An *IPRF* Research Report
Innovative Pavement Research Foundation
Airport Concrete Pavement Technology Program

Report IPRF-01-G-002-02-1(G)

Stabilized and Drainable Base for Rigid Pavement

A Design and Construction Guide

Programs Management Office
5420 Old Orchard Road
Skokie, IL 60077

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Stabilized and Drainable Base for Rigid Pavement

A Design and Construction Guide

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CHAPTER 1. INTRODUCTION

1.1 BACKGROUND

The base layer plays an important role in the short- and long-term performance of portland cement concrete (PCC) pavements. Federal Aviation Administration (FAA) Advisory Circular (AC) 150/5320-6D, *Airport Pavement Design and Evaluation,* allows for the use of various base types in concrete airfield pavement design—granular, chemically stabilized (cement and asphalt), pozzolanic, and mechanically stabilized layers. To ensure that the key structural design requirements are satisfied, this FAA AC recommends that stabilized bases—cement-treated base (CTB), lean concrete base (LCB), or asphalt-treated base (ATB)—be provided when the pavement is designed for gross aircraft loads of 100,000 lb (45,250 kg) or greater. Various military agencies/departments (Army, Air Force, Navy, Marine Corps) also allow the use of stabilized layers in thickness design of rigid pavements.

Base Layer – the layer immediately below the PCC surface.

Subbase Layer – the layer(s) between the base and subgrade.

Drainage layers in the form of an asphalt-treated permeable base (ATPB), cement-treated permeable base (CTPB), or an untreated permeable base (UPB) are also used routinely in typical sections of military airfield pavements. Although not explicitly addressed in the FAA design AC, these layers are also incorporated in the civilian airfield pavements.

Until recently, FAA AC 150/5370-10A, *Specifying Construction of Airports,* provided guidance on materials, mix design, and construction for various base layers including stabilized bases[1]. Although neither this FAA AC, nor its replacement FAA AC 150/5370-10B, cover permeable layers, they are commonly used in commercial airfield pavements. Project specifications for these layers on civilian airfields are typically handled through modification of the existing specifications for stabilized materials. For military airfields, the Unified Facilities Guide Specification (UFGS) 02706—*Drainage Layer*, covers specification aspects of the various drainage layers.

When specified, designed, and properly constructed, stabilized and permeable bases have a positive impact on pavement performance. However, to ensure success, the selection and specification of these layers should be considered in the overall context of the rigid pavement design and construction process. Stated in another way, mere inclusion of these bases in the typical section is not adequate to guarantee pavement performance under all situations. On the contrary, if careful attention is not paid to how these layers alter the early-age and long-term performance of pavements, they could even prove not as beneficial as anticipated. Design details of the PCC layers (thickness, joint spacing, etc.), PCC mixture properties, ambient conditions at the time of paving, and curing and jointing of the PCC layer interact with the base layer's as-

[1] AC 150/5370-10A was replaced by AC 150/5370-10B by the FAA in September, 2005. However, the guidance provided herein is on the basis of empirical observations of pavements built in accordance with the former AC. For the base types discussed here, the differences between these two ACs are minimal. Therefore, the guidance provided herein is very relevant.

constructed stiffness, thickness, and friction properties to create a unique set of circumstances for each project which need to be carefully accounted for to ensure a successful end product.

Deliberate decisions and decisive actions during design and construction of rigid pavements with stabilized and permeable bases are necessary to achieve the desired pavement performance goals—both early-age and long-term.

1.2 PURPOSE OF THE GUIDE

There is emerging evidence suggesting that, under certain circumstances, rigid pavements constructed over certain types of stabilized and permeable bases have a higher risk of early-age, uncontrolled cracking (even when constructed in accordance with standard specifications). This is overshadowing the potential long-term benefits of these layers. Early-age cracking is defined as cracking that occurs up to 90 days after paving has been completed. In some cases, this has resulted in the removal and replacement of up to 7 percent of the total number of slabs on a project—an expensive proposition for owners and contractors.

Forensic investigations and engineering analyses performed on pavements with such early failures have identified several plausible design, materials, and construction factors that act either independently or in concert with other factors, leading to the early-age cracking phenomenon. Measures to control some of these factors can be addressed by revising and updating the current specifications. However, additional guidance is also needed for these materials from a design and construction perspective, so that stabilized and drainable bases may be more effectively and appropriately used in rigid pavement systems.

This document is intended to provide the engineer or constructor an understanding of the materials used and the design and construction criteria to apply when specifying stabilized or permeable base courses in airfield rigid pavement structures. The criteria and techniques described herein should result in a pavement system that will provide the owner the expected level of service.

The purpose of this document is to supplement FAA AC 150/5320-5B, FAA AC 150/5320-6D, and FAA AC 150/5370-10B for guidance in designing and constructing a PCC pavement. This Guide does not purport to address the issues of rigid pavement design and construction in totality. Only those aspects of pavement design and construction that interact with the stabilized or permeable base that are critical to minimize the probability of early-age cracking are addressed here.

1.3 SCOPE OF THE GUIDE

The scope of this design and construction Guide is limited to the following base types:

- Stabilized Layers
    - Cement-treated base (CTB)
    - Lean concrete base (LCB) or econocrete
    - Asphalt-treated base (ATB)

- Permeable Layers
    - Cement-treated permeable base (CTPB)
    - Asphalt-treated permeable base (ATPB)

Although unbound permeable base (UPB) layers offer excellent drainability and have been used successfully in some rigid airfield pavement structures, their ability to be stable under construction and actual traffic, as well as their long-term durability as a base course, has not been proven. Therefore, these layers are not recommended to be used as base layers in rigid airfield pavement structures carrying aircraft weighing 100,000 lb (45,250 kg) or greater. They may be used deeper in the pavement structure. UPB layers are not covered in this Guide.

Since rigid airfield concrete pavements typically are jointed plain concrete (JPC) pavement, the discussion in the Guide is further restricted to this pavement type.

1.4 ORGANIZATION AND USE

The Guide is a compilation of good design practices, materials selection, construction, and inspection methods that should reduce the risk of early-age cracking in rigid pavements built on stabilized and permeable base layers. It is anticipated that this, in turn, will help these pavement structures to realize their long-term pavement performance goals. In addition to highlighting the best practices to avoid early-age cracking, a discussion of design, materials selection, and construction practices that are known to cause these problems is also presented.

This Guide is divided into four chapters. This introductory chapter provides the background and need for additional guidance when using stabilized and permeable bases in rigid pavements.

Chapter 2 discusses the functions of a base layer, its role in ensuring long-term pavement performance, and issues related to early-age cracking in rigid pavements. This chapter also identifies the environmental trigger factors and PCC and base layer design issues, material deficiencies, and construction variants that interact to elevate the risk of early-cracking.

Chapter 3 guides the user in selecting appropriate materials for use in the various stabilized and permeable base layers, and provides discussions related to mix design for each of these layers. This chapter also discusses the choke stone layer and separation layers used in conjunction with various stabilized and permeable base layers.

Finally, chapter 4 provides guidance on the construction of stabilized and permeable bases including pre-construction activities, test strip construction and evaluation, and base layer construction. In addition, issues related to the placement of PCC surface layers on stabilized and permeable bases are also discussed.

More detailed technical information and discussions concerning the justification for the guidelines presented herein are available in the final report of FAA IPRF Project FAA-01-002-02-1, *Design Guide and Recommendations for the Use of Stabilized and Drainable Subbase in Rigid Pavement Systems*.

1.5 DISCLAIMER

This manual is neither a construction guidance specification nor a design tool. It does not provide detailed instructions on conducting specific design or construction-related activities. It does not constitute a standard, specification, or regulation. This manual should not be used in lieu of a project specification. The specific requirements of plans and specifications for a project have precedence.

CHAPTER 2. SELECTION, DESIGN, AND INCORPORATION OF STABILIZED AND PERMEABLE BASES IN RIGID AIRFIELD PAVEMENTS

2.1 INTRODUCTION

2.1.1 Stabilized and Permeable Base Functions

The main functions of the base layer in a rigid pavement system include providing a stable construction platform, providing uniform support, preventing pumping, providing subsurface drainage (in the case of permeable bases), and reducing detrimental frost effects.

In a rigid pavement system, the PCC layer carries most of the applied loads; therefore, high-strength bases are not required. In fact, a durable base layer that provides reasonably uniform support over the design life of the pavement structure is preferred over a high-strength base.

A uniform, non-erodible base is preferred over a high-strength base in a rigid pavement system.

A well-designed and constructed stabilized base layer increases the foundation support, helps reduce stresses and deflections from aircraft wheel loads, and improves load transfer across joints in the PCC slab. All these lead to a reduction in the cracking and faulting potential of the pavement.

Similarly, a well designed and constructed permeable base layer rapidly removes water from within the pavement structure. This leads to a mitigation of PCC durability-related distresses (e.g., D-cracking) and helps increase resistance to joint faulting.

2.1.2 Consideration of Stabilized Bases in the FAA Rigid Pavement Design Procedure

2.1.2.1 Structural Considerations

The FAA AC 150/5320-6D requires stabilized base layers (CTB, LCB, or ATB) for all new rigid pavements designed to accommodate aircraft weighing 100,000 lb (45,250 kg) or more. The structural benefit imparted to a pavement section by a stabilized base is reflected in the increase to the modulus of subgrade reaction (*k*) assigned to the foundation. The foundation *k*-value is increased by a factor proportional to the thickness of the base layer. An increased *k*-value translates to a decreased slab thickness in the current design procedure due to the decrease in load related stresses. The maximum *k*-value that can be used in the AC is restricted to approximately 500 psi/in (1,840 kPa/mm); this range represents the highest *k*-value that can be accurately measured in the field.

The following aspects of the design procedure are noteworthy:

- The minimum prescribed thickness of the stabilized base layer is 4 in (102 mm).

- The FAA design procedure considers load stresses alone in determining PCC layer thickness. The effects of temperature and moisture (curling and warping) on pavement thickness design are considered indirectly through field calibration of the theoretical fatigue model, application of a design "safety factor," and the guidance provided on joint spacing and slab length-to-width ratios.
- In adjusting the foundation k-value to account for the presence of a stabilized base layer, the stiffnesses of all stabilized base layers are considered equal.

2.1.2.2 Material Considerations

FAA AC 150/5370-10A provided standards for the construction of airports in the United States until recently. The guide specifications for the CTB, LCB, and ATB layers are referred to in this AC as Items P-304, P-306, and P-401, respectively.

Salient aspects of the specifications for the base types contained in FAA AC 150/5370-10A are discussed in this section; only items of relevance to this Guide are highlighted. The information summarized in this section is excerpted from the 1991 publication of the AC for P-304 and P-306 and the 1999 publication for P-401 (the last published changes for these items).

Cement Treated Base – Item P-304

The P-304 layer mixture design specifications are based on strength and durability criteria. A minimum 7-day compressive strength of 750 psi (5,171 kPa) is suggested. A durability criterion in the form of maximum freeze-thaw weight loss is optionally applicable for areas subject to considerable freeze-thaw cycles.

In the 1991 specification, a bond-breaking layer between the PCC layer and CTB is not required (in AC 150/5370-10B, a bond-breaking layer is recommended).

The acceptance of CTB layers is done on the basis of density and smoothness. Contractor pay adjustments are made on the basis of density.

Lean Concrete Base – Item P-306

The mixture design of LCB in the FAA's guide specifications are based on the following criteria:

- Compressive strength—Minimum compressive strengths of 500 and 750 psi (3,448 and 5,171 kPa) are specified at 7- and 28-days, respectively. Recognizing the detrimental effects of high strength bases, the P-306 guide specification suggests that an upper limit of 1,200 psi (8,274 kPa) may be imposed on the compressive strength as an optional requirement.
- Cement content—A minimum cement content of 200 lbs/yd^3 (118 kg/m^3) is specified.
- Slump—A slump of 1 to 3 in (25 to 76 mm) is specified.
- Durability—As with CTB, a freeze-thaw weight loss based durability criterion is applicable for areas subject to considerable freeze-thaw cycles. For these areas, air contents between 6 and 10 percent ±2 percent is also specified.

To prevent shrinkage cracks in the LCB layer from reflecting into the PCC layer, joints are recommended when the compressive strength is greater than 1,200 psi (8,274 kPa). However, this requirement is waived if a good bond breaker is used between the LCB layer and the overlying pavement.

The acceptance of the LCB layer is based on consistency (slump), air content, thickness, strength, and grade. Contractor pay adjustments are made as a function of thickness.

Asphalt Treated Base– Item P-403

The Item P-401 guide specification, which is also used for the hot mix asphalt (HMA) pavement surface layers, has been used until recently to specify ATB layer construction. In AC 150/5370-10B, published by the FAA in September, 2005, a new guide specification—Item P-403—specifically for ATB and asphalt leveling courses was incorporated.

The job mix formula for the ATB mixture in the P-403 specification is established using the Marshall mixture design criteria for stability, flow, air voids, and percent voids in mineral aggregate (VMA) for a given number of blows (corresponding to the anticipated live load expected on the pavement). In addition, a tensile strength ratio (TSR) based criterion is used to ensure durability of the mixture. Performance grade (PG) asphalt binders are encouraged to be used in the specification, where available.

Mat density, joint density, thickness, smoothness, and grade are used for contractor pay adjustment. In addition, the contractor is required to run a quality control (QC) program to control the production and construction processes. Variations in asphalt content and aggregate gradation along the project are required to be plotted and maintained on linear control charts.

2.1.3 Permeable Bases in Rigid Pavement Design

Permeable base layers are not directly addressed in the current FAA design procedure. However, they are allowed in airfield rigid pavement construction.

The structural contribution of permeable base layers is ignored in the design process since they are relatively weak. There is also no clear consensus on the best location of these layers within the typical section.

The construction specifications for these layers are typically developed by modifying existing guide specifications, such as Items P-401 or 402 for ATPB and Item P-304 for CTPB, etc. However, the open-graded nature of these materials prevents the application of conventional techniques for performing mix designs and specifying their construction. For example, the ATPB mix designs often are specified on the basis of a gradation and percent binder content. Permeability—an important consideration for this base type—is seldom specified or monitored. Furthermore, field compaction of the mixtures is achieved using method specifications. Acceptance of the mixture is done on the basis of thickness. As can be noted, considerable empiricism is used to specify and construct these mixes, some of which is unavoidable until further research is done.

2.1.4 Stabilized and Permeable Bases and Early-Age Rigid Pavement Performance

There is ample evidence to support the notion that well designed and constructed stabilized and permeable bases help rigid pavements achieve their long-term performance goals. However, when the primary functions of the base layer are not fully considered when incorporating them into the pavement structure, short- and long-term performance deficiencies, such as early cracking and base pumping, can occur. Examples of such misapplications include:

- Selecting the wrong base type for a given application. Certain base types are more effective than others for a given application. For example, permeable bases are most effective when there is a need to rapidly remove water from within a pavement structure; stabilized bases (e.g., CTB, LCB), when designed and constructed correctly, are effective in providing uniform, non-erodible support, etc. The selection of a base for a given paving project is governed by several factors, including agency policy, economics, availability of materials, and local experience. However, issues related to both short- and long-term performance should also be factored into the selection process.
- Increasing stabilized base thickness to reduce PCC layer thickness.
- Increasing stabilized base strength to achieve construction expediency.
- Increasing permeability of permeable bases without properly balancing stability- or durability-related issues.

Long-term performance deficiencies are well known and understood. They manifest themselves in the form of pavement distress—joint faulting, flexural fatigue cracking, corner cracking, loss of smoothness, etc. However, there has been increasing occurrence of early-age cracking in rigid pavements when constructed over certain types of stabilized and permeable bases. Certain qualities of these bases in combination with other rigid pavement design, materials, and construction factors are primary causes for such cracking. These causes need to be understood and addressed.

> Certain qualities of stabilized and permeable bases contribute to early-age cracking, even when such bases are designed and built in accordance with existing guide specifications.

2.2 EARLY-AGE CRACKING IN RIGID PAVEMENTS

2.2.1 Types of Early-Age Cracking

Early-age cracking in hardened PCC can take any of the following forms (Kohn et al., 2003):

- Random cracking (random orientation).
- Longitudinal cracking (cracking parallel to the centerline of the feature being investigated).
- Transverse cracking (cracking perpendicular to the centerline of the feature being investigated).

- Corner cracking (cracking located at the PCC slab corner intersecting the longitudinal and transverse joints).
- Pop-off cracks (cracking that happens just ahead of the sawing operation).
- Later stage cracking (early-age slab bottom cracking propagating to the surface).
- Sympathy cracks (cracking that occurs in adjacent slabs when joints between the slabs in questions are not aligned during new construction).
- Settlement cracks over dowel or tie bars.
- Re-entrant cracks.

Figure 2-1 illustrates several forms of early cracking photographed on recently completed airfield paving projects (within the past 5 years). Most early cracking occurs when the tensile stresses induced by slab movements exceed the tensile strength of young concrete.

(a) Longitudinal cracking (b) Transverse cracking (c) Diagonal cracking

Figure 2-1. Example illustrations of early cracking from recent airfield paving projects.

2.2.2 Factors Contributing to Early-Age Cracking

For early-age cracking to occur, two sets of factors need to be present simultaneously on a given project: (1) driving forces that induce movements in the young concrete pavement, and (2) factors that aggravate the impact of these movements on the tensile or flexural stresses developed in the pavement. The former set is referred to as trigger factors, or simply *triggers*. Triggers are basically the forcing functions that cause deformations in the PCC slabs. The latter set of factors is termed as variant factors, or *variants*.

Triggers are associated primarily with ambient conditions accompanying the placement of the PCC layer on top of the stabilized or permeable base layer. Variants are key design, materials, and construction properties of the stabilized/permeable base and PCC layer. When the variants exceed their respective threshold levels, the risk of early cracking is elevated.

2.3 TRIGGERS LEADING TO EARLY-AGE CRACKING IN PCC

Three types of environmental triggers—large ambient temperature drops, hot-weather paving, and excessive surface evaporation—set off early-age cracking in PCC, with the first two accounting for a majority of early failures. A discussion on each of these triggers and how they affect early-age behavior of PCC pavements is presented in this section.

2.3.1 Large Ambient Temperature Drops

A drop in ambient temperature of 25°F (14°C) or greater, shortly after initial set of the concrete, is sufficient to elevate the risk of early cracking significantly. This is particularly true when the temperature falls to a level where the strength gain of the PCC is affected significantly. For example, a temperature drop from 70 to 45°F (21 to 7°C) causes a greater risk of early cracking than a drop from 100 to 75°F (38 to 24°C).

Large ambient temperature swings, commonly encountered during late fall or early spring in northern and northeastern climates, can result from cold fronts, differences in daytime and nighttime temperatures, or unexpected snow/rain events.

A large ambient temperature drop imposes a negative thermal gradient through the slab (where the top is cooler than the bottom). If the slab is sufficiently hardened, this can lead to tensile stresses at the top of the slab and a potential for top-down cracking. Large temperature swings are typically prevalent in northern and northeastern climates during late fall or spring construction. A sudden rain or snow event shortly after PCC placement can also cause these swings.

