, ft. (m)
3-1/2 (90)	8-1/2 (2.5)
4, 4-1/2 (100, 110)	10 (3)
5, 5-1/2 (125, 140)	12-1/2 (4)
6 or greater (150 or greater)	15 (4.5)

3.8 JOINT FILLING

A. Prepare, clean, and install joint filler according to manufacturer's written instructions.

B. Unless otherwise allowed by the Engineer, before any portion of the pavement is opened to the Contractor's equipment or to general traffic, clean and seal joints that require sealing. Remove dirt, debris, saw cuttings, curing compounds, and sealers from joints; leave contact faces of joint clean and dry.

C. Hot-Poured Liquid Sealants:

1. Place joint sealer when the pavement and surrounding air temperature are 40°F (5°C) or higher.
2. Where specified, backer rods shall be installed to provide proper shape factor.
3. Use an indirect heating kettle with an agitator to prevent localized overheating. Discard overheated material.
4. Use insulated hoses. Fit the application wand with a recirculation line to prevent the temperature of the sealant in the hose from dropping below application temperature.
5. Make sure that the top of the sealant is 1/8 to 1/4 in. (3 to 6 mm) below the pavement surface.
6. Clean any spilled or overfilled joint sealant from the concrete surface.

D. Cold-Poured Silicone Sealants:

1. Place joint sealer when the pavement and surrounding air temperature are 40°F (5°C) or higher.
2. Where specified, backer rods shall be installed to provide proper shape factor.
3. Use joint primer provided by the manufacturer to ensure a good bond between the sealant and the joint reservoir face.
4. Tool non-self-leveling sealants before the material cures.
5. Clean any spilled or overfilled joint sealant from the concrete surface.

E. Preformed Compression Sealers:

1. Check joint width for compatibility.

2. Make sure the joint width doesn't vary, especially at points where the saw reenters the joint.
3. Clean and dry the saw cut reservoir before sealing the joint. Seal joints only when the joint surfaces appear dry.
4. Follow the manufacturer's recommendation for sealant sizing and installation.
5. Make sure the sealant is lubricated, straight, vertical, and undamaged before installation.
6. Make sure that the installation device does not stretch the sealant.

3.9 OPENING TO TRAFFIC

A. Do not open the pavement to vehicular traffic until the in-place compressive strength is at least 3,000 psi (21 MPa), or 75% of the specified strength, or until the pavement is accepted by the Engineer for opening to traffic. In-place strength shall be determined using field cured cylinders in accordance with ASTM C31/C31M or maturity methods in accordance with ASTM C1074.

3.10 TOLERANCES

A. Construct pavement to comply with the following tolerances:

1. Final Elevation: ±3/4 in. (±19 mm)
2. Concrete Thickness: +3/8 in., -1/4 in. (+10 mm, -6 mm)

B. Joint reinforcement:

1. Tie bars: alignment of tie bar end relative to line perpendicular to edge of pavement: ±1/2 in./ft (±13 mm/305 mm) of tie bars

C. Dowels:

1. Lateral alignment and spacing: ±1 in. (±25 mm)
2. Vertical alignment: ±1/4 in. (±6 mm)
3. Alignment of dowel bar end relative to line perpendicular to edge of pavement: ±1/4 in./ft (±6 mm/305 mm) of dowel

D. Joint Spacing (see Table 2)

1. Contraction joint depth: +1/4 in. (+6 mm), -0 in.
2. Joint width: +1/8 in. (+3 mm), -0 in.

3.11 QUALITY CONTROL

A. Aggregates:

1. Stockpile Grading: ASTM C136; Material producer shall provide the Engineer with testing data demonstrating that the individual stockpile aggregates to be used for production meet the requirements of ASTM C33. A minimum of 10 randomly selected tests shall be provided for each stockpile used for each concrete mix design submitted for paving. One set of tests may be submitted for a stockpile used in multiple mix designs.

2. Aggregate Moisture: ASTM C566; On the individual stockpiles utilized for each concrete mixture, test at a minimum of every [**150 yd^3 (115 m^3)**] **or** [**insert volume**], but not less than one test for each day's pour of each concrete mixture to determine aggregate moisture content. Make adjustments to batch quantities based on measured aggregate moisture content. Testing requirements for aggregate moisture may be eliminated if moisture probes, calibrated at least every [**3 months**] **or** [**insert frequency**], are used.

B. Concrete Mixtures: Contractor shall perform quality control testing and test one composite sample at a minimum of every [**150 yd^3 (115 m^3)**] **or** [**insert volume**], but not less than one test for each day's pour of each concrete mixture. Samples for quality control tests shall be obtained either at the concrete production facility or at the jobsite. It is permitted to obtain this sample after all adjustments are made to the batch and after discharge of at least ¼ yd^3 (0.25 m^3) of concrete.