2.3.2 Hot-Weather Paving

When ambient temperatures are in excess of 90°F (32°C), the risk of early cracking is significantly elevated. Hot-weather concreting practices must be followed when paving under these conditions. Further, if the concrete is being placed on a dark-colored base, such as an ATB or ATPB, care needs to be taken to cool the surface of the base prior to PCC placement.

If hot-weather paving precautions are ignored, excessive drying shrinkage can lead to warping and axial deformations. The effect of warping is similar to that of a negative thermal gradient. Axial deformations lead to stress build-up at locations of restraint—slab/base interface, tie bars, etc. Cracking can be of any orientation depending on the variants present.

Although hot-weather paving conditions are prevalent throughout the country during the normal construction season (summertime), early cracking problems due to this trigger factor occur more frequently in the hotter parts of the western and southern United States.

Hot-weather paving precautions, typically found in project specifications, need to be enforced to mitigate the risk of early-age cracking.

2.3.3 High Surface Evaporation Rate

Surface evaporation rates exceeding 0.1 lb/ft^2 (0.5 kg/m^2) elevate the risk of early-age cracking in the PCC slabs. High evaporation rates can occur due to a critical combination of high ambient and concrete temperatures, high wind speeds, and low ambient relative humidities. High surface evaporation rates generally result in plastic shrinkage cracking. However, they can also lead to early-age cracking, particularly due to their ability to cause differential volumetric shrinkage through the slab (slab warping).

2.4 Design, Construction, and Materials Variants Leading to Early-Age Cracking in PCC

Trigger conditions are necessary for the development of early cracking. Several design, materials, and construction variants must also be unfavorably aligned (i.e., exceed their threshold values) for early cracking to occur. Variants include both stabilized/permeable base properties as well as PCC layer related factors. The most important variants and their disposition leading to early-age cracking include:

- Design Variants
  - Excess base thickness.
  - PCC panels with large aspect ratios.
  - Excessive restraint within the slab.
- Materials Variants
  - High PCC/base interface friction.
  - Excessive base strength/stiffness.
  - High PCC cement factor.
  - Shrinkage susceptible PCC mixture.
- Construction Variants
  - Surface condition of base prior to paving.
  - Shrinkage cracking in base.
  - Late sawing or inadequate sawcut depth.
  - Absence of bond-breaker.
  - Inadequate PCC curing.

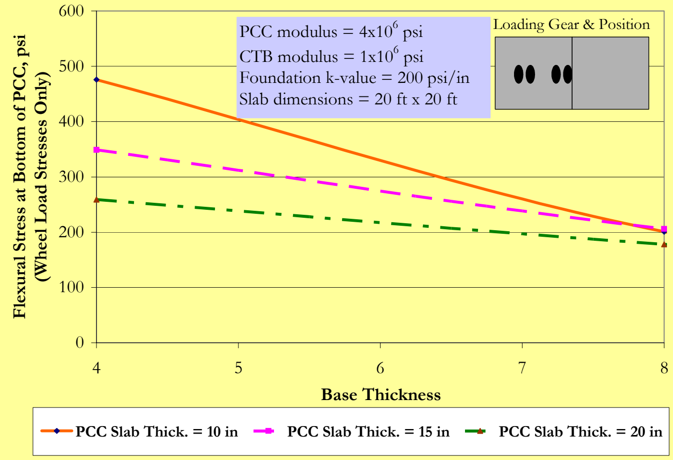
Detailed discussion of these factors is presented in the following sections.

2.4.1 Design Variants

<u>2.4.1.1 Thick Stabilized or Permeable Bases</u>

The FAA AC 150/5320-6D specifies a minimum stabilized base thickness of 4 in (102 mm). In this procedure, increasing the thickness beyond this value increases the *k*-value of the foundation. While a higher *k*-value is beneficial in reducing stresses imposed by wheel loads, its effectiveness in doing that decreases with increasing thickness of the PCC layer, as illustrated in Example Scenario 1.

Example Scenario 1: Effect of Stabilized Base Thickness on PCC Stresses due to Wheel Loads
The effect of stabilized base layer thickness on the maximum flexural stresses in a PCC pavement subject to a B-727 aircraft load is shown in the figure below. The range of k-values in the figure corresponds to stabilized base thicknesses ranging from 4 to 12 in (102 to 305 mm) resting on a 100 psi/in (28 kPa/mm) subgrade. The ISLAB2000 finite element program (Khazanovich et al., 2000) was used to obtain the solutions.

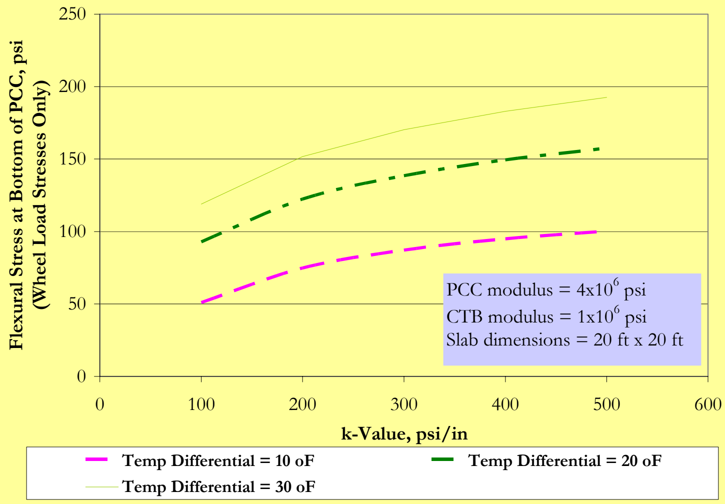


It can be noted that wheel load stresses decrease with increasing stabilized base thickness. However, the ability of base thickness to reduce load stresses decreases with increasing PCC thickness. This is no surprise since the primary load in a rigid pavement is the PCC layer itself. Further, both base thickness and stiffness contribute to the reduction in load stresses. If a stiffer base was chosen for this scenario, the impact of base thickness would have been further diminished and vice versa.

Further, for a given slab thickness and joint spacing, increasing the foundation *k*-value can actually increase the curling and warping stresses induced by temperature and moisture gradients, respectively. This is illustrated in Example Scenario 2 for a typical airfield pavement section. Therefore, load and curl stresses are affected in opposite directions by an increasing k-value leading to a marginal improvement in the combined stresses. In some cases, depending on the slab thickness and joint spacing, the combined stresses for a higher *k*-value can be higher than for a lower *k*-value.

Example Scenario 2: Effect of Stabilized Base Thickness on PCC Curl Stresses

The effect of stabilized base layer thickness on the PCC curl stresses for different positive (daytime) temperature gradients (top of slab is warmer than bottom) are shown below based on ISLAB2000 analysis. It can be noted that higher k-values can actually lead to higher curling stresses at any given temperature gradient.



Higher curling stresses can lead to higher combined stresses (load plus curl) in pavements. Therefore, while a thicker base can lower stresses due to wheel loads, this advantage is negated to a degree by an increase in the curling stresses.

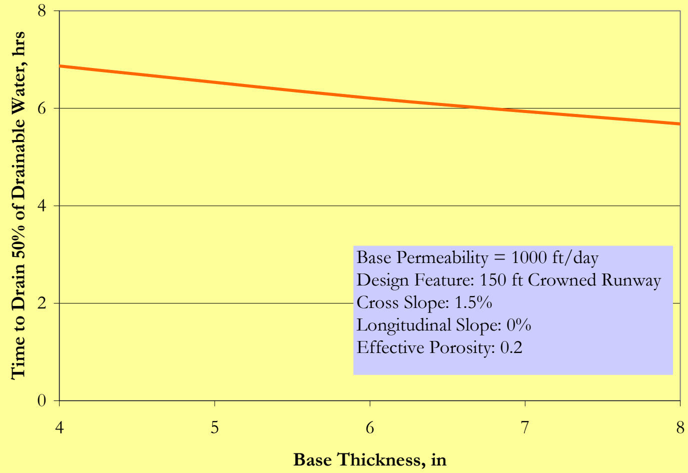
When a permeable base is used, its thickness should be that which is required for it to serve as an adequate hydraulic channel, even though large volumes of water are not expected in the pavement subsurface. Beyond a certain practical limit, however, increasing the permeable base thickness does not have a great impact on pavement drainability. In fact, since a permeable base is an inherently weak layer, thicker layers could actually be detrimental to pavement performance. Example Scenario 3 shows the relationship between base layer thickness and base drainability for a typical CTPB layer. It can be noted that increasing the permeable base thickness has a very small impact on the degree of drainability of the pavement.

Based on the discussion above, it is clear that thickness, in excess of that required to achieve the desired goals of stabilized or permeable base layers, is not necessary when designing rigid pavements. From practical and economical considerations, a stabilized base thickness between 6 and 8 in (152 and 203 mm) is sufficient for most applications. Similarly, a permeable base between 4 and 6 in (102 and 152 mm) is adequate. This thickness range allows for the base to be placed without segregation and provides for an adequate hydraulic conduit.

A stabilized base layer thickness of 6 to 8 in (152 to 203 mm) is adequate for rigid airfield pavements.

A permeable base thickness of 4 to 6 in (102 to 152 mm) is adequate for rigid airfield pavements.

Example Scenario 3: Effect of Permeable Base Thickness on Drainability
The effect of permeable base thickness on the time required to drain 50 percent of the drainable water from within the pavement structure after an initial storm saturates the base layer is shown below. The DRIP 2.0 program (Larson et al., 2001) was used to obtain the solutions presented in the figure. It can be noted that increasing the base thickness only has a marginal effect on drainability of the pavement system.



2.4.1.2 Large PCC Panel Sizes and Aspect Ratios

Long PCC panels affect the slab stresses in two ways: (1) the longer the panel size, the higher the stresses in the slab due to a given temperature or moisture gradient, and (2) the longer the joint spacing, the higher the degree of movement of the slab edges with respect to the fixed point in the slab (typically slab center), and therefore, the higher the restraint stresses in the presence of slab/base friction. The impact of long panel sizes is more pronounced in thinner PCC layers and is exacerbated by the presence of stiff stabilized bases (which cannot accommodate themselves to the curled or warped shape of the slab) and a high coefficient of thermal expansion concrete.

Another aspect of panel dimensions that affects slab stresses is the slab length-to-width or aspect ratio. Panels with higher aspect ratios have a skewed biaxial stress distribution and can lead to cracking parallel to the shorter dimension. Example Scenario 4 illustrates the how panel sizes and aspect ratios affect curling stresses in the PCC slab. To prevent excessive stresses due to curling and warping and to minimize restraint stresses due to slab/base friction, it is desirable to keep the panel dimensions below 5 times the radius of relative stiffness (*l*). The *l* value is determined as follows:

$$l = \sqrt[4]{\frac{E_{PCC} h_{PCC}^3}{12k(1 - v_{PCC}^2)}}$$

To prevent excessive curling and restraint stresses in PCC slabs built over stabilized and permeable bases, the maximum joint spacing in either direction should be less than 5**l*. In no event should a panel dimension be greater than 20 ft (6.1 m) for slabs that are 12 in (305 mm) or thicker. Further, the slab aspect ratio should be restricted to 1.25 to reduce the probability of cracking.

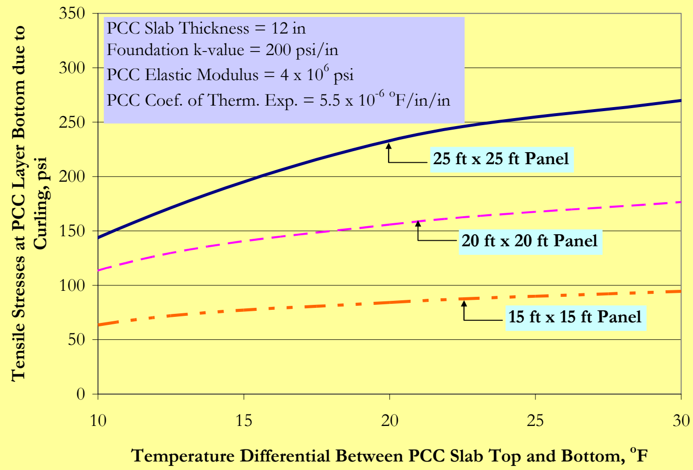
where:

E_{PCC} = PCC modulus of elasticity, psi.
h_{PCC} = PCC slab thickness, in.
ν_{PCC} = PCC Poisson's ratio.

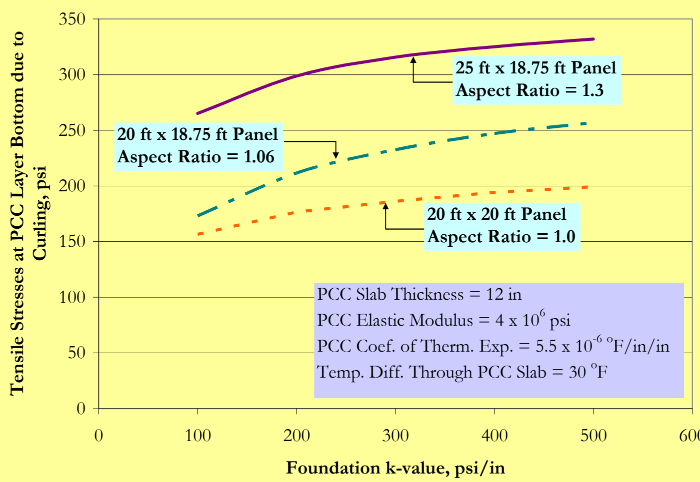
It is recommended that a maximum panel size of 20 ft (6.1 m) be adopted for PCC slabs greater than 12 in (305 mm) thick. Further, it is advisable to maintain the aspect ratio of the slab below 1.25, to avoid long, narrow slabs.

Example Scenario 4: Effect of Panel Dimensions and Aspect Ratio

The effect of slab size on the PCC curling stresses caused by a given positive temperature differential in a PCC slab is presented in the figure below for various square panels (aspect ratio = 1.0) based on ISLAB2000 analysis. Clearly, longer panel dimensions not only increase the curling stresses for any given temperature differential, but also increase the sensitivity of slab stresses to the applied thermal gradient.



The impact of slab aspect ratio on PCC curling stresses is illustrated below as a function of the foundation *k*-value. Clearly panels with higher aspect ratios lead to higher curling stresses. Further, high aspect ratios lead to critical stress development over a wider portion of the slab span (not shown here), thereby increasing the probability of cracking.



2.4.2 Materials Variants

2.4.2.1 PCC Slab/Base Interface Friction

Like most materials, the nature of concrete is that expansion and contraction occur as a function of the applied "through-thickness" temperature or moisture variations or gradients. The degree of movement and the associated tensile stresses developed as a result of these changes are directly governed by several factors, including the applied temperature and moisture loads, the thermal and mechanical properties of concrete, self-weight of the concrete, slab geometry, and the restraint provided at the slab-base interface.

Rough PCC slab/base interfaces promote a higher degree of friction, which causes excessive axial restraint to volumetric shrinkage and to thermal expansion and contraction. As horizontal forces developed by either drying shrinkage or temperature differential pull the slab in one direction, frictional resistance forces are developed in the opposite direction. This type of friction has been researched the most with regard to early-age cracking problems. Also, any forcing function (e.g., thermal and moisture stresses) imparted to the slab when the concrete is still relatively young, can cause apparent adhesion, which can impact the frictional restraint produced at the PCC slab/base interface. This phenomenon is termed "contact friction."

Certain types of high-strength stabilized bases, such as CTB and LCB, offer a high degree of restraint at the PCC slab/base interface due to their rough finished texture. Permeable bases, such as CTPB, also offer a high degree of restraint due to the near surface penetration of cement paste into these bases (although PCC paste also penetrates the ATPB layer, the lower stiffness of this layer offsets the development of high restraint stresses). The relatively high stiffness of the CTB, LCB, and CTPB layers, coupled with the high degree of restraint they offer, increases the risk of early cracking in concrete pavements built over these base types.

Stiff base layers, such as CTB, LCB, and CTPB, offer a high degree of restraint at the PCC slab/base interface, elevating the risk of early cracking. Precautions need to be taken in designing, specifying, and constructing concrete pavements with these bases to ensure that the risk of early cracking due to excessive restraint at the slab/base interface is minimized.

In addition, the bond developed at the interface of the PCC slab/base increases the effective slab thickness rendering planned sawing depths inadequate in some instances. Therefore, extra precautions need to be taken to ensure that uncontrolled cracking does not happen in the field when using these base types. These can include a variety of measures, such as the use of bond breakers, more favorable slab geometry (e.g., panel sizes and aspect ratios), and better material selection and construction practices to reduce slab movements.

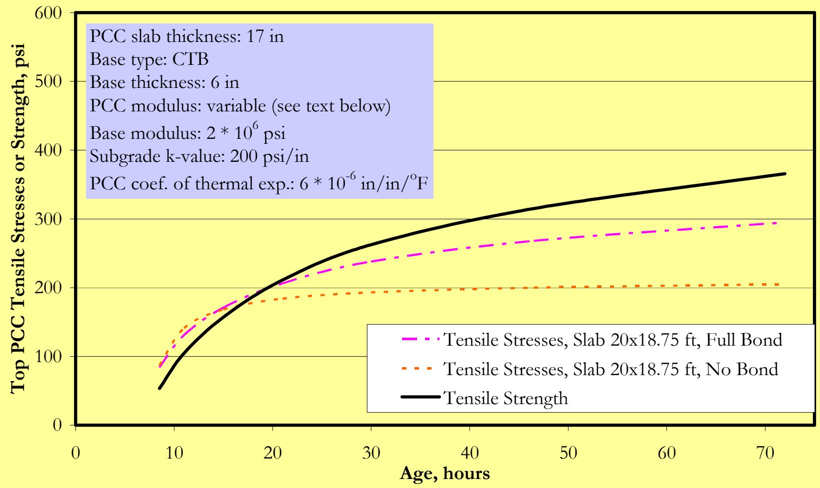
Example Scenario 5 demonstrates the impact of PCC slab/base interface friction on the maximum tensile stresses developed in a slab.

Example Scenario 5: Effect of PCC Slab/Base Interface Friction

The effect of PCC slab/base interface friction is demonstrated in this example. The details of the pavement structure analyzed are shown in the figure below. The PCC modulus of elasticity, E_{PCC}, was estimated at different ages based on the compressive strength, which was varied from 70 to 4,300 psi (483 to 29,650 kPa) to simulate aging of the concrete over the first 72 hours after placement.

The loading is assumed to be in the form of a nighttime temperature gradient with the PCC surface at 35°F (2°C) and the PCC bottom at 85°F (29°C), thereby simulating a thermal shock soon after PCC placement (the high bottom temperatures are assumed to be from the heat of hydration).

Two bond conditions—full bond and no bond—were simulated using the ISLAB2000 program. The maximum tensile stresses developed at the top of the slab are reported for these two interface conditions for the first 72 hours of the pavement's life are shown in the figure below along with a projection of PCC tensile strength.



It can be seen from the figure that although the projected PCC tensile strength is greater than the calculated stress for the most part (except immediately after placement) for both the full bond and no bond cases, clearly, the risk of early cracking (probability that the maximum tensile stresses developed will exceed the tensile strength of the PCC) due to any fluctuations in the projected strength (brought about by weather conditions or other causes), is greater for the former case. If longer panel dimensions (e.g., 25 ft x 25 ft [7.6 m x 7.6 m] slabs) had been used, the computed stresses would have exceeded the tensile strength.

2.4.2.2 Excessive Base Strength/Stiffness

High Strength Stabilized Bases

Often, strength is misused as a surrogate for durability. High strength stabilized bases, such as CTB and LCB, are typically designed for a minimum 7-day compressive strength of 750 psi (5,171 kPa). This strength requirement was established in the current FAA guidance because, at this strength level, the long-term durability of these layers when subject to repeated cycles of wetting and drying or freezing and thawing was deemed to be virtually assured (PCA, 1971).

However, the selection of this strength level is conservative and somewhat arbitrary since the strength level corresponding to adequate durability characteristics ranges from 300 to 800 psi (2,070 to 5,516 kPa).

As stated earlier, strong stabilized bases are not necessarily better bases. While a high strength stabilized base increases the *k*-value of the foundation, thus reducing load stresses and improving joint load transfer efficiency, it can also lead to higher curling stresses (see Example Scenario 2). In addition, a very stiff base does not conform easily to changes in the curvature of the PCC slab (particularly at the corners), resulting in an increased tendency for top-down cracking, corner breaks, and high corner deflections.

A strength level of 350 psi (2,413 kPa) is adequate to allow construction traffic on CTB and LCB layers.

7-day compressive strengths of CTB and LCB layers should not exceed 1,000 psi (6,895 kPa), to minimize the risk of early-age cracking.

Freeze-thaw durability testing of CTB and LCB needs to be performed only when local experience warrants it.

For construction purposes, a compressive strength of 350 psi (2,413 kPa) for CTB and LCB layers is adequate for supporting construction traffic used to place the overlying PCC layers. From a mix design standpoint, a minimum 7-day compressive strength of 500 psi (3,448 kPa) and a maximum strength of 1,000 psi (6,895 kPa) are desirable for these layers. When the 7-day strengths of CTB or LCB exceed 1,000 psi (6,895 kPa), the risk of early-age cracking in the PCC slabs built over them is significantly increased.

Using compressive strength as a criterion for designing CTB and LCB mixes is adequate in most situations. Freeze-thaw testing can be performed as a supplemental durability test when local experience indicates that it is an important consideration in the performance of the pavements. As far as long-term durability is concerned, since the CTB and LCB continue to gain strength well beyond 7 days, the strength required for durability purposes is reached soon after initial construction has been accomplished and the pavement is in service.

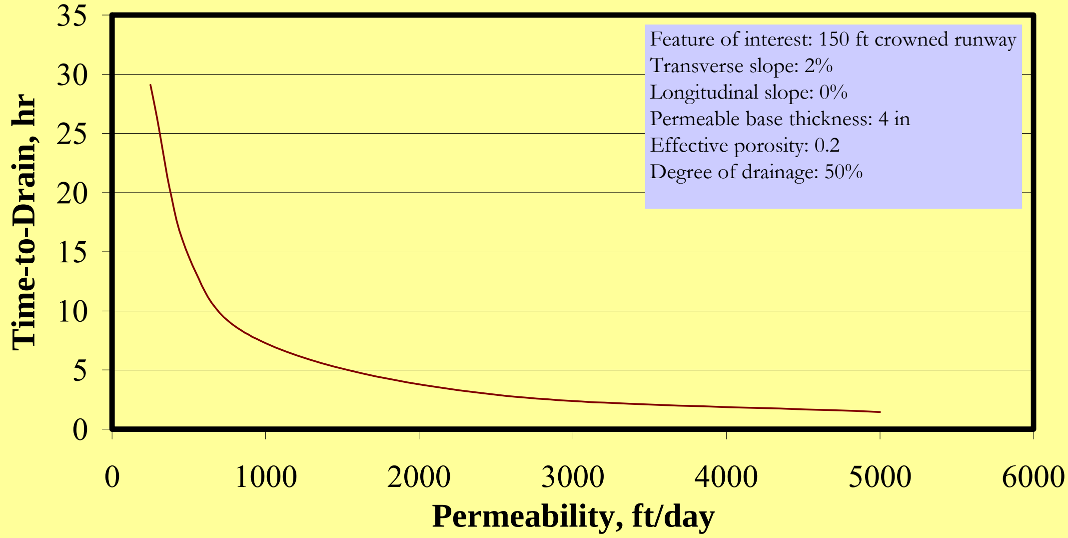
Permeable Bases

For permeable bases, the ability of it to hold up under construction traffic, its long-term durability in terms of erosion potential, and its drainability are the important concerns. Balancing the need for these three items are the keys to success of these layers. Permeability values in the range of 500 to 1,500 ft/day (152 to 458 m/day) are adequate for these layers in most situations. The effect of permeability on the time required to drain a base from an initially saturated condition to where 50 percent of the drainable water has been removed is demonstrated in Example Scenario 6.

Mix designs for permeable bases should be center around permeability, initial constructability, and long-term durability requirements. The need for permeability should be balanced with initial stability and long-term durability. A permeability value in the range of 500 to 1,500 ft/day (152 to 458 m/day) is adequate to drain rigid airfield pavements quickly.

Example Scenario 6: Effect of Permeability on Drainability

The effect of permeability on the time required to drain 50 percent of the drainable water from a base that is saturated from a rain event is demonstrated in this case study below. The drainage calculations were made with the DRIP 2.0 computer program.



The requirement to drain 50 percent of the permeable water is a conservative one, since studies have shown that bringing the saturation level to an 85% level is adequate to decrease the harmful effects of water. However, even for this case, it can be seen that the base with the least amount of permeability takes just over a day to drain the water. It can also be noted that increasing the permeability beyond approximately 800 ft/day (244 m/day) has practically negligible effect on the time required to drain the pavement for this case.

A minimum cement content of 250 lb/yd^3 (148 kg/m^3) for CTPB and asphalt content between 2.0 and 3.5 percent by weight of total mixture for ATPB are recommended to ensure uniform particle coating (related to long-term durability) and adequate strength. The final dosage rate of the binder should be optimized based on the permeability requirements for a given mix.

2.4.2.3 High Cement Factor and Shrinkage Susceptible PCC Mixes

A poor concrete mix design can aggravate the problem of premature cracking in PCC pavements. The main factors that influence premature cracking include (Shilstone, 1990; Lafrenz, 1997):

- Mixtures with higher water demand—These mixes have an increased potential for volumetric shrinkage. Factors that increase water demand include higher cement factor concrete and concrete made with fine sand.
- Gradation of combined aggregates—This affects the workability of concrete mixtures, which, in turn, may affect performance.
- Type of coarse aggregate—This can influence the temperature sensitivity of concrete.

In addition, certain types of chemical admixtures (e.g., accelerators such as calcium chloride and water reducers which contain an accelerator) can increase drying shrinkage. Another problem that has come to the forefront lately is the issue of self-desiccation of concrete, which results in autogenous shrinkage brought about by a combination of low water-cement ratios, high cement factors, and fine cements being employed in paving mixtures. Some of these variants are discussed below.

Cementitious Material

Mixtures with higher cement factors (quantities of cement and/or pozzolanic and slag additions) require more mixing water, even if the water-cementitious materials ratio is minimized, and consequently have a higher potential to shrink. When shrinkage is resisted by internal restraints in the PCC slab or external restraints (PCC slab/base friction), random cracking can develop. Mixes with cement factors greater than 500 lb/yd^3 (295 kg/m^3) have a risk of early cracking.

Concrete with cement factors in excess of 500 lb/yd^3 (295 kg/m^3) is susceptible to excess shrinkage and can lead to early cracking, especially when placed in hot weather conditions.

Conversely, mixtures with high contents of pozzolans or ground-granulated blast furnace slag, or lower contents of cement may experience delayed early-age strength development in cooler weather. Depending on the air, base, and concrete temperatures, this could delay the concrete set time and the ability to saw without excessive raveling (ACPA, 2002a and 2002b). In the end, the considerations for early-age cracking need to be balanced with requirements of strength, workability, and durability.

Sand

FAA specifications, as implemented on several projects, require that the sand for the PCC meet the ASTM C 33 specification. ASTM C 33 provides a gradation band for material passing the ⅜ in (9.5 mm) sieve to the No. 100 (150 µm) sieve and stipulates the following acceptability characteristics for the concrete sand gradation:

- No more than 45 percent of material is retained on any one sieve.
- Fineness modulus between 2.3 and 3.1.

When applied indiscriminately, this specification can lead to a mix design that is susceptible to uncontrolled cracking (even when criteria noted above are satisfied), due to the possibility of the production of gap-graded mixtures with excessive fine sand contents. The presence of fine sand (excessive minus No. 50 [300 µm] sieve material) increases the bulking potential dramatically and thereby the potential for volumetric shrinkage and early cracking.

The use of well-graded, coarse sand (FM in the range of 3.1 to 3.4) and minimum cement factor is encouraged in PCC mixes to control the water demand and reduce volumetric shrinkage potential.

To circumvent this problem, the use of coarse sand and a minimum cement factor is encouraged. Both of these mix components directly control the water demand. In general, concrete with a high cement factor, such as those used in airfield pavement construction, should include coarse sand. ASTM C 33 allows for a reduction of the portion of the sand passing the No. 50 and No. 100 (300 μm and 150 μm) sieves to 5 and 0 percent, respectively, for pavement grade concrete.

If attention is paid to these guidelines and coarse sand with fineness modulus values in the range of 3.1 to 3.4 is used in pavement concrete, excellent results can be obtained from a volumetric shrinkage standpoint. If sand with a well-graded character and fineness modulus values above 3.1 is not available, manufactured sand may need to be used (ACPA, 2002b).

Combined Aggregate Gradation

Examination of the combined aggregate gradation provides insight into the workability and segregation potential of concrete mixtures. Mixtures prone to segregation are also prone to early distress. Shilstone (1990) provided a tool in the form of a coarseness factor chart (CFC) to evaluate concrete mixture workability and the risk of problems such as uncontrolled cracking, which was validated by the United States Air Force (see Figure 2-2). The factors considered in evaluating a given mixture include the workability factor and the coarseness factor. The workability factor is simply the percent passing the No. 8 (2.36 mm) sieve for the combined aggregate gradation. The coarseness factor is expressed as a fraction of the percentage of aggregate retained on the ⅜ in (9.5 mm) sieve to that retained on the No. 8 (2.36 mm) sieve, multiplied by 100.

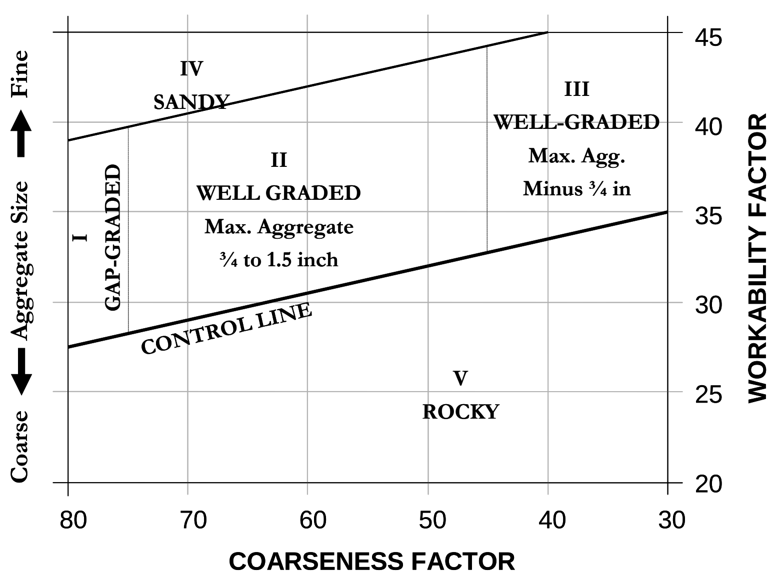


Figure 2-2. Coarseness factor chart (after Shilstone, 1990).

Generally speaking, a potentially optimized concrete mix with the least risk of premature cracking should be made with a combined aggregate that falls within Zone II of the CFC shown in Figure 2-2. A well-graded, optimized concrete mixture will reduce water demand and drying shrinkage potential and provide better workability and improved early strength development (ACPA, 2002b).

Total Water Content and Mortar Volume

Total water less than 250 lb (113 kg) and mortar volume below 60% are desirable to reduce shrinkage potential in PCC slabs—a leading trigger condition—and the risk of early cracking.

Being within the workability box defined by the workability and coarseness factors does not alone reduce the risk of excessive shrinkage. The total water in the mixture and the total mortar volume (combined volume of the cementitious materials, sand [passing the No. 8 {2.36 mm} sieve on the combined aggregate gradation], water, and entrapped air content) also contribute to this risk and must be kept within recommended limits. Total water content less than 250 lb (113 kg) and a paste volume below 60 percent are desirable for most paving mixes. Note that these numbers are to be used as guidelines and the final concrete constituents should be selected based on an optimization of other concrete properties (e.g., durability, strength).

Coarse Aggregate

Recognizing the impact of coarse aggregate type on slab movements is an important step in countering it through appropriate adjustments to design.

The type of coarse aggregate used directly controls the uniaxial expansion and contraction and curling deformations in PCC slabs. Generally, limestone, granite, and basalt have lower coefficients of thermal expansion (CTE) than quartz, sandstone, and siliceous gravel (Kosmatka et al., 2002; Mallela et al. 2005). This means that concrete made with the former materials will be more insensitive to ambient conditions and will perhaps exhibit lower tendencies to crack at early and later ages. While aggregate types/sources cannot be changed economically on a given paving project, recognition of their impact on pavement performance can lead to optimization of other design and materials parameters that can counteract the effect of these variables. For example, PCC slabs built with shorter joint spacing (less than 20 ft [6.1 m]) can mitigate the adverse impact of a high CTE aggregate in the PCC mix significantly.

2.4.3 Construction Variants

2.4.3.1 Surface Condition of Base Prior to Paving

Texture of the Finished Base

High strength stabilized bases, such as CTB and LCB, tend to have a rough surface texture. In addition, CTB and ATB layers are often trimmed to meet grade requirements, creating a rough surface texture. Rough textured bases cause high PCC slab/base friction, which increases the restraint to the slab during curing. To minimize high friction slab/base interfaces, it is advisable to use bond breakers or meet specified grade tolerances the first time the base is constructed. If trimming is unavoidable, bond breakers or leveling courses are recommended.

Cement paste penetrates the open-graded permeable bases causing slab/base interlock, which increases restraint. The impact of this interlock is more severe in stiffer bases such as CTPB than ATPB.

Even in the case of permeable bases, the possibility of excessive restraint at the PCC slab/base interface exists due to the penetration of the PCC paste into the "near-surface" portion of these bases. This penetration causes an interlocking of the slab and base, which increases the restraint stresses in the presence of trigger-induced deformations. If the base layer is stiff and resists these deformations, early-age cracking can occur. This tendency is greater in relatively stiffer bases, such as CTPB, than in ATPB. Another aspect of the concrete penetration into the stiff permeable bases is that the effective slab thickness increases as a result, and the planned sawcut depths may not be adequate to cause controlled cracking. Deeper sawcuts may be needed in this situation.

Surface Temperature

An important consideration for dark-colored bases, such as ATB and ATPB, is the capacity of these bases to absorb heat. In summer conditions particularly, the surface of these layers can reach 140°F (60°C), which impacts both strength gain and shrinkage rate of fresh concrete (Kohn et al., 2003). Therefore, these layers should be whitewashed with a lime-water solution prior to concrete placement to depress their surface temperature.

To prevent excessive heat absorption, the surface of ATB and ATPB layers should be whitewashed with lime-water solution.

<u>2.4.3.2 Shrinkage Cracking in Base</u>

In addition to restraint issues, other aspects of base layer surface conditions can lead to a heightened risk of early cracking in PCC slabs. For example, CTB layers tend to develop shrinkage cracks when high cement contents are used and adequate water for hydration is not available or inadequate curing is performed. An example of this is shown in Figure 2-3.

Experience has shown that not all shrinkage cracks in stabilized bases propagate into the PCC slab. However, care must be exercised to minimize shrinkage cracking in stabilized layers as much as possible through proper mix design and construction.

Although there is evidence that not all shrinkage cracks present in a base propagate into the PCC layer above it, there is a valid concern for increased stress concentrations (just above the cracks in the base layer) in the PCC surface layer during strength gain and the possibility of reflection cracking. This is particularly true when the PCC has not developed adequate strength. When wide (>0.5 in [13 mm]) shrinkage cracks are visible in the base, it is advisable to treat them with a reflection crack relief layer, such as a medium to high-density geotextile fabric.

Figure 2-3. Shrinkage cracking in CTB.

2.4.3.3 Late or Inadequate Sawing

Timing of Sawcut

One of the biggest variants contributing to early cracking is late or inadequate initial sawing. To derive the anticipated benefit of jointing, there is an optimum window for sawcutting joints, as illustrated in Figure 2-4 (after Okamoto et al., 1991; ACPA, 1994). This window typically occurs a few hours after the concrete placement, but the exact timing is variable. The window begins when concrete strength is acceptable to operate the saw equipment without excessive raveling at the joints. The window ends when the concrete's volume reduces significantly (from drying shrinkage or temperature contraction) and restraint of the reduction induces tensile stresses greater than the tensile strength. If sawing is performed after this point, pop-off cracks (i.e., cracks just ahead of the sawing operation) can occur (Voigt, 2002).

The paving contractor typically is provided with guidance that the saws should be operated on the pavement at the earliest possible time to provide the initial sawcut, without excessively raveling the slab. Typically, the sawing window is long enough and affords adequate time for the paving contractors to make a decision as to when to saw. However, the combination of certain design, materials, and weather-related factors can considerably shorten the window. In extreme conditions, the window can be so short as to be impracticable for crack control (ACPA, 2002b). Table 2-1 presents a listing of factors and the way each factor influences the sawing window (Voigt, 2002), which can be used as a basis for making adjustments to the sawing operation as necessary.

Both early entry and conventional sawing can be used to good effect provided the factors influencing the sawing window are recognized and enforced adequately in the field.

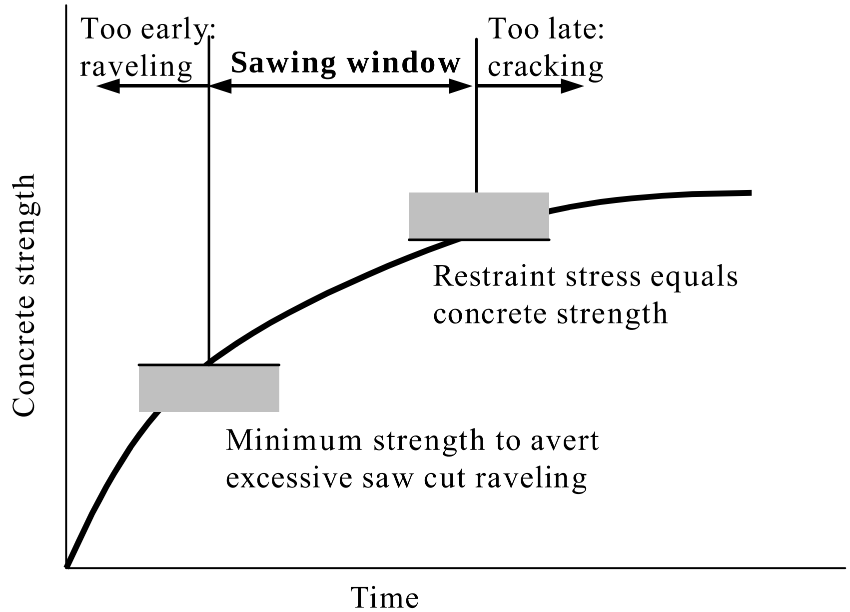


Figure 2-4. Joint sawing window of opportunity (Okamoto et al., 1991; ACPA, 1994).