1. Slump: ASTM C143/C143M
2. Air Content: ASTM C231/C231M (normal weight concrete)
3. Density: ASTM C138/C138M
4. <**Optional: if maturity methods are used for early opening to traffic**> Strength-Maturity Relationship (see Section 3.9 Opening to Traffic): ASTM C1074

C. Statistical Process Control Charts:

1. Prepare statistical process control charts (control charts)[9] according to the Quality Control Plan described in Section 1.6 and the following requirements Prepare control charts for the following test results:

   a. Slump
   b. Air Content
   c. Density

2. Control charts shall be developed using the following components:

   a. The average of test results plotted as the centerline.
   b. Test data plotted continuously over time with each result representing a single test point.
   c. Upper and lower control limits, plotted at 2 times the standard deviation (2s) of the test data.

3. The initial standard deviation for each test parameter shall be developed based upon historical data from the concrete producer and revised as project specific data is obtained. A minimum of 10 project samples shall be used to determine the revised standard deviations. If historical information is unavailable, the following values may be used to calculate one standard deviation (1s) until sufficient data is available.

   a. Slump = 0.231 * Target Value
   b. Air Content = 0.0.097 * Target Value

[9] Background information related to QC testing and statistical process control charts may be found in the CPTech Center Report entitled *Testing Guide for Implementing Concrete Paving Quality Control Procedures* dated March 2008 at http://www.cptechcenter.org/publications/mco/testing_guide.pdf

c. Density = 0.007 * Target Value

4. Investigate process control instability when one of the following occurs:

   a. One test result is outside of the 2s limits.
   b. Five consecutive test results are all increasing or decreasing.
   c. Five consecutive test results are on the same side of the average value.
   d. Ten consecutive test results are alternating up and down.

3.12 QUALITY ACCEPTANCE

A. Testing and Inspecting: Contractor shall engage a qualified testing and inspecting agency meeting the requirements of Section 1.7.C to perform tests and inspections and to submit reports for acceptance in accordance with Section 1.5.F.

B. Inspections: Prior to commencement of portions of the work, the inspection agency shall provide verification that the following items meet the specification requirements:

   1. Subgrade and/or subbase density and elevation.
   2. Steel tie and dowel bar reinforcement placement, if used.
   3. Use of required design mixture.
   4. Concrete placement, including conveying and depositing.
   5. Curing procedures.
   6. Concrete strength before removal of forms, if used.

C. Concrete Tests: Testing of composite samples of fresh concrete obtained according to ASTM C172/C172M shall be performed according to the following requirements:

   1. <u>Preliminary Samples/Tests:</u> Preliminary samples to measure slump and air content and to make necessary adjustments to mixtures to achieve specified requirements are permitted in accordance with ASTM C94/C94M.

   2. <u>Testing Frequency:</u> Obtain at least one random composite sample for each [**500 yd^3 (382 m^3)**] **or** [**insert volume**] or fraction thereof of each concrete mixture placed each day.

      a. When frequency of testing will provide fewer than five compressive-strength tests for each concrete mixture, testing shall be conducted from at least five randomly selected batches or from each batch if fewer than five are used.

   3. <u>Slump:</u> ASTM C143/C143M; one test at point of placement for each composite sample when compressive strength specimens are made, but not less than one test for each day's pour of each concrete mixture.

   4. <u>Air Content:</u> ASTM C231/C231M, pressure method, for normal-weight concrete; one test for each composite sample, but not less than one test for each day's pour of each concrete mixture.

   5. <u>Density:</u> ASTM C138/C138M; one test for each composite sample when strength specimens are made.

6. Concrete Temperature: ASTM C1064/C1064M; one test hourly when air temperature is 40ºF (5ºC) and below and when 80ºF (27ºC) and above, and one test for each composite sample when strength specimens are made.

7. Compression Test Specimens: ASTM C31/C31M; two sets of two standard-cured cylinder specimens for each composite sample. Specimen sizes of 6 x 12 in. (150 x 300 mm) or 4 x 8 in. (100 x 200 mm) are permitted.

8. Compressive-Strength Tests: ASTM C39/C39M; test one set of two standard-cured specimens at 7 days and one set of two specimens at 28 days. A compressive-strength test result shall be the average compressive strength from a set of two specimens obtained from same composite sample and tested at age indicated.

   a. Strength of each concrete mixture is satisfactory if every average of any three consecutive compressive-strength test results equals or exceeds specified compressive strength and no compressive-strength test result falls below specified compressive strength by more than 500 psi (3.5 MPa).

D. Concrete Thickness: ASTM C174/C174M; Obtain at least one random sample for each [**500 yd^3 (382 m^3)**] **or** [**insert volume**] or fraction thereof of each concrete mixture placed each day.

E. Smoothness: Determine smoothness based upon one of the following methods.

1. Straightedge: For pavements with a speed limit of 40 mph (64 kph) or below, use a 10 ft (3 m) metal straightedge to measure the locations marked by the Engineer. A minimum of one test location per 500 feet (152 m) in each travel lane that will carry traffic will be marked. Where there is more than 1/4 in. in 10 ft (6 mm in 3 m), between any two contacts of the straightedge with the surface, the surface requires correction. Following correction, retest the area to verify compliance with this section. Pavement surfaces that have been purposely warped to meet fixtures (manholes, drainage inlets, catch basins, etc.), existing curb and gutter, or cross- and side-road connections are exempt from this straightedge requirement.