Table 2-1. Factors that shorten the sawing window (after Voigt, 2002).

Factor	**Affects**
Weather-related factors	
Sudden temperature drop or rain shower	End of Window
Sudden temperature rise	End of Window
High winds and low humidity	Start of Window
Cool temperatures & cloudy	End of Window
Hot temperatures & sunny	End of Window
Base-related factors	
High friction between the underlying subbase and concrete slab	End of Window
Bond between the underlying subbase and concrete slab	End of Window
Dry surface	Start of Window
Porous aggregate subbase materials	Start of Window
PCC mixture-related factors	
Rapid early strength	End of Window
Slow early strength	Start of Window
Retarded set	Start of Window
Coarse aggregate	Start and End of Window
Miscellaneous factors	
Paving against or between existing lanes	End of Window
Saw blade selection	Start of Window (False)[1]
Delay in curing protection	Start of Window

[1] Inadequate equipment or blunt saw blades give a false indication regarding the start of the sawing window.

Depth of Sawcut

The initial sawcut should be one-third the depth of the PCC slab when the slab is placed on stabilized or permeable bases.

The initial sawcut depth, along with the sawcut timing and the equipment used, has a significant impact on the performance of the contraction joint. The issue of sawcut depth is further aggravated when concrete is placed over stabilized or permeable bases. When the PCC surface layer bonds with the base, its effective thickness is increased and the depth of the initial sawcut (which may otherwise be adequate) becomes ineffective in forcing a controlled crack at the desired locations, thereby increasing the likelihood of random cracking. Therefore, for rigid airfield pavements constructed on stabilized and permeable bases, an initial sawcut depth of one-third the PCC thickness should be employed for sawing longitudinal and transverse contraction joints to decrease the potential for random, uncontrolled cracking. The use of early entry saws can also minimize the potential for uncontrolled cracking provided the deepest initial sawcut that is practical is made.

2.4.3.4 Bond Breakers

Choke stone is the most effective bond breaker between the PCC slab and CTB, LCB, and CTPB layers. No bond breaker is necessary over ATB and ATPB layers with a smooth surface texture.

A variety of bond breakers are available to reduce the friction between the PCC slab and base layer. The most effective bond breaker for a CTB, LCB, and CTPB layer is a thin layer of choke stone[2] broadcast over its surface just prior to the placement of the PCC layer. In addition to being a bond breaker, the choke stone, in the case of the CTPB, also prevents interlocking of the PCC layer due to paste penetration. For ATB and ATPB layers, no bond breakers are necessary since the lower stiffnesses of these layers mitigate the impact of frictional restraint. The only exception is when large areas (> 15 yd^2 [12.5 m^2]) of the ATB layer are milled to achieve grade tolerance. In such an event, a single-coat of asphalt emulsion should be applied to the milled areas to reduce friction.

Conventional bond breakers, such as asphalt emulsion and wax-based liquid membrane forming curing compound (LMFCC), have variable success. In some cases, these materials do not break the bond between the PCC surface and the base layer at all. Figure 2-5 shows photos of slab liftoff tests that were performed to verify the effectiveness of the conventional bond breakers, such as asphalt emulsion and double-coat of wax-based LMFCC on CTB.

[2] A choke stone layer is a small-size stone layer (generally 0.5 to 1.0 in [13 to 25 mm] thick). A new specification for this layer was developed under FAA IPRF Project DOT/FAA-01-G-002-02-1.

(a) Slab liftoff – PCC/asphalt emulsion bond breaker/CTB

(b) Hole resulting from slab liftoff – CTB with asphalt emulsion bond breaker.

(a) Slab liftoff – PCC/wax base LMFCC bond breaker/CTB

(b) Hole resulting from slab liftoff – CTB with wax-based LMFCC bond breaker.

Figure 2-5. Slab liftoff tests with conventional curing compounds.

<u>2.4.3.5 Curing</u>

Curing is the maintenance of adequate moisture and temperature regimes in freshly placed concrete (Kohn et al., 2003). Curing is essential for proper hydration, reduction of the potential for shrinkage, reduction in built-in thermal and moisture gradients, etc., and it has an impact on long-term performance. When PCC layers are placed over stabilized or permeable bases, the impact of shrinkage and curling and warping gradients due to improper curing will be exaggerated. Therefore, special care should be taken to ensure that adequate curing is provided to the PCC layers in the presence of certain stabilized and permeable bases (namely, CTB, LCB, and CTPB). As far as curing is concerned, enforcement of specifications seems to be a bigger factor than guidance.

2.5 Interaction Between Triggers and Variants

As stated earlier, both triggers and variants need to be present to cause early-age cracking. It is the interaction between the trigger-induced deformations with various design, materials, and construction variants on any given construction project. Table 2-2 presents an overview of the relationship between two key trigger conditions, the variants that combine with them to cause early-age cracking, and the modes of cracking resulting from this combination. This table helps illustrate the “cause and effect” relationship that exists between triggers and variants.

Table 2-2. Effect of triggers and variants on pavement responses and early-age cracking.

Trigger Factor	Effect on Pavement Response & Potential Distress Modes	Aggravating Variants and Interactions
Large temperature drop-induced thermal shock caused by an approaching cold front or a significant rain/snow event.	• Imposes a negative thermal gradient though the slab (top cooler than bottom). • If the slab is sufficiently hardened, this can lead to tensile stresses at the top of the slab and a potential for top-down cracking.	• Late sawing or inadequate sawcut depth. • Long PCC slab panels or high slab aspect ratios. • Very thick or stiff base. • Improper timing of PCC placement with respect to the timing of thermal shock (e.g., placing it when the heat of hydration is maximum at the time of steepest temp. drop). • Excessive restraint at the slab/base interface. • Inadequate planning or execution of cold weather paving plans.
Hot weather paving conditions caused by high ambient temperatures, high solar radiation, low relative humidity, and high wind speeds.	• Causes excessive drying shrinkage through the slab leading to warping and axial deformations. • The effect of drying shrinkage is similar to that of a negative thermal gradient. Axial deformations cause stress build-up at locations of restraint (e.g., slab/base interface, tie bars). Cracking can be of any orientation depending on variants present.	• Hot concrete temperatures (> 85°F [29°C]). • Inadequate or late curing. • Late sawing or inadequate sawcut depth. • Excessive restraint at the slab/base interface. • High cement factor concrete without supplementary admixtures. • Shrinkage susceptible PCC mixture. • Certain types of chemical admixtures (e.g., high-range water reducers). • Placing PCC in a way that the maximum heat from hydration occurs during the hottest part of the day. • Placing PCC on a hot base layer. • Inadequate planning/execution of hot weather paving plans.

Each trigger has a threshold value that, when exceeded, contributes to the risk of premature cracking. It is important to note that if the trigger factors do not exceed their thresholds, the chances of premature cracking are minimal, regardless of the alignment of parameters. For this reason, proper planning and execution of the construction to anticipate and account for adverse climate conditions is the first and foremost defense against early-age cracking. However, since it is difficult to always exercise direct control over climatic factors, a good way to build insurance against early-age cracking is to control the variants.

The ranking of the key variants that have the most influence on the development of early-age cracking is as follows (ranked in decreasing order of importance):

- Base strength/stiffness.
- Sawing.
- Panel sizes and aspect ratios.
- PCC/base interface friction.
- PCC cement factor.
- Presence or absence of bond-breaker.
- PCC curing.
- Shrinkage susceptibility of PCC mixes.
- Base thickness.

- Presence of shrinkage cracking in base.
- Internal slab restraint (dowel bars, tie bars, etc.).

Figure 2-6 summarizes the various triggers and their threshold values, and quantifies the risk of early cracking as combination of these factors. Using this figure, the risk of early cracking for any given project can be assessed and mitigated. Note that the presence of one trigger factor is adequate to cause early-age cracking. However, the greater the number the triggers that are unfavorably aligned, the higher the risk of early cracking. Also, as the number of trigger factors increases, fewer variants need to be unfavorably aligned for the risk of early cracking to increase.

As suggested in Figure 2-6, the value of favorably aligning multiple variants to mitigate the risk of premature cracking over stabilized bases is demonstrated in Example Scenario 7. In this case study, the impact of variants, such as the panel size, PCC slab/base interface friction, and stabilized base stiffness on the tensile stresses developed in PCC slabs, is illustrated.

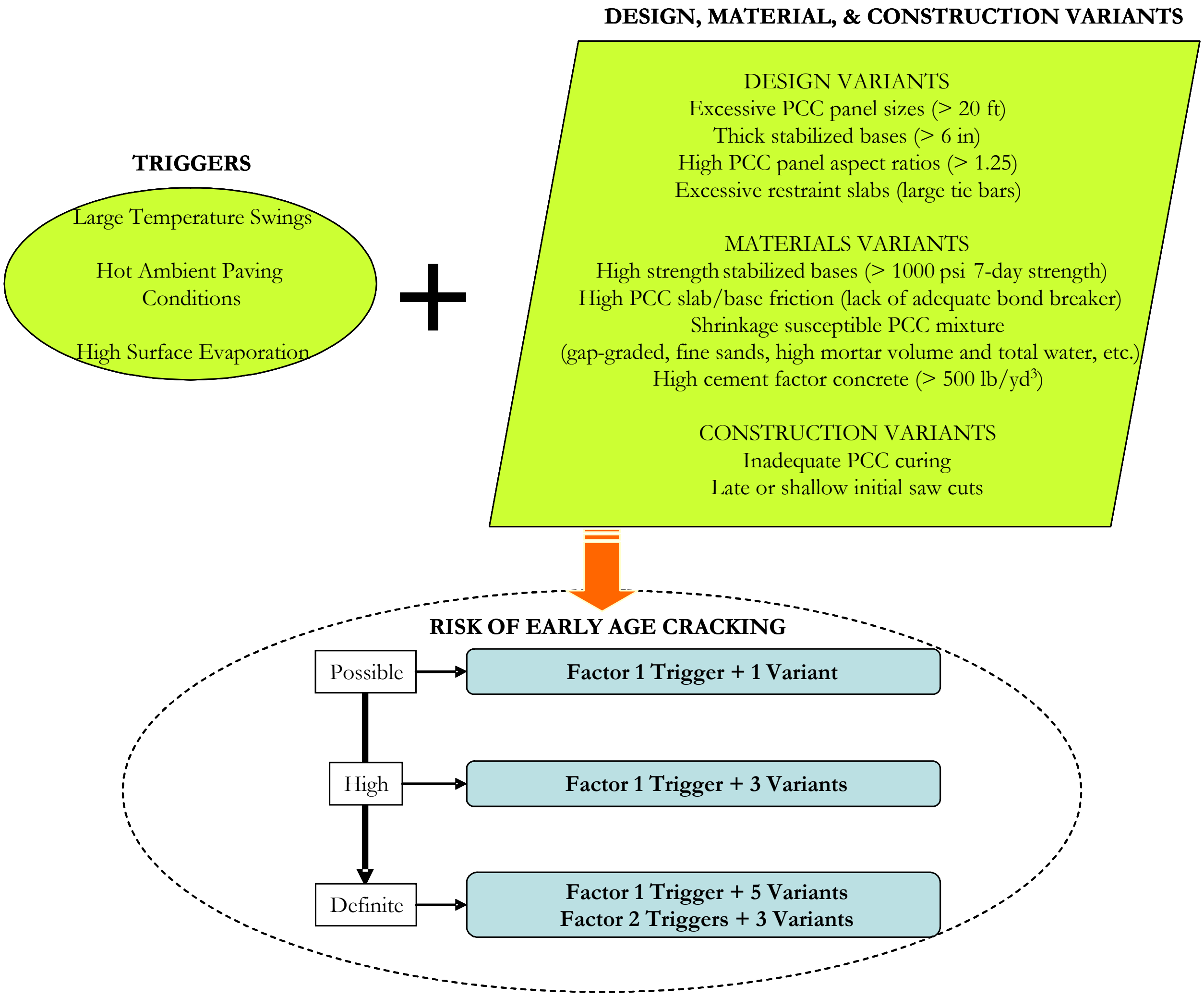
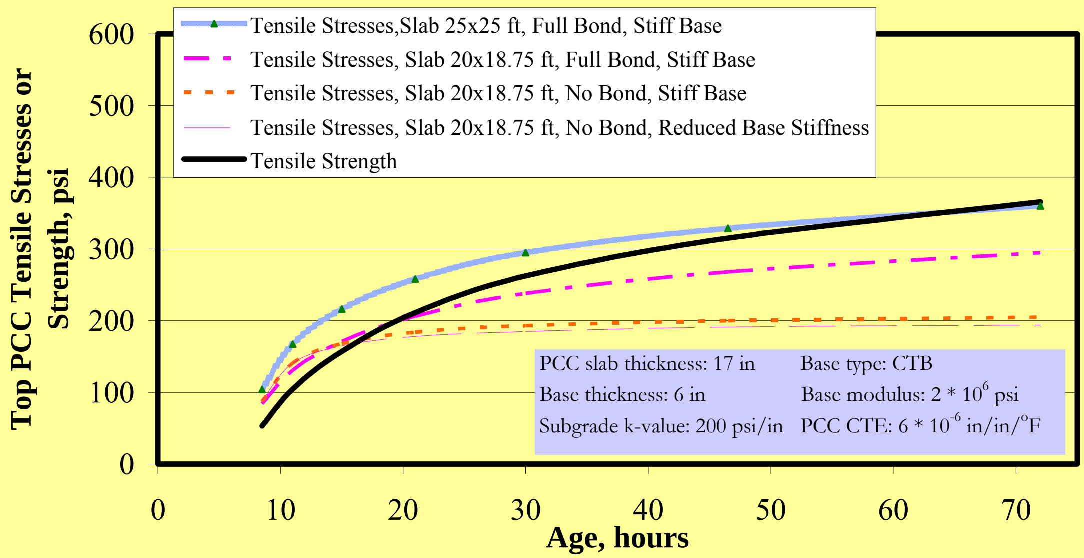


Figure 2-6. Quantification of risk of early cracking in rigid airfield pavement built over stabilized or permeable bases.

Example Scenario 7: Effect of Controlling Multiple Variants on Early-Age Cracking Risk
The effect of panel size, base friction, and base stiffness on tensile stress development in PCC slabs in the first 72 hours after placement is demonstrated in this example. The details of the pavement structure analyzed are shown in the figure. The PCC modulus of elasticity, E_{PCC}, was estimated at different ages based on the compressive strength given in Example Scenario 5. The loading is also similar to that assumed in Example Scenario 5.

The maximum tensile stresses developed at the top of the slab for various combinations of slab sizes, friction, and stiffness, are reported during the first 72 hours of the pavement's life in the figure below along with a projection of PCC tensile strength. Stress calculations were performed using ISLAB2000.



The curve representing the 25 ft x 25 ft (7.6 m x 7.6 m) slabs built on a stiff base layers with a high degree of friction develops the highest tensile stresses due to the application of the thermal shock. As some of the variants are brought within acceptable ranges with their desired threshold parameters values, the stresses developed begin to drop. However, the lowest developed stresses, and therefore the least risk of cracking at an early age is for the scenario where all three variants (i.e., panel size, interface friction, and base stiffness) are within the guidance suggested.

2.6 Base Type Selection

2.6.1 Stabilized Bases

2.6.1.1 Cement-Treated Base

CTB has several advantages that make it a good choice for a base under rigid airfield pavements. For example, it offers considerable resistance to erosion and pumping, improves load transfer efficiency, and improves foundation support (increased *k*-value) and thereby the load carrying capacity of the pavement structure. From a construction standpoint, these materials can be processed and placed easily and allow for the construction of the overlying pavement layers relatively quickly. CTB can improve the long-term performance of pavements.

One of the highest incidences of early-age cracking in rigid airfield pavements in recent years has been found on pavements that include a CTB. The reasons cited include excessive stiffness and high friction. To realize the long-term benefits of this material and to mitigate the risks of early-age cracking, the guidance provided in this chapter with regard to base related variants can be utilized during design and construction. Other non-base related variants should also be controlled; specifically, the bond breaker, PCC joint spacing, and PCC slab aspect ratio. Generally, avoiding bases with excessive thickness and stiffness, using shorter PCC joint spacing, more favorable PCC slab aspect ratios, and an effective bond breaker is preferred when using this base type.

2.6.1.2 Lean Concrete Base

The advantages LCB offers to the pavement structure are similar to those offered by CTB. They have been successfully incorporated in rigid airfield pavement structures albeit to a lesser extent than CTB layers. From a construction standpoint, LCB layers are more cumbersome to place than CTB layers since they generally require slipform equipment and a longer curing period.

Like CTB, LCB elevates the risk of early-age cracking in rigid airfield pavements. Among the primary reasons are the excessive stiffness of the base and the high friction at the PCC slab/base interface. The friction is particularly an issue with this layer since, unlike CTB, finishing generally is not performed on these layers and the aggregate structure can be relatively coarse in some instances. To realize the long-term benefits of this material and to mitigate the risks of early-age cracking, LCB thickness and LCB stiffness should not be excessive. LCB layers may also be notched to prevent uncontrolled cracking in the LCB. Other variants similar to those discussed for CTB should also be controlled.

2.6.1.3 Asphalt Concrete Base

ATB layers offer the same advantages as a CTB or LCB layer in terms of erosion resistance, improved joint load transfer, and improved foundation support. The key difference is that the stiffness of ATB layer is, on average, lower than that of the CTB and the LCB layers. The PCC slab/base interface friction is not an issue with ATB since a smooth surface texture can be obtained as a product of construction. Further, the lower stiffness of the layer offers less restraint to axial and curling deformations. Therefore, a bond breaker is not required unless the surface of the layer is milled for grade control.

The lower stiffness of the ATB layer also allows it to conform to the shape of the slab and provide more uniform support. From a construction standpoint, ATB layers are easy to place and can expedite the pavement construction schedule. There are relatively fewer instances of reported early-age cracking in rigid airfield pavements constructed over ATB layers when compared to CTB and LCB layers.

There are relatively few disadvantages of using ATB layers. A significant issue that needs attention during construction of ATB in hot weather is managing the surface temperatures prior to concrete placement. A drawback is that a mobilization cost for the asphalt paving operation will be required.

2.6.2 Permeable Bases

2.6.2.1 Cement-Treated Permeable Base

Due to the open-graded nature of the CTPB mixtures, these layers tend to be weaker than the stabilized bases. However, they must be constructed strong enough to withstand construction traffic without deformation. They improve the durability of PCC layers (e.g., D-cracking) because of positive drainage and provide reasonably uniform support to the surface layer. The primary purpose of these layers, however, is to provide positive drainage. Hence, they should be used only when there is a need for drainage (e.g., high rainfall, perched water table, low permeability subgrade soils, heavy traffic). If designed and constructed properly, CTPB layers can improve the long-term performance of pavements. CTPB is being used successfully in rigid airfield pavement structures, particularly in the mid-western United States.

CTPB layers do suffer from some of the issues that CTB and LCB layers do. A significant issue is the considerable surface penetration of PCC paste into the void structure of these bases. This penetration increases the PCC slab/base interface restraint and also the effective thickness of the PCC slab. Also, since a CTPB layer is inherently weak, its thickness should be restricted to a maximum value so that the stability of the structure is not compromised. Segregation during placement can be a significant issue with this layer.

To realize the long-term benefits of CTPB and to mitigate the risks of early-age cracking, the guidance provided in this Guide with regard to base-related variants such as thickness, the need for drainability with permeability, aggregate gradation, and durability, should be referenced. Other variants—such as use of an appropriate bond breaker, PCC joint spacing, PCC slab aspect ratio, and non-shrinkage susceptible PCC mixtures—should also be controlled.

2.6.2.2 Asphalt-Treated Permeable Base

With the exception of ATPB layers being generally weaker (less stiff) than CTPB layers, they offer a similar set of advantages when used in rigid airfield pavement structures. Because they are less stiff, the restraint created from PCC cement paste penetration at the surface of the ATPB is not as great. Thus, ATPB layers are able to accommodate more unfavorably aligned variants. A bond breaker is not considered essential for this base type.

Just as with CTPB, the primary purpose of an ATPB is to provide positive drainage. Significant concerns when using ATPB include the overheating of the base in hot-weather paving conditions (similar to ATB) and stripping and stability problems. Also, similar to ATB, the use of an ATPB adds an extra mobilization cost.

To realize the long-term benefits of this material and mitigate the risks of early-age cracking, the guidance provided in this Guide with regard to base-related variants such as thickness, balancing the need for drainability with permeability, aggregate gradation, ATPB surface temperature management, and durability, should be referenced during design and construction. Other non-base related variants should also be controlled particularly PCC joint spacing and PCC slab aspect ratio.

2.6.3 Decision Making – Base Type Selection

The selection of a base type for a given project should be based on (1) the intended role of the base layer within the pavement structure, (2) its effect on both short- and long-term performance, (3) economics, and (4) local experience.

The functions of the base layer in a rigid pavement system were previously defined, and the designer should keep these in mind when selecting a base type. For example, permeable bases should be used only when there is a need for drainage in the first place. Generally speaking, if there is adequate vertical drainage (i.e., subgrade permeability is greater than 10 ft/day [3 m/day]), permeable bases are not needed. Similarly, one of the main functions of a base layer in a rigid pavement system is to provide a uniform and non-erodible support. This is often misinterpreted as a “strong” support. An LCB layer is not necessary when an ATB layer can do the job.

During the selection process, the performance of the base type should also be weighted properly. Since a majority of the base types discussed in this Guide are viable candidates for inclusion in a rigid pavement structure from a long-term performance standpoint, their impact on short-term performance should be evaluated thoroughly. Certain types of bases, such as the CTB and LCB, bring a greater inherent “risk” of early-age cracking in certain construction seasons when compared to ATB. If local design guidance, policy, and/or materials permit accommodation of an ATB without compromising long-term pavement performance, it should be given preference. If a CTB or LCB is used, it is advisable to thoroughly understand the risks involved so that they can be mitigated during the design and construction process. The intent here is not to discourage the use of any given base type. Rather, recognition of the issues involved will help incorporate good design and construction in a more effective manner.

Availability of materials, equipment, and crew to place the material of choice dictates if a given base can be used on a given project. Local experience with a given base type should be used to guide the final selection.

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CHAPTER 3. MATERIALS SELECTION AND MIX DESIGN

3.1 BASE LAYER MATERIALS

This section describes the materials, mix proportioning requirements, and attainable properties of CTB, LCB, ATB, CTPB, and ATPB layers.

3.1.1 Cement-Treated Base

CTBs are composed of mineral aggregate and cementitious materials uniformly blended and mixed with water. They are generally of a higher quality than a soil-cement base (Item P-301) and are produced in a central mixing plant. Since the consistency of CTB material is on the drier side, materials need to be compacted with rollers after placement, usually with a paver.

3.1.1.1 Materials for CTB

Aggregate Materials

CTB includes select aggregate material comprised of crushed or uncrushed gravel and/or stone or recycled crushed and graded PCC. The use of hard, durable particles of accepted quality, free from an excess of soft, flat, elongated, or disintegrated pieces, and matter deleterious to reaction with cement is a principal requirement for strength and durability.

The aggregate used should conform to one of the two gradations shown in Table 3-1. The final aggregate blend should be well graded from coarse to fine within the limits designated in the table and should not vary from the low limit on one sieve to the high limit on adjacent sieves, or vice versa, within the gradation bands. The portion of final aggregate blend passing the No. 40 (425-µm) sieve should have a liquid limit less than 25 and a plasticity index less than 6.

Table 3-1. Aggregate gradation for CTB material.

Sieve Size	Percentage by Weight Passing Sieves	
	Gradation A	**Gradation B**
2 in (51 mm)	100	100
No. 4 (4.75 mm)	45 - 100	55 - 100
No. 10 (1.80 mm)	37 - 80	45 - 100
No. 40 (450 µm)	15 - 50	25 - 80
No. 80 (210 µm)	0 - 25	10 - 35

The top size of the aggregate is restricted to 1 in (25 mm) when CTB is placed under a PCC layer.

When the CTB is placed under a PCC surface course, the maximum size of the aggregate should be restricted to 1 in (25 mm) to permit accurate grading of the base course and to ensure that a closed texture can be obtained by compaction.

The percentage of wear of the crushed aggregate retained on the No. 4 (4.75 mm) sieve is restricted to 40 percent. The sodium sulfate soundness loss of this material should not exceed 10 percent, or the magnesium sulfate soundness loss should not exceed 13 percent, after five cycles. Additionally, all crushed material to be used in CTB should be evaluated and tested for alkali-aggregate reactivity using ASTM C 1260. The test results should have a measured expansion equal to or less than 0.10 percent in 16 days.

If recycled crushed and graded PCC are used, they should meet the requirements for virgin aggregate for gradation, LA abrasion resistance, and sulfate soundness. Guidance is available in IPRF Report 01-G-002-03-5.

Cementitious Materials

Several types of portland or blended hydraulic cements may be used to produce CTB. These include the following:

- ASTM C 150 Type I, II, III, IV, or V. Type II cements can be specified in areas with a history of sulfate reaction with the selected aggregate.
- ASTM C 595 Type IS, IS-A, IP, IP-A, P, or PA.

In addition, certain pozzolanic materials and ground granulated blast furnace (GGBF) slag may also be added to the CTB mix as a partial replacement for cement. Pozzolanic materials should meet the requirements of ASTM C 618, Class C, F, or N with the exception of loss of ignition, where the maximum must be less than 6 percent for Class F or N. GGBF slag should conform to ASTM C 989, Grade 80, 100, or 120.

Typical cement contents used in CTB are between 4 and 5 percent by weight. The final cement content used should be based on the mix proportioning requirements.

Water

Water used in CTB mixture production and curing should be clean and free of oil, salt, acid, alkali, sugar, vegetable, or other deleterious substances injurious to the finished product. Water known to be of potable quality may be used without testing. Seawater has also been successfully used to produce CTB when fresh water was not available (PCA, 1995).

3.1.1.2 CTB Mix Design Requirements

The mix proportioning of CTB can be based on strength criteria alone. Freeze-thaw and wet-dry durability testing should be restricted to areas where past experience has demonstrated that the long-term durability of the CTB layer and long-term performance of the pavement is compromised by wet-dry and/or freeze-thaw of base materials. When wet-dry and freeze-thaw durability testing is required, the weight loss for each type of test must not exceed 14 percent

CTB mix design can be based on strength criteria alone. Both minimum and maximum strength limits are needed for strength.

Freeze-thaw and wet-dry durability testing is optional.

after 12 cycles. However, if a 7-day compressive strength of 750 psi (5,171 kPa) is achieved, the wet-dry and freeze-thaw tests are not necessary. When considering durability testing, it should be noted that base materials are subject to lesser freeze-thaw/ wet-dry cycles than pavement surfaces.

The CTB mixture to be placed under a PCC surface layer should utilize a cement content that, when tested in the laboratory in accordance with ASTM D 1633, produces a 7-day compressive strength meeting the following requirements:

- A minimum 7-day compressive strength of 500 psi (3,448 kPa).
- A maximum 7-day compressive strength of 1,000 psi (6,895 kPa).

An estimate of the cement mixture proportioning is determined from table 1, chapter 2, of the *Soil-Cement Laboratory Handbook*, published by the Portland Cement Association (1971). In designing the CTB mixture, cement contents above and below the initial estimated amount should be tested to determine the minimum quantity of cement needed to achieve the required strength (or strength and durability where freeze-thaw resistance is deemed necessary).

> An opening strength of 350 psi (2,413 kPa) is adequate for allowing construction traffic.

Construction and other traffic can be allowed on the CTB layer when a minimum compressive strength of 350 psi (2,413 kPa) is achieved. The laboratory mix proportioning study can be used to estimate the time required for strength to be achieved. Figure 3-1 shows proof rolling of a CTB layer (with approximately 5 percent cement content) using a track-type asphalt paver 2 days after placement. No significant deformations were noticed on the CTB (right side paver tracks in Figure 3-1 are on CTB) when compared to the compacted granular material (left side paver tracks).

Figure 3-1. Application of construction traffic to a 2-day old CTB surface.

3.1.2 Lean Concrete Base

Lean concrete consists of aggregate and cementitious materials uniformly blended together and mixed with water. The term econocrete, sometimes used interchangeably with lean concrete, implies that the materials used in producing this material are of marginal quality when compared to those used to produce conventional concrete. The material is manufactured in a central mixing plant and usually contains 200 to 300 pounds of portland cement per cubic yard. This material is slip formed or placed using side forms just as PCC layers.

3.1.2.1 Materials for LCB

Aggregate Materials

The use of lean concrete is usually proposed to overcome shortages in the supply of quality aggregates and to be able to use local materials and still produce a high-quality paving layer. A wide range of aggregates can be used in the production of lean concrete. The coarse aggregate fraction in lean concrete can include crushed stone, crushed or uncrushed gravel, crushed recycled PCC pavement, or a combination thereof. The fine aggregate fraction may be part of the natural aggregate blend as obtained from the borrow source or it may be natural sand added at the mixer.

> A single aggregate gradation is often used for lean concrete in lieu of a blend of coarse and fine aggregates, as in conventional concrete. The percent passing the No. 100 and No. 200 (150 and 75 µm) sieves is greater than that used for conventional concrete to improve workability.

The aggregate should be hard, durable particles, free from an excess of flat, elongated, soft, or disintegrated pieces, or other deleterious matter that inhibits reaction with cement. The aggregate blend should conform to one of the gradations shown in Table 3-2.

Table 3-2. Aggregate gradation for LCB material.

Sieve Size	Percentage by Weight Passing Sieves	
	1½ in (38 mm) Maximum	1 in (25 mm) Maximum
2 in (51 mm)	–	–
1½ in (38 mm)	100	–
1 in (25 mm)	70 - 95	100
¾ in (19 mm)	55 - 85	70 - 100
No. 4 (4.75 mm)	30 - 60	35 - 65
No. 40 (425 µm)	10 - 30	15 - 30
No. 200 (75 µm)	0 - 15	0 -15

Certain types of slags, pozzolans, and chemical admixtures are effective in controlling alkali silica reactivity.

Aggregate proposed to be used in lean concrete should be tested for alkali-aggregate reactivity using ASTM C 1260. The test data should have an expansion less than 0.10 percent at 16 days.

Cementitious Materials

The types of portland and blended hydraulic cements allowed for the production of CTB can also be used to produce lean concrete. Further, pozzolanic materials and GGBF slag may be added to the lean concrete mix as a partial replacement for cement. The pozzolanic materials allowed in lean concrete must, however, meet the requirements of ASTM C 618, Class F fly ash. Allowable slag types are similar to those proposed for CTB.

Water

Water used in LCB mixture production and curing should be clean and free of oil, salt, acid, alkali, sugar, vegetable, or other deleterious substances injurious to the finished product. Water known to be of potable quality may be used without testing.

<u>3.1.2.2 LCB Mix Proportioning Requirements</u>

The mix proportioning of LCB should be based on strength requirements. Workability and compatibility with placement-related issues must be acknowledged. Freeze-thaw durability testing should not be used unless past experience has demonstrated that the long-term durability of the LCB layer and long-term pavement performance is compromised by freeze-thaw cycles.

Cement contents used in LCB are greater than those used in CTB but less than that used in PCC mixes. Typical cement contents range from 6 to 10 percent of the LCB mix (roughly 2 to 3 bags of cementitious material) by weight. The final cement content used should be based on the mix design requirements.

The LCB material should be proportioned based on 7-day minimum and maximum strength guidance.

If the 3-day lab strength of the proposed project mix exceeds 500 psi (3,448 kPa), the contractor must notch the LCB to match the planned pavement joints.

The LCB mixture should include enough cementitious material to obtain a compressive strength not less than 500 psi (3,448 kPa) nor greater than 800 psi (5,516 kPa) at 7 days, when tested in accordance with ASTM C 192 and ASTM C 39. If the maximum strength is exceeded, the LCB should be notched to match planned joints in the PCC layer. Alternatively, a new mix design that satisfies the strength requirements can be proportioned.

When freeze-thaw durability testing is performed, it should be performed in accordance with ASTM D 560. The weight loss for each type of test must not exceed 14 percent after 12 cycles. However, if a 7-day compressive strength of 750 psi (5,171 kPa) is achieved, the wet-dry and freeze-thaw tests are not necessary. When considering durability testing, it should be noted that base materials are subject to lesser freeze-thaw/ wet-dry cycles than pavement surfaces.

The water-to-cementitious material ratio is typically higher for LCB than for conventional concrete and is generally around 1.0 or higher. The percentage of air entrainment in LCB is usually at 6 percent to promote workability. The use of fly ash, water reducing admixtures, extra fines, workability agents, or a combination thereof can also be used.

Similar to CTB, construction and other traffic can be allowed on the LCB layer when a minimum compressive strength of 350 psi (2,413 kPa) is achieved.

3.1.3 Asphalt-Treated Base

ATB material consists of a bituminous plant mix composed of a mixture of well graded aggregate, filler, anti-stripping agent if required, and bituminous material.

3.1.3.1 Materials for ATB

Aggregate Materials

The quality of coarse and fine aggregate used in the ATB mixes is similar to that of a high-quality HMA layer. Aggregates used in the ATB typically consist of crushed stone, crushed gravel, or crushed slag with or without natural sand or other inert finely divided mineral aggregate. Normal weight, air cooled, blast furnace slag can be used.

The use of up to 30 percent RAP is allowed in ATB made up of recycled HMA.

Recycled HMA can consist of reclaimed asphalt pavement (RAP), coarse aggregate, fine aggregate, mineral filler, and asphalt cement. The RAP should be of a consistent gradation and asphalt content. The amount of RAP is limited to 30 percent for base courses as long as the resulting recycled mix meets all requirements that are specified for virgin mixtures.

The gradation or gradations of the mineral aggregates for any given project should conform to the requirements given in Table 3-3. The selected aggregate from within the ranges suggested should be well graded from coarse to fine aggregate and should not vary from the low limit on one sieve to the high limit on the adjacent sieve, or vice versa.

Table 3-3. Aggregate gradations for ATB material.

Sieve Size	**Percentage by Weight Passing Sieves**			
	1½ in (38 mm) max	**1 in (25 mm) max**	**¾ in (19 mm) max**	**½ in (13 mm) max**
1-½ in. (38 mm)	100	–	–	–
1 in. (25 mm)	86 - 98	100	--	–
¾ in. (19 mm)	68 - 93	76 - 98	100	–
½ in. (13 mm)	57 - 81	66 - 86	79 - 99	100
⅜ in. (9.5 mm)	49 - 69	57 - 77	68 - 88	79 - 99
No. 4 (4.75 mm)	34 - 54	40 - 60	48 - 68	58 - 78
No. 8 (2.36 mm)	22 - 42	26 - 46	33 - 53	39 - 59
No. 16 (1.18 mm)	13 - 33	17 - 37	20 - 40	26 - 46
No. 30 (0.600 mm)	8 - 24	11 - 27	14 - 30	19 - 35
No. 50 (0.300 mm)	6 - 18	7 - 19	9 - 21	12 - 24
No. 100 (0.150 mm)	4 - 12	6 - 16	6 - 16	7 - 17
No. 200 (0.075 mm)	3 - 6	3 - 6	3 - 6	3 - 6
Asphalt percent:				
Stone or gravel	4.5 - 7.0	4.5 - 7.0	5.0 - 7.5	5.5 - 8.0
Slag	5.0 - 7.5	5.0 - 7.5	6.5 - 9.5	7.0 - 10.5

Bituminous Material

The asphalt cement used in the ATB layer can conform to either a performance grade (PG), viscosity grade, or a penetration grade. For optimum performance, the grade of the bituminous material should be selected in accordance with geographical location and climatic conditions. Where possible, the use of PG graded binders is encouraged.

Mineral Filler

If filler, in addition to that naturally present in the aggregate, is necessary, it should meet the requirements of ASTM D 242.

Anti-stripping Agent

An anti-stripping agent may be needed for some mixes based on durability requirements of the mix (tensile strength ratio). If needed, a heat stable anti-stripping agent that does not modify the asphalt cement viscosity beyond specifications is recommended for use.

3.1.3.2 ATB Mix Design Requirements

The job mix formula (JMF) for ATB mixtures is currently established on the basis of the Marshall method of mixture design. The mix design criteria for a 1-in (25-mm) maximum size ATB mixture intended for use in pavements designed for aircraft gross weights of 60,000 lbs (27,120 kg) or more or tire pressures of 100 psi (690 kPa) or more are as follows:

- Number of blows: 75
- Stability, lbs: 1,800
- Flow, 0.01 in: 8 - 16
- Air voids, percent: 2 - 5
- Voids in Mineral Aggregate (VMA), percent: See Table 3-4 (expressed as a function of maximum aggregate size).

Table 3-4. VMA as a function of maximum aggregate size.

Maximum Particle Size	Minimum VMA, percent
½ in (13 mm)	16
¾ in (19 mm)	15
1 in (25 mm)	14
1½ in (38 mm)	13

An air void content of 4 percent is typically used to determine the asphalt content based on the criteria above.

Stripping is perhaps one of the most significant problems with this base type. This should be mitigated during mix proportioning.