2. Inertial Profiler: For pavements with a speed limit greater than 40 mph (64 kph), perform tests in each travel lane that will carry traffic using an inertial profiler in conformance with ASTM E950/E950M. Coordinate with and obtain authorization from the Engineer before starting testing. Perform tests on the finished surface of the completed project or at the completion of a major stage of construction as approved by the Engineer. Perform tests within 7 days after receiving authorization.

   The Engineer may require testing to be performed at times of off-peak traffic flow. Operate the inertial profiler in a manner that does not unduly disrupt traffic flow as determined by the Engineer. When using a lightweight inertial profiler to measure a surface that is open to traffic, use a moving traffic control plan in accordance with the MUTCD and the plans.

   IRI values will be calculated for 0.1 mi. (0.1 km) sections using the average of both wheel paths. The maximum allowable IRI for any 0.1 mi. (.1 km) section will be 70 in./mi (1,184 mm/km). For each 0.1 mi. (0.1 km) section measured to be over 70 in./mi (1,184 mm/km) but not exceeding 80 in./mi. (1,262 mm/km) [**$250**] **or** [**insert $ value**] will be deducted from the payment for this item. For each 0.1 mi. (0.1 km) section measured to be over 80 in./mi (1,262 mm/km) but not exceeding 90 in./mi. (1,429 mm/km) [**$500**] **or** [**insert $ value**] will be deducted from the payment for this item. Use diamond grinding or other approved work methods to correct any 0.1 mi (0.1 km) section with an average IRI over 90 in./mi (1,429 mm/km). Correct the deficient section to an IRI of 70 in./mi (1,184 mm/km) or less. After making corrections, reprofile the pavement section to verify that corrections have produced the required improvements.

F. Reporting: Test results shall be reported in writing to Engineer, contractor, and concrete producer if different from contractor within 48 hours of testing. Reports shall contain project identification information, date of concrete placement, name of concrete testing and inspecting agency, and location of concrete batch in Work.

G. Additional Tests: Testing and inspecting agency shall make additional tests of concrete when test results indicate that slump, air entrainment, compressive strengths, or other requirements have not been met, as directed by Engineer. Testing and inspecting agency may conduct tests to determine adequacy of concrete by cored cylinders complying with ASTM C42/C42M or by other methods as directed by Engineer.

H. Additional testing and inspecting, at Contractor's expense, will be performed to determine compliance of replaced or additional work with specified requirements.

I. Correct deficiencies in the Work that test reports and inspections indicate does not comply with this specification and/or the Contract Documents.

3.13 MEASUREMENT AND PAYMENT

A. Measurement: Measurement will be in square yards (square meters) for each different thickness of concrete pavement. The area of manholes, intakes, or other fixtures in the pavement will not be deducted from the measured pavement area. When the curb is integral with the pavement, the width for pavement square yards will be measured from back of curb to back of curb.

B. Payment: Payment will be at the unit price per square yard (square meters) for each thickness of concrete pavement. Unit price includes, but is not limited to, final trimming of subgrade or subbase, integral curb, bars and reinforcement, joints and sealing, surface curing and pavement protection, safety fencing, concrete for rigid headers, box outs for fixtures, and pavement smoothness testing.

END OF SECTION 32 13 13.51

APPENDIX A – Pertinent NRMCA Concrete In Practice (CIP) Series References

The following NRMCA documents may be used for further guidance on topics related to this specification and concrete pavement construction. The requirements, criteria, or language in the above guide specification should supersede if there are any discrepancies between the specification and the CIP documents. The CIP documents are provided for reference only to the specification writer and should not be included in the project specification either directly or through reference.

Concrete In Practice Series Title	**CIP #**
Joints in Concrete Slabs on Grade	CIP 6
Discrepancies in Yield	CIP 8
Low Concrete Cylinder Strength	CIP 9
Strength of In-Place Concrete	CIP 10
Curing In-Place Concrete	CIP 11
Hot Weather Concreting	CIP 12
Chemical Admixtures for Concrete	CIP 15
Flexural Strength of Concrete	CIP 16
Synthetic Fibers for Concrete	CIP 24
Jobsite Addition of Water	CIP 26
Cold Weather Concreting	CIP 27
Concrete Slab Moisture	CIP 28
Supplementary Cementitious Materials	CIP 30
Ordering Ready Mixed Concrete	CIP 31
Concrete Pre-Construction Conference	CIP 32
Making Concrete Cylinders in the Field	CIP 34
Testing Compressive Strength of Concrete	CIP 35
Concrete Maturity	CIP 39
Acceptance Testing of Concrete	CIP 41

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