A mixture durability requirement in the form of a tensile strength ratio (TSR) is also typically imposed. The TSR value should be greater than 75 (80 in areas with a history of stripping [e.g., wet climates and local aggregates that are not limestone or dolomite]). An anti-stripping agent can be added to the ATB mixture, as necessary, to meet the TSR requirements.

3.1.4 Cement-Treated Permeable Base

A CTPB consists of durable, high-quality mineral aggregate with negligible fines, blended with sufficient amounts of cement and water to coat the particles uniformly. The gradation of a CTPB allows for a large void structure so that moisture that seeps into the pavement is drained away rapidly and efficiently.

<u>3.1.4.1 Materials for CTPB</u>

Aggregate Materials

Aggregate quality is of primary importance for CTPB (as well as ATPB). Due to the low cement content used, it is expected that the long-term stability of the mixture will come from the aggregate structure.

The aggregate used in the CTPB should consist of clean, sound, hard, durable, angular particles of crushed stone that meets the specification requirements. The aggregate should be free from clay balls, organic matter, and other deleterious substances. Guidance on deleterious materials should be developed in accordance with ASTM C 33.

The aggregate should contain not more than 15 percent, by weight, of flat or elongated pieces, as defined in ASTM D 693. The use of crushed aggregate that has at least 90 percent by weight of particles with at least two fractured faces and 100 percent with at least one fractured face is highly encouraged. The percentage of wear of the crushed aggregate retained on the No. 4 (4.75 mm) should not be greater than 50 percent. The sodium sulfate soundness loss should not exceed 10 percent, or the magnesium sulfate soundness loss should not exceed 13 percent, after five cycles, when tested in accordance with ASTM C 88.

The CTPB gradation should conform to one of the aggregate gradations shown in Table 3-5 when tested in accordance with ASTM C 136. The gradations can easily be obtained by blending aggregates of different sizes. The permeability of the CTPB can be expected to increase slightly from Gradation A to Gradation C.

Table 3-5. Aggregate gradation for CTPB material.

	Percentage by Weight Passing Sieves		
Sieve Size	**Gradation A (¾ in [19 mm] max.)**	**Gradation B (1 in [25 mm] max.)**	**Gradation C (1½ in [38 mm] max.)**
1½ in (38 mm)	–	–	95 - 100
1 in (25 mm)	–	95 - 100	72 - 82
¾ in (19 mm)	95 - 100	77 - 87	60 - 70
½ in (13 mm)	67 - 77	53 - 63	40 - 50
⅜ in (9.5 mm)	50 - 60	41 - 51	30 - 40
No. 4 (4.75 mm)	19 - 29	15 - 25	10 - 20
No. 8 (2.36 mm)	0 - 6	0 - 6	0 - 6

3.1.4.2 CTPB Mix Proportioning Requirements

The mix design establishes the percentage of dry weight of aggregate passing each specified sieve size and the percentage of cement required based upon the weight of the total mix.

The criterion to establish the amount of cement required for a selected gradation from Table 3-5 is to have sufficient paste volume to adequately coat the aggregate particles without creating excess that can plug the pore structure. The recommended way to determine this is through visual examination in the laboratory. It is recommended that the mix proportioning contain about 250 lbs/yd^3 (148 kg/m^3) to meet this requirement. The cement content can be varied from this minimum amount to satisfy the desired mix characteristics.

> The mix design of CTPB is subjective due to the lack of understanding between differences in laboratory and field compaction of CTPB mixes.
>
> A goal should be to provide adequate paste to optimize durability and strength, while still retaining an open-graded structure for drainage.

Field permeability criteria are established on the basis of how much water needs to be removed from the pavement and how quickly. Removing 50 percent of the drainable water from the base layer within a 24-hour period after a rainstorm is adequate for most airfield pavement.

A mix prepared, placed, and compacted in the field should have a permeability of not less than 500 ft/day (152 m/day) nor more than 1,500 ft/day (458 m/day) when tested in the laboratory in accordance with ASTM D 2434/AASHTO T 215 (Constant Head Permeability Test). The permeability requirements may be verified in the field by taking cores from the test section. If the test section permeability is significantly less than that stated above, a new mix design with a coarser gradation or lower cement content may be needed. If the test section permeability is greater than that stated above, additional rolling may be permitted to close-up the void structure, as long as such rolling does not crush the aggregates or deform the surface. Alternatively, a mix design with a finer aggregate gradation may be proposed.

3.1.5 Asphalt-Treated Permeable Base

ATPB consists of durable, high quality mineral aggregate with negligible amount of fines. The aggregates are blended with an adequate amount of bituminous material to coat the particles uniformly. An anti-stripping agent should be used.

<u>3.1.5.1 Materials for ATPB</u>

Aggregate Materials

The aggregate used in ATPB should consist of clean, sound, hard, durable, angular particles of crushed stone. The aggregate should be free from clay balls, organic matter, and other deleterious substances.

The aggregate should contain not more than 10 percent by weight of flat or elongated pieces and should have at least 90 percent by weight of particles with at least two fractured faces. The percentage of wear of the crushed aggregate retained on the No. 4 (4.75 mm) sieve is restricted to 40 percent when tested in accordance with ASTM C 131. The sodium sulfate soundness or magnesium sulfate loss should be less than 10 and 13 percent, respectively, after five cycles.

The quality requirements for the aggregates used for ATPB are more stringent than those for CTPB, due to the increased importance of aggregate interlock during construction and resultant long-term performance of these layers.

Aggregate quality is more important for ATPB than for CTPB.

The gradations proposed for the CTPB (see Table 3-5) can be used for ATPB mixtures as well.

Bituminous Materials

The asphalt cement binder should be selected based on geographical location and climatic conditions to improve layer performance. The asphalt grade used for P-401 material for the project location or a stiffer grade (to prevent drain down of the asphalt cement) is adequate.

Anti-stripping Agent

By design, ATPB allows water to drain through it. In such situations, stripping of the asphalt is a major concern. Therefore, to improve the durability of ATPB, an anti-stripping agent in the form of hydrated lime is highly recommended, particularly if the coarse aggregate is not limestone or dolomite. Lime should be added at a dosage rate of rate of 0.5 to 1.0 percent by weight.

> The addition of lime not only improves the durability, but also improves ATPB stiffness.

3.1.5.2 ATPB Mix Proportioning Requirements

The JMF establishes the percentage of dry weight of aggregate passing each required sieve, a percentage of asphalt cement to be added, and a temperature for the mixture.

The most important criterion is to establish the amount of asphalt binder required for a selected gradation that provides adequate coating of the aggregates and a permeability value between 500 and 1,500 ft/day (152 and 458 m/day). To prepare the specimen for permeability testing, the component aggregates are blended together, mixed with the specified amount of asphalt cement at a temperature of 250°F (121°C) (note: higher mixing temperatures may be required when modified asphalts are used), and compacted on one-side at 150°F (66°C) with 35 blows of a standard Marshall hammer. This level of compaction roughly correlates with field compaction of ATPB layers. The JMF should have a minimum asphalt binder content of 2.0 percent by weight, which can be adjusted upward to 3.5 percent to provide stability under rollers during construction and for durability of the mix.

The permeability requirements may be verified in the field by taking cores from the test section. If the test section permeability is significantly less than that stated above, a new mix design with a coarser gradation and/or lower asphalt content may be needed. If the test section permeability is greater than that stated above, additional rolling may be permitted to close-up the void structure as long as such rolling does not crush the aggregates or deform the surface. Alternatively, a new mix design with a finer aggregate gradation may be proposed.

3.2 CHOKE STONE MATERIALS

3.2.1 Definition and Purpose

A choke stone is a small-size stone layer (generally 0.5 to 1.0 in [13 to 25 mm] thick). It is used in conjunction with stabilized bases, such as CTB and LCB, to serve as a bond-breaking layer and with permeable bases, such as CTPB, to

> When a choke stone layer is used, it should be identified in the plans. However, it should be considered a part of the layer on which it is placed.

prevent excessive penetration of the PCC paste and to guard against yield loss of the PCC surface. The bond prevention qualities of the choke stone are superior to that of a wax-base liquid membrane forming curing compound or asphalt emulsion. These latter materials are commonly specified in project specifications as bond breakers but were found to be largely ineffective in a field trial conducted as part of FAA IPRF Project FAA-01-002-02-1.

3.2.2 Materials

A choke stone course is comprised of crushed mineral aggregate. The aggregate should consist of clean, sound, hard, durable, angular particles of crushed stone free from clay balls, organic matter, and other deleterious substances.

The aggregate should conform to the gradation shown in Table 3-6 or the gradation requirements for ASTM No. 89 stone.

Table 3-6. Aggregate gradation for choke stone material.

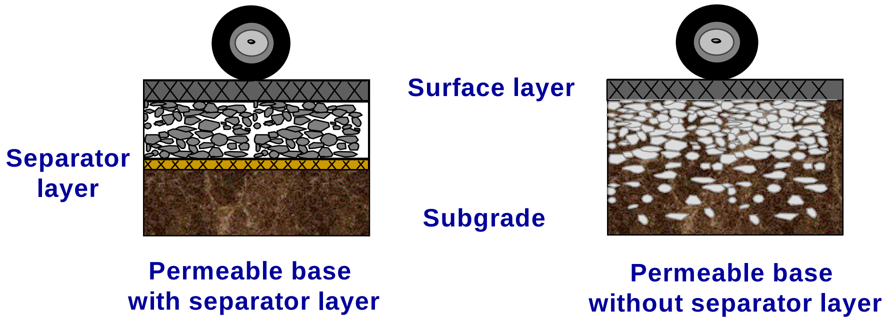
Sieve Size	Percentage by Weight Passing Sieves Choke Stone
½ in (13 mm)	100
⅜ in (9.5 mm)	80 - 100
No. 4 (4.75 mm)	10 - 100
No. 8 (2.36 mm)	5 - 50
No. 16 (1.18 mm)	0 - 10

3.3 SEPARATION LAYER MATERIALS

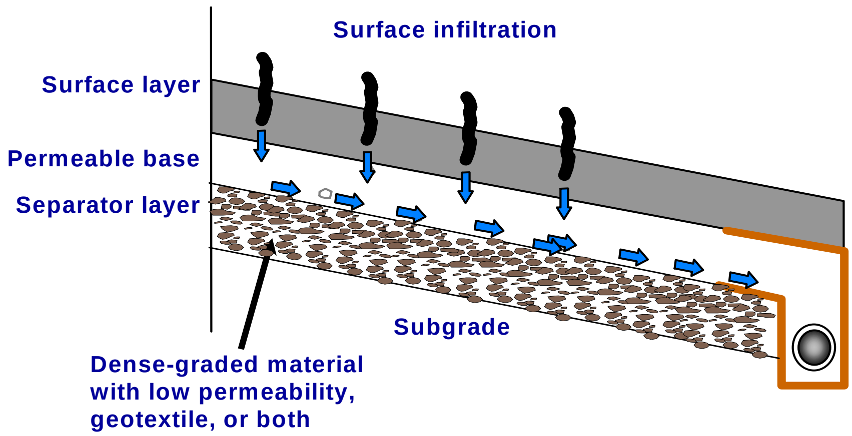
3.3.1 Definition and Purpose

A separation layer is the soil, fabric, or other material that is placed between a permeable base and the underlying layer (subgrade or subbase) to preserve the integrity of the permeable base and to improve the efficiency of the entire drainage system. An effective separation layer is required to maintain the design thickness and permeability of the permeable base to enable it to perform efficiently.

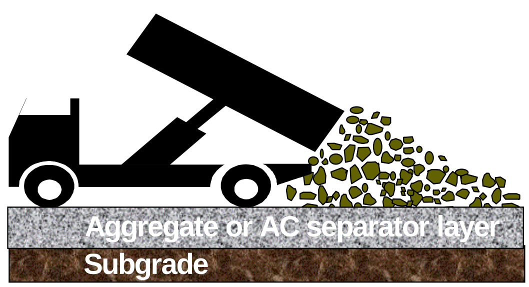
As Figure 3-2 shows, the separation layer specifically (a) maintains separation between the permeable base and subgrade, preventing them from intermixing, and (b) forms an impermeable barrier that deflects water from the permeable base horizontally toward the pavement edge. The separation layer can also provide support to construction traffic when an adequate construction platform has not been constructed. The separation layer is not required to act as a filter (i.e., allowing groundwater through, while holding back soil material). However, when the drainage layer is placed to intercept ground water, a separation layer will still be needed but it can be designed to act as a filter.



(a) Separation (Holtz et al., 1998).



(b) Facilitation of horizontal drainage (ERES, 1998).



(c) Construction support (FHWA, 1995).

Figure 3-2. Roles of a separation layer in a pavement system with a permeable base.

3.3.2 Materials

Pozzolanic or cement-treated materials tend to develop shrinkage cracks which allow for moisture from the subgrade to seep through into the permeable base. If these materials have to be placed beneath the permeable base, a geotextile separator may be used.

Separation layers can be dense-graded aggregate, dense-graded HMA, or geotextile materials having certain characteristics. Lime- or cement-treated subgrades and cement-treated layers are not acceptable as separation layers over fine-grained soils.

3.3.2.1 Aggregate Separation Layers

Dense-graded aggregate layers can fulfill the requirements of a separation layer. A minimum thickness of 4 in (102 mm) is recommended for this layer. The thickness may be increased up to 8 in (203 mm) if the layer is placed directly over the subgrade to meet design requirements. The following physical properties are desirable of an aggregate separation layer (FHWA 1994):

- It should be a durable, crushed angular aggregate material. As a minimum, the aggregate should have at least two fractured faces, as determined by the material retained on the No. 4 (4.75 mm) sieve; preferably, it should consist of 98 percent crushed stone.
- The percentage of wear of the crushed aggregate retained on the No. 4 (4.75 mm) sieve is restricted to 50 percent when tested in accordance with ASTM C 131.
- The sodium sulfate soundness loss should not exceed 10 percent, or the magnesium sulfate soundness loss should not exceed 13 percent, after five cycles, when tested in accordance with ASTM C 88.
- A California Bearing Ratio (CBR) of 50 or greater.
- The gradation should allow a maximum permeability of approximately 15 ft/day (5 m/day).

The gradation of the aggregate separation layer is engineered to satisfy uniformity and separation requirements at both its bottom interface (subgrade/subbase) and top interface (permeable base). The aggregate separation layer gradation design is a three-step process (ARA, 2004), as described below.

Step 1: Check for Aggregate Separation Layer–Subgrade/Subbase Layer Interface Requirements

The gradation of the separation layer must meet the interface requirements listed below:

- Separation requirement: D_{15} (separation layer) < $5D_{85}$ (subgrade/subbase layer).
- Uniformity requirement: D_{50} (separation layer) < $25D_{50}$ (subgrade/subbase layer).

D_X represents the particle size that x percent of the material is smaller than by weight.

Step 2: Check for Aggregate Separation Layer–Permeable Base Interface Requirements

Similar requirements must be applied to the separation layer–permeable base interface, as listed below.

- Separation requirement: D_{15} (permeable base) < $5D_{85}$ (separation layer).
- Uniformity requirement: D_{50} (permeable base) < $25D_{50}$ (separation layer).

Step 3: Other Requirements

The following requirements ensure that the dense-graded aggregate separation layer does not have too many fines and is well-graded:

- Maximum percentage of material passing the No. 200 (75 µm) sieve should not exceed 12 percent, by weight.
- Coefficient of uniformity (D_{60}/D_{10}) should be greater than 20; preferably greater than 40.

The first criterion limits the amount of fines in the aggregate separation layer, and the second provides guidance for developing a well-graded aggregate base.

The results of these checks are typically plotted on a gradation chart to develop a design envelop through which the gradation of the aggregate separation layer must pass. A sample plot of a gradation that satisfies the design checks is shown in Figure 3-3. Also plotted in this figure is the design envelop developed from the criteria discussed above for sample permeable base and subgrade gradations.

An asphalt prime coat can be applied to the dense-graded separation layer to reduce the risk of erosion of fines at its surface.

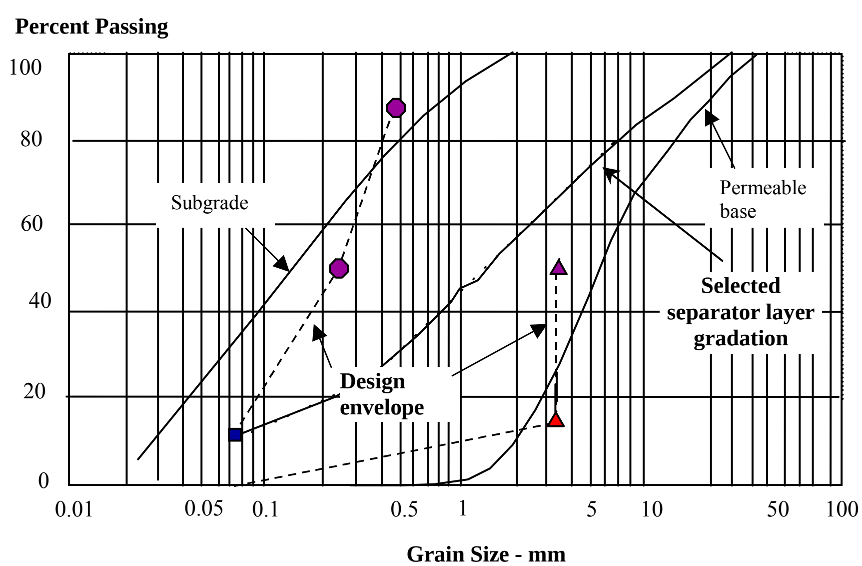


Figure 3-3. Plot of design envelop superimposed on base, subgrade, and the dense-graded aggregate gradations (ARA, 1999).

3.3.2.2 Dense-Graded HMA Separation Layers

Dense-graded HMA mixtures, such as those specified in Item P-403 of FAA AC 150/5370-10B, satisfy all the requirements of a separation layer.

3.3.2.3 Geotextile Separation Layers

Geotextile separation layers are typically used when a construction platform (e.g., a stabilized layer, a granular layer, or a subgrade with a CBR greater than 10) exists. Both woven and non-woven geotextiles have been used for the separation application.

The important design criteria to be considered when specifying the properties of geotextile as a separator layer are divided into four categories, namely:

- Soil retention.
- Permeability.
- Clogging.
- Survivability and endurance.

The design guidelines for the soil retention, permeability, and clogging criteria are summarized in the flowchart in Figure 3-4. In addition to these criteria, to ensure that the geotextile will survive the construction process, certain strength and endurance properties are required. Geotextile fabrics satisfying the AASHTO M 288 Survivability Class 2 criteria (either woven or non-woven fabrics) tend to have adequate strength and durability to survive both construction and long-term use. A relatively heavy (weight-to-area ratio of 0.1 oz/ft^2 [30.5 gm/m^2]), non-woven geotextile is recommended for separation layer applications.

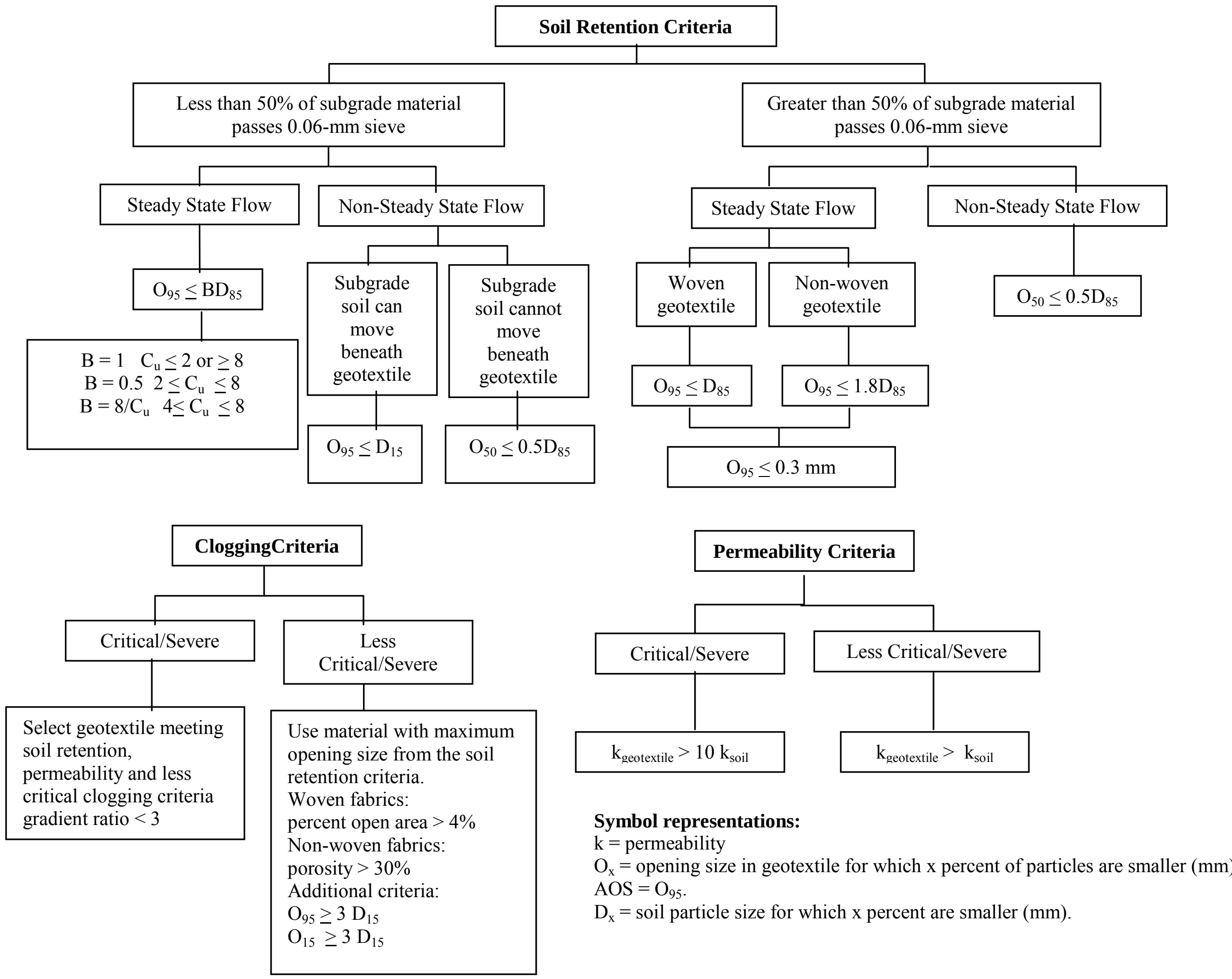


Figure 3-4. Flowchart summarizing the soil retention, permeability, and clogging criteria for selecting the properties of geotextile (ARA, 1999).

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CHAPTER 4. STABILIZED AND PERMEABLE BASE CONSTRUCTION

4.1 PRE-CONSTRUCTION ACTIVITIES

4.1.1 Test Section Construction

Test sections are recommended for ATPB and CTPB layers to verify the mix design and constructability.

Depending on the type of material to be used on a given project, a test section should be constructed to evaluate constructability issues related to producing, hauling, placing, and finishing the material. Test section construction should closely mimic the design details of the project and the anticipated construction processes and conditions.

The test section should be of sufficient size to allow the contractor to fully demonstrate the paving operation. The Engineer should be able to fully evaluate each aspect of the construction work. The size best represented is dual lane paving that extends for either (a) 500 ft (152 m) in length or (b) 1 hour of production, whichever transpires first.

Specific items that should be evaluated in the construction of the test section are:

- Pre-paving Inspection Activities
  - Subgrade/subbase condition—Check grade, stability, general surface conditions.
  - Grade control adequacy—Check grade stakes, pins, forms to be used in placing base material.
  - Equipment—Check adequacy of equipment used to mix, haul, place, compact, and finish the material.
- Mix Production Inspection Activities
  - Conformity of mix with approved job mix formula (JMF)/mix design.
  - Mix uniformity—Check for consistency within and among mix batches and throughout continuous mix production. Check for improper sequencing of materials, improper feed/metering rates, inadequate mixing times, changes in stockpile moisture.
  - Mix temperature (for asphalt-treated base materials and cement-treated base materials that require heating).
  - Production rate adequacy—Check for acceptable stockpile management plans, efficient loading operations, acceptable mixing times based on mix uniformity testing.
- Mix Hauling Inspection Activities
  - For cement-treated base materials, check time between start of moist mixing and delivery of the material on-site to verify that the material can be produced, transported, and delivered within specified time limits (typically 30 minutes for non-agitating trucks and 45 minutes for transit mixers).
  - For asphalt-treated base materials, check temperature of delivered material to verify that the material can be produced, transported, and delivered within the specified temperature limits (typically 250°F [121°C] minimum for non-permeable mixes and between 200 and 250°F [93 and 121°C] for permeable mixes).

  - For all materials, make sure there is adequate equipment to prevent stop-and-go paving.
  - For all materials, material transfer devices or dumping procedures ensure that segregation is not occurring.
- Mix Placement Inspection Activities
  - Spreading and laydown of material—Check for damage to separation layer (if used) caused by trucks and/or laydown equipment, adequacy of spreading across paving width, adequacy of coating of aggregate particles by cement paste or asphalt binder, mix segregation, proper depth of placement taking into account roll-down, speed of laydown.
  - Compaction and finishing of material—Check for stability (firm and unyielding), surface texture (uniform, with no crushing of aggregate), and depth (using probes, string lines and ruler) during rolling. Test for surface tolerance, grade, mat and joint density (note: nuclear gauge is unsuitable for use on permeable bases), and permeability of permeable bases (1 gal/minute [3.8 L/minute] water pour), as specified by the project. Check for depth following roll-down and undue displacement, cracking, or shoving caused by rollers or improper roller speeds.

When there are difficulties in mix uniformity, temperature, or production rate, changes to the plant, the mixing process, the JMF/mix design, and/or the production testing procedure should be considered. Similarly, if deficiencies in the field operations are observed that impact the desired quality of the constructed base, changes should be made to the process. Construction of test sections should be continued until a base is placed successfully.

4.2 SUBGRADE AND SUBBASE ISSUES

Depending on the project, the stabilized and/or permeable base will be placed on top of a subgrade or subbase, with or without the inclusion of an aggregate or geotextile separation layer. As pointed out by Kohn et al. (2003), uniformity and stability of the prepared subgrade or subbase affect both the long-term performance of the pavement and the construction process. Moreover, proper grade control of the underlying layer(s) will help minimize the potential for deficient base and/or concrete slab thickness.

Kohn et al. (2003) covers in great detail the key issues concerning the grading, stabilizing, and compacting of subgrade materials and the placement and compaction of granular subbase materials. When a separation layer is to be included on top of the prepared subgrade/subbase, the importance of achieving a solid working platform—with the proper grade and surface tolerance—cannot be over-emphasized. In addition, great care must be exercised in the allowance of construction traffic on the prepared subgrade/subbase, so as to ensure that the layer(s) is free of ruts, depressions, and bumps prior to the placement of the separation layer or stabilized and/or permeable base.

Separation layers should not be placed on soft, muddy, or frozen subgrade/subbase and caution should be exercised to prevent incorporating subgrade/subbase or shoulder material into the aggregate or HMA separation layer material. If a geotextile is used for the separation layer, the underlying subgrade/subbase layer should be free of all sharp objects (sticks, stumps, metal debris) and large stones that could puncture the fabric.

The geotextile should be placed in accordance with the requirements and standard details provided in the project plans, as well as the manufacturer's recommendations. The fabric should be draped taut over the prepared subgrade/subbase, so as to avoid wrinkles, but it should not be stretched so tight as to produce tearing. Fabric overlaps and seams should be made as specified and securing of the fabric to the subgrade/subbase should be achieved through sufficient pinning and/or placement of soil.

Construction traffic should only be allowed on the secured geotextile fabric after it has been demonstrated that the material can hold up under the loads and movements of the traffic. Any tears, holes, or other damage done to the fabric during installation should be repaired via patches or replacement. Routine checks of vertical and horizontal displacement of the fabric are recommended.

4.3 BASE MATERIALS CONSTRUCTION

4.3.1 Cement-Treated Base

4.3.1.1 CTB Mix Production

CTB mixes should be produced in a central plant, continuous flow pugmill mixer to ensure uniform quality. Batch pugmill or rotary drum mixers may be used on smaller jobs (say less than 2,500 yd^2 [2,090 m^2]). The continuous flow plants should be equipped with feeders to proportion aggregates and bulk cement, by weight, automatically. The plant site, layout, equipment, and provisions for transporting material should assure a continuous supply of material to the work. The plant should be calibrated before mixing and placing operations begin to ensure that the correct proportion of material will be discharged.

Aggregate stockpiles should be constructed in a manner that prevents segregation and intermixing of deleterious materials. Aggregates that are segregated or mixed with earth or foreign material should not be accepted.

Aggregate and cement may be proportioned either by weight or volume, and must be mixed sufficiently to prevent the forming of cement balls after water is added. The mixing time should be that which is required to secure a uniform mixture of aggregate, cement, water, and pozzolan (if used). This time varies based on the material feed rates, belt speed, pugmill tilt, and paddle pitch of the mixer; therefore, prescriptive mixing times are not recommended. The minimum mixing time should be based on the uniformity and consistency of the mixture produced based on visual examination. Typically, a minimum mixing time of 30 seconds can be expected (PCA, 1995).

4.3.1.2 CTB Mix Hauling and Placement

Hauling

The mixed CTB material should be transported from the plant to the job site in trucks or other hauling equipment having beds that are smooth, clean, and tight. Truck bed covers should be used to protect the CTB from rain. CTB material that becomes wet by rain during transport or placement should be examined and rejected if there is evidence of any alteration in the consistency and uniformity of the mix.

Placement

The CTB mixture should be deposited on moistened subgrade or subbase and spread into a uniform layer. The layer should be of such width and thickness that, following compaction to the required density and trimming, it conforms to the required grade and cross-section. Mechanical spreaders or equipment capable of receiving, spreading, and shaping the mixture (without segregation) into a uniform layer/lift can be used. The equipment should be equipped with a strike-off plate capable of being adjusted to the specified layer thickness. It should also be equipped with two end gates or cut off plates, so that the CTB may be spread in widths varying up to lane width. Figure 4-1 illustrates CTB placement using an asphalt laydown machine.

Figure 4-1. CTB placement with an asphalt paver.

A single spreader may be used over the entire width, provided it is capable of placing a uniform, full-depth layer of material across the full width of the base in one pass. Otherwise, two or more spreaders will be required. When using two spreaders in adjacent lanes, they should operate in a staggered position and the adjacent lanes should be paved such that there is not more than a 30-minute gap between the placing times at any given point in time (PCA, 1995).

The CTB material should not be mixed or placed while the air temperature is below 40°F (4°C) or when conditions indicate that the temperature may fall below 35°F (2°C) within 24 hours. The CTB should not be placed on frozen ground. Further, CTB should not be placed when rainfall is occurring. If an unexpected rain event occurs during placement, the layer should be quickly compacted and protected. CTB material that becomes wet by rain during transport or placement should be examined and rejected if excess water in the mixture changes its consistency and uniformity.

4.3.1.3 Compaction

Immediately upon completion of the spreading operations, the CTB material should be compacted. Compaction can be accomplished using one or a combination of the following pieces of equipment: tamping or grid roller, steel-wheeled roller, vibratory roller, pneumatic-tire roller, vibrating plate compactor (for areas inaccessible to rollers). The number, type, and weight of rollers and/or compactors must be sufficient to compact the mixture to the required density.

Generally speaking, a combination of rubber tired and vibratory rollers give the best compaction results (Kohn et al., 2003).

In-place density can be monitored using a nuclear density gage. At the start of compaction, the moisture content should be within 2 percentage points of the specified optimum moisture. For summertime construction conditions, a moisture content of +2 percent is recommended (Kohn et al., 2003).

The CTB layer may be placed in single or multiple compacted lifts; however, each compacted lift must be at least 4 in (102 mm) thick and no greater than 8 in (203 mm) thick. Greater lift thicknesses (up to 12 in [305 mm]) may be permitted if equipment is available to achieve the desired compaction. In multi-lift construction, the surface of the compacted lift should be kept moist until covered with the covering lift. Successive lifts should be placed and compacted so that the required total depth of the CTB layer is completed within a 12-hour period. While forming construction joints, the material at the joint should be compacted adequately and the joints finished level with the remainder of the layer.

4.3.1.4 Finishing

After compaction, the surface of the CTB layer should be shaped to the specified lines, grades, and cross-section. Final trimming of the compacted CTB to meet surface requirements should be accomplished using a self-propelled trimming machine, with a mold board cutting edge, which is at least 12 ft (3.7 m) wide and is automatically controlled by sensors in conjunction with an independent grade control from a taut stringline. Stringline will be required on both sides of the sensor controls for the pilot lane. For all other lanes, a single stringline on the outside and grade matching with previously completed adjacent lanes is permissible. Since CTB is a rigid material, it is not practical to re-grade after compaction. Thus, care needs to be taken to achieve the specified grade tolerances the first time (Kohn et al., 2003).

The surface of the CTB should be kept moist in hot weather to prevent shrinkage cracks.

In hot weather, the surface should be kept moist by means of fog-type sprayers. Compaction and finishing should be done in such a manner as to produce a smooth, dense surface, free of ruts, cracks, ridges, and loose material. All placement, compaction, and finishing operations should be completed within 2 hours from the start of mixing. Material not completed within the 2-hour time limit should be removed and replaced.

CTB layer limits that extend beyond the edges of the new PCC surface course should be rolled down or shaped in such a manner that the drainage is away from the edge of the proposed PCC surface layer.

4.3.1.5 Jointing

A placement plan should be developed that will minimize the number of longitudinal and transverse joints. At the end of each day's construction, or when continuing placement is interrupted for more than 60 minutes, a transverse construction joint should be formed that is a true vertical face (perpendicular to the centerline) free of loose material.

A near vertical longitudinal edge is considered adequate. A true vertical edge by sawcutting is optional.

Longitudinal construction joints (parallel to the centerline) should be a consistent well-defined "near vertical" edge that is free of loose material. The longitudinal joints should be located such that there is a 2-ft (0.6-m) minimum offset from planned joints in any overlying layer.

4.3.1.6 Curing

The compacted and finished CTB should be cured as soon as possible, no later than 2 hours after completion of the finishing operations. The layer should be kept moist using a moisture-retaining cover or a light application of water until the curing material is applied (care should be taken to not oversaturate the surface of CTB with water).

A LMFCC is recommended for use as a curing agent. The entire surface of the CTB layer should be uniformly sprayed with the compound at the rate of 1 gal to not more than 200 ft^2 (1 L to not more than 4.9 m^2).

The curing seal should be maintained and protected until the PCC surface layer is placed above it. Should the surface of the finished CTB and/or the curing seal become damaged, additional curing material should be applied at the time it is damaged or when the damage is first observed.

4.3.1.7 Acceptance

The CTB layer should be tested for density, thickness, grade, and surface tolerance on a lot basis. The following are the target values for each of these criteria:

- Density—A density of 98 percent or greater of the maximum density for full pay.
- Thickness—Thickness within 0.5 in (13 mm) of the specified thickness.

- Grade—The completed surface should not be 0.5 in (13 mm) above the plan grade.
- Surface Tolerance—Tolerance should vary by no more than 0.38 in (9.5 mm) when tested with a 16-ft (4.9-m) straightedge.

4.3.1.8 Bond-Breaker Application

A single uniform layer of choke stone, no thicker than 0.5 in (13 mm), should be broadcast onto the CTB layer prior to the placement of the PCC pavement. The choke stone should be worked into the surface of the CTB using two additional passes of a vibratory roller.

4.3.2 Lean Concrete Base

4.3.2.1 LCB Mix Production

Lean concrete production is similar to that of conventional concrete. It may be produced in a stationary mixer, at a central batch plant, or in a truck mixer.

The mixing time must be adequate to produce a mix that is uniform in appearance, with all ingredients evenly distributed. If mixing in a plant, the mixing time should not be less than 50 nor greater than 90 seconds. If mixing in a truck, the mixing time should not be less than 70 nor more than 125 truck-drum revolutions at a mixing speed of not less than 6 nor more than 18 truck-drum revolutions per minute.

Retempering lean concrete by adding water is not permitted, except when delivered in truck mixers. With truck mixers, additional water may be added to the batch materials and additional mixing performed to allow proper placement of the material, provided (a) the addition of water is performed within 45 minutes after the initial mixing operations and (b) the water/cementitious ratio specified in the mix design is not exceeded.

4.3.2.2 LCB Mix Hauling and Placement

Hauling

Lean concrete mixes can be hauled from the plant to the job site in an agitator truck, a truck mixer operating at agitating speed, or a non-agitating truck. When truck mixers are used to mix lean concrete, they may be transported to the job site in the same truck operating at agitating speeds, truck agitators, or a non-agitating truck. The bodies of non-agitating trucks should be smooth, metal containers and must be capable of discharging the concrete at a controlled rate without segregation.

The elapsed time from the addition of cementitious material to the mix until the lean concrete is deposited in place at the work site should not exceed 45 minutes when the lean concrete is hauled in non-agitating trucks, nor 90 minutes when it is hauled in truck mixers or truck agitators.

Placement

Similar to conventional concrete, lean concrete can be placed by both machine and hand paving. Machine paving should be used for mainline paving, connecting taxiway sections, and other areas large enough to accommodate a paving machine. However, areas too small for machine paving will need hand paving. Slipform pavers, bridge deck pavers, or fixed form pavers may be used, provided they are capable of handling the amount of lean concrete required for the full-lane width specified, and consolidating it full depth. Rotating pipe and tube floats are not considered suitable for placing lean concrete.

Lean concrete should not be placed when the ambient temperature is below 40°F (4°C) or when conditions indicate that the temperature may fall below 35°F (2°C) within 24 hours. Under no circumstances should the LCB be placed on frozen underlying courses or mixed when the aggregate is frozen. During periods of warm weather, when the maximum daily air temperature exceeds 85°F (30°C), the forms and/or the underlying material should be sprinkled with water immediately before placing the LCB.

All mixing and batching operations should be halted during rain showers and any plastic LCB placed should be covered immediately. The LCB should be kept covered with plastic sheeting or other waterproof material until such time that the rain does not make any surface indentation on the LCB layer. Areas damaged by rain should be refinished.

4.3.2.3 Placement and Consolidation

Regardless of the method of paving, hauled lean concrete material should be discharged onto the prepared underlying course such that segregation of the mix is minimized and minimum handling of the mix is needed. Placement of the econocrete material should be continuous between construction joints.

Side Form Construction

For side form placement, the lean concrete should be spread uniformly between the forms. Necessary hand spreading can be done with shovels, not rakes.

The spreading should be followed immediately by thorough consolidation using vibrating screeds or spud vibrators. The vibrators may be either the surface pan type for layers less than 8 in (203 mm) thick or the internal type with either immersed tube or multiple spuds for the full width of the slab. In no case should the vibrator be operated longer than 20 seconds in any one location, nor should the vibrators be used to move the lean concrete. Hand finishing will not be permitted except in areas where the mechanical finisher cannot operate.

Slipform Construction

The slipform paver should spread, consolidate, and shape the freshly placed econocrete in one complete pass of the machine. The slipform paver should vibrate the lean concrete

Consolidation adequacy is to be determined subjectively by visual examination. Honeycombed and over-consolidated areas should be removed and replaced.

mix for the full width and depth of the strip of pavement being placed. The number, spacing, frequency, and eccentric weights of vibrators should be provided as necessary to achieve an acceptable consolidation and finishing quality.

Adequate power to operate all vibrators at the weight and frequency required for a satisfactory finish must be available on the paver. The internal vibrators may be supplemented by vibrating screeds operating on the surface of the LCB. The frequency of each of the individual vibrators should be monitored continuously using electronic means during paving. Also, the consolidation process should be carefully monitored to avoid honeycombing or over-consolidation.

4.3.2.4 Finishing

Finishing the lean concrete surface is not necessary since it is not an exposed layer in the rigid pavement system. The surface produced after screeding or strikeoff is adequate.

4.3.2.5 Curing

Just as with conventional concrete, immediately after the placing operations are complete, within 2 hours of placement, the entire surface and edges of the econocrete should be sprayed uniformly with white pigmented LMFCC. The curing material should be applied using mechanical sprayers under pressure at the rate of 1 gal to not more than 200 ft^2 (1 L to not more than 4.9 m^2). The layer should be kept moist using a moisture-retaining cover or a light application of water until the curing material is applied. Excessive delays in applying the curing compound can result in uncontrolled shrinkage cracking. Hand spraying of odd widths or shapes and econocrete surfaces exposed by the removal of forms is permitted.

Should the film of curing material become damaged from any cause, including sawing operations, the damaged portions should be repaired immediately with additional compound or other approved means as quickly as practical.

4.3.2.6 Jointing

There are primarily two types of joints in the LCB layer—construction joints and contraction joints. Construction joints separate adjacent construction placed at different times, at the end of a day's placement, or between paving lanes. The placing plan should minimize construction joints as much as possible.

The jointing plan for LCB should be approved in advance. Proper alignment of the LCB and PCC joints is critical. If misaligned, reflection cracking can occur.

Contraction joints control the location of LCB cracking. These joints should match within 3 in (76 mm) of the planned joints of the concrete surface.

4.3.2.7 Acceptance

The LCB should be tested for air content, compressive strength, thickness, grade, and surface tolerance on a lot basis. The following are the target values for each of these criteria:

- Air content—Test results should be between 4 and 8 percent for (a) the first three truckloads of lean concrete produced at the start of operations each day and (b) the first three truckloads produced after any scheduled or non-scheduled shutdown.
- 7-day compressive strength—Minimum lot average of 500 psi (3,448 kPa), with no more than 20 percent of individual cylinders tested within a lot having a 7-day strength greater than 800 psi (5,516 kPa). When greater than 20 percent of the individual cylinders in a given lot have 7-day strengths in excess of 800 psi (5,516 kPa), and transverse joints have not been notched, a choke stone layer must be used as a bond breaker.
- Thickness—Thickness should be within 0.5 in (13 mm) of the specified thickness.
- Grade—Completed surface will not be more than 0.5 in (13 mm) above the plan grade.
- Surface tolerance—Tolerance should vary by no more than 0.38 in (9.5 mm) when tested with a 16-ft (4.9-m) straightedge.

4.3.2.8 Bond Breaker

When lean concrete is placed directly beneath PCC pavement, a bond breaker must be used. A second application of the curing compound can be as a bond breaker when the 7-day compressive strength values satisfy the minimum and maximum requirements. This application should be made at least 8 hours and not more than 24 hours prior to beginning the placement of the PCC surface layer. The rate of application should be the same as that specified for the curing application. After application of the bond breaker coat, traffic will be limited to that required for the placement of the overlying pavement layer.

If the maximum 7-day compressive strength values exceed the maximum strength requirements, choke stone must be used as a bond breaker.

4.3.3 Asphalt-Treated Base

The production, placement, control, and acceptance of ATB are similar to that of a high-quality asphalt paving layer. Guidance on HMA layer construction is provided in other documents, such as FAA AC 150/5370-14A, *Hot-Mix Asphalt Paving Handbook* (2000). Therefore, only salient points specific to the construction of ATB under rigid pavements are presented here. Much of the guidance here has been excerpted from new Item P-403 in AC 150/5370-10B and Kohn et al. (2003).

- The ATB mix should be produced in a central mixing plant.
- A test section is required prior to full production to determine that mix can be satisfactorily produced, placed, and compacted with the proposed equipment on the project. The test section should be a minimum of 300 ft (92 m) long and 20 to 30 ft (6.1 to 9.2 m) wide, and it should include a longitudinal cold joint and have the same thickness as the planned ATB layer. The test section affords the opportunity to determine the quality of the mixture in place, as well as performance of the plant and laydown equipment. Any adjustments needed to the JMF should be made at this stage.

- During production, careful consideration should be given to controlling the mix by ensuring that it satisfies the JMF through periodic sampling. Frequent plant inspections are also recommended to check batch proportions, temperatures, etc.
- Acceptance of the mix should be based on mat density, joint density, thickness, smoothness (same as surface tolerance), and grade.
- Contractor quality control testing should include monitoring aggregate gradation, asphalt content, moisture content of aggregate and mixtures, in-place density, and temperatures (at the dryer, the bitumen in the storage tank, the mixture at the plant, and the mixture at the job site).
- When ATB is placed, care should be taken to meet the surface tolerance and grade requirements the first time. Milling of the layer over large areas (> 15 yd^2 [12.5 m^2]) to establish evenness and grade can result in bonding of PCC to ATB and can lead to early cracking of the PCC. If milling is necessary, a thin leveling course of the same material, a coat of asphalt emulsion, or a medium- to heavy-duty geotextile fabric should be applied over the affected areas just prior to the placement of the PCC.
- Temperatures at the surface of the ATB in hot weather paving conditions, which can be as high as 140°F (60°C), will affect the hydration of the PCC. Early cracking is possible unless temperatures of the ATB are controlled. The ATB should be whitewashed using a lime-water solution before concrete placement to reduce its surface temperature.

4.3.4 Cement-Treated Permeable Base

4.3.4.1 CTPB Mix Production

The CTPB material should be mixed in a stationary mixer at a central batch plant. The mixing time should be adequate to produce CTPB that is uniform in appearance, with all ingredients evenly distributed.

4.3.4.2 CTPB Test Section

A test section is necessary. Use the guidance presented at the beginning of this chapter.

4.3.4.3 CTPB Mix Hauling and Placement

Hauling

The mixed CTPB material should be transported from the plant and delivered to the spreader in trucks having smooth, clean beds. The nature of the CTPB mix makes segregation a potential problem during transport; therefore, hauling time should be minimized, and haul routes should be smooth. The elapsed time between the start of moist mixing and the time the CTPB is deposited in-place at the work site should not exceed (a) 30 minutes when the CTPB is hauled in non-agitating trucks, or (b) 45 minutes when the CTPB is hauled in transit mixers. Retempering the CTPB material by adding water or by other means should not be permitted.

> To minimize segregation, handling of the mix should be minimized. Also, when placing the mix on grade, minimum drop heights should be used.

Placement

The CTPB material can be placed using a mechanical spreader. An asphalt paving machine with dual tamping bars can be used, but care must be taken when using this machine to not fracture the aggregates. If a spreader is used, the equipment should be capable of placing the material, without segregation, into a uniform layer or lift meeting the required grade and cross-section. The equipment should be equipped with a strike-off plate capable of being adjusted to the specified layer thickness and two end gates or cut-off plates such that the CTPB may be spread in varying widths.

CTPB layers can be installed in single or multiple compacted lifts; however, each compacted lift must be at least 4 in (102 mm) thick but not greater than 6 in (152 mm) thick to ensure compaction.

CTPB material must not be mixed or placed while the air temperature is below 40°F (4°C) or when conditions indicate that the temperature may fall below 35°F (2°C) within 24 hours. The CTPB must not be placed on frozen underlying courses or mixed when aggregate is frozen. The CTPB may also not be placed when rainfall is occurring or where rain is imminent. Any CTPB material that has become excessively wet by rain during transport and/or placement should be rejected.

<u>4.3.4.4 Compaction</u>

Immediately after the spreading operations are completed, the CTPB material should be compacted using the approved compaction equipment and roller pattern/sequence, as determined in the approved test section. There must be a sufficient number of rollers to match the output of the plant. A preferred method of compaction of CTPB is with a static roller (see Figure 4-2). Density testing with a nuclear gage has limited value for this material. In places not accessible to rollers, the CTPB material can be compacted with hand-operated tampers.

> Vibratory rollers or vibrating screeds should be used with caution to prevent aggregate degradation and liquefaction of wet soil under the CTPB.

Field compaction should begin no more than 30 minutes from the start of moist mixing. The surface of the CTPB should be kept lightly moist prior to compaction. In addition, field compaction should be completed within 60 minutes.

Figure 4-2. CTPB compaction with a static roller.

4.3.4.5 Curing

There is no consensus on a suitable method for curing CTPB. The CTPB can be covered with polyethylene sheeting for 3 to 5 days subsequent to a fine water mist cure applied on the day after the base is placed. Other schools of thought say not to cure CTPB at all because test data show that there is no significant difference in strength of cured and uncured CTPB. The use of wax-based LMFCCs is not recommended since they can plug the void structure of the CTPB. Also, when mist curing or fog spraying the CTPB, adequate care should be taken not to flush the cement paste into the void structure.

4.3.2.6 Acceptance

The CTPB layer is accepted based on thickness, grade, and surface tolerance on a lot basis. The following are the target values for each of these criteria:

- Thickness—Thickness within 1 in (25 mm) of the planned thickness.
- Grade—The completed surface should not be more than 0.5 in (13 mm) above or below the plan grade.
- Surface tolerance—Tolerance should vary by no more than 0.5 in (13 mm) when tested with a 16-ft (4.9-m) straightedge.

4.3.4.7 Bond Breaker

When the CTPB is placed beneath PCC pavement, a single uniform layer of choke stone, no thicker than 0.5 in (13 mm), should be broadcast onto the CTPB layer shortly prior to the placement of the PCC pavement. The choke stone should be worked into the surface of the CTPB using two passes of a vibratory roller. This layer prevents excessive PCC paste penetration into the CTPB and reduces slab restraint.

Completed portions of the CTPB layer, following placement of the choke stone, can be opened immediately to low-speed traffic and to construction equipment, provided the CTPB does not ravel or loosen under such traffic. The CTPB must be protected from freezing.

4.3.5 Asphalt-Treated Permeable Base

4.3.5.1 ATPB Mix Production

The ATPB material may be produced either batch type or continuous mixing type plants. The mixing time should be adequate to produce ATPB that is uniform in appearance, with all ingredients evenly distributed.

The aggregate for the ATPB mixture should be dried and heated prior to mixing with asphalt. The resulting mix should have a combined aggregate moisture content (weighted according to the composition of the blend) less than 0.25 percent for aggregate blends with water absorption less than or equal to 2.5 percent, or less than 0.50 percent for aggregate blends with water absorption greater than 2.5 percent.

At the time of mixing, the temperature of the aggregate must be within the range specified in the JMF. The maximum temperature and rate of heating should be such that no damage occurs to the aggregates.

The dried aggregates should be combined in the mixer to meet the gradation requirements for the mix design. The asphalt cement should be weighed or metered and introduced into the mixer in the amount specified by the JMF. The combined materials must be mixed until the aggregate obtains a uniform coating of asphalt binder and is thoroughly distributed throughout the mixture.

The temperature at the discharge from the plant or surge and storage bins should be maintained between 275 and 325°F (135 and 163°C), depending on the viscosity of the binder.

4.3.5.2 ATPB Test Section

A test section is required for this layer. See the introduction to this chapter.

4.3.5.3 ATPB Mix Hauling and Placement

Hauling

Trucks used for hauling the ATPB mixture from the plant to the job site should have clean and smooth beds. To prevent the mixture from adhering to the truck beds, they could be lightly coated with a minimum amount of concentrated hydrated lime-water solution. The truck beds should be raised to drain any excess solution before loading the mixture in the trucks. Each truck should have a suitable cover to protect the mixture from adverse weather or long hauls.

The ATPB mixture should be transported to the job site and delivered to the asphalt paver for placement. Any truck causing excessive segregation of the ATPB mixture should be removed from the work until such conditions are corrected. Hauling over freshly placed material should not be permitted until the material has been compacted, as specified, and allowed to cool to atmospheric temperature (typically a period of 24 hours is recommended).

Placement

The ATPB material can be placed using an asphalt lay-down machine that is self-contained, power-propelled, and equipped with an activated screed or strike-off assembly (heated as necessary). The laydown machine should be capable of spreading (without segregation) and finishing courses of ATPB material that will meet the specified thickness, smoothness, and grade. An alternative method for placement that provides compaction of the ATPB material is with a large asphalt paving machine with dual tamping bars (care must be taken when using this machine to not fracture the aggregates).

> To avoid segregation of ATPB mixture due to draindown during transport, the use of a remixing system is recommended in the paving operation.

The ATPB should be spread at a temperature between 200 and 250°F (93 and 121°C), as measured in the hopper of the paving machine. It should be placed to the full width by the asphalt paver in a uniform layer of such depth that, when compacted, it is of the required thickness and conforms to the grade and contour indicated. The speed of the paver must be regulated to eliminate pulling and tearing of the ATPB mat.

ATPB can be placed in a single or multiple compacted lifts; however, each compacted lift must be at least 4 in (102 mm) thick and no greater than 6 in (152 mm) thick. If multiple lifts are used, the longitudinal joint in one lift should offset the longitudinal joint in the lift immediately below by at least 1 ft (0.3 m); however, the joint in the surface lift should be at the centerline of crowned pavements. Transverse joints in one lift should be offset by at least 2 ft (0.6 m) from transverse joints in the previous lift. Transverse joints in adjacent strips should be offset a minimum of 10 ft (3.1 m).

In placing adjacent strips of ATPB, the screed of the paving machine should overlap the previously placed strip 3 to 4 in (76 to 102 mm) and should be sufficiently high so that compaction will produce a smooth, dense joint. The ATPB material placed on the edge of the previously placed strip by the paver should be pushed back to the edge of the strip being placed. Excess material should be removed and wasted.

In areas where machine spreading is impractical, the ATPB material can be spread using hand tools, shovels, and lutes; rakes should not be allowed. The material should be spread uniformly in a loose layer to prevent segregation. The material should conform to the required grade and thickness after compaction.

4.3.5.4 Compaction

Compaction of the ATPB material should begin when the temperature of the mix has cooled to 150°F (66°C) and should be completed before the temperature falls below 100°F (38°C). The ATPB material should be compacted using the approved compaction equipment and roller pattern/sequence as determined in the test section. Each roller should operate at a speed no greater than 1.5 mi/hr (2.4 km/hr). The use of pneumatic rollers is preferred. Vibratory rollers should be used with caution since they can degrade the aggregate and cause liquefaction of underlying unbound materials if they are wet.

If the designated rolling pattern/sequence deviates from that approved in the test section, or if crushing of the aggregate is observed, work should be stopped until the cause(s) can be determined and corrections are made. Generally speaking, static steel wheel rollers or pneumatic rollers are preferable and give best results. Vibratory rollers should be used with care for the same reasons as mentioned for CTPB. In all places not accessible to the rollers, the ATPB material should be compacted with approved mechanical hand-operated tampers.

4.3.5.5 Curing

Curing of ATPB layers is not required.

4.3.5.6 Acceptance

The ATPB layer is generally accepted based on thickness, grade, and surface tolerance on a lot basis. The following are the target values for each of these criteria:

- Thickness—Thickness within 1 in (25 mm) of the specified thickness.
- Grade—The completed surface should not be more than 0.5 in (13 mm) above the plan grade.
- Surface tolerance—Tolerance should vary by no more than 0.5 in (13 mm) when tested with a 16-ft (4.9-m) straightedge.

The finished texture and drainability of the completed ATPB is illustrated in Figure 4-3. The small spread of water in the figure illustrates the quality of drainage.

Figure 4-3. Drainability and texture of finished ATPB.

4.3.5.7 Bond Breaker

A bond breaker is not required.

4.3.5.8 Whitewashing

The surface temperatures of the ATPB layers can reach 140°F (60°C) during summer time construction. When hot-weather paving conditions exist, these layers should be whitewashed using a lime-water solution to reduce their surface temperature immediately prior to PCC placement.

4.4 PCC PLACEMENT IN CONJUNCTION WITH STABILIZED/PERMEABLE BASES

When PCC layers are placed over high strength/stiffness stabilized or permeable bases, certain aspects of the construction process need to be dealt with more carefully to avoid the risk of early cracking. Some of these items are discussed below.

4.4.1 Timing of PCC Placement in Relation to Stabilized/Permeable Base Placement

When a stabilized layer, such as a CTB or LCB, is placed several months in advance of the PCC layer (common occurrence in large, multi phase projects), its strength and stiffness increases significantly over the design values due to the continued hydration of cement. Higher strengths and stiffnesses increase the curling stresses in fresh concrete and, hence, increase the risk of early-age cracking. Therefore, careful attention needs to be paid to factors that aggravate the movements in new PCC slabs, including panel sizes, PCC mixes, curing (or lack thereof) and factors that cause restraint stresses. If possible, PCC slab related design and materials variants need to be altered or construction variants need to be more vigilantly kept under control.

Stabilized layers may need to be trimmed/milled to establish grade control prior to the PCC placement. If this is done, the surface of the base layer will have a rougher texture that will affect the early-age performance. The design, materials, and construction variants should be adjusted to mitigate the risk of early cracking.

4.4.2 Bond Breaker/Choke Stone Application

A bond breaker should be applied on top of the stabilized bases prior to the placement of the PCC. When the bond breaker is a wax-based LMFCC, the application should be between 8 and 24 hours prior to paving. When choke stone layers are used, they can be applied any time prior to PCC placement, provided contamination of this layer with fines due to construction traffic is minimized. This is particularly important when choke stone layers are used for CTPB layers.

4.4.3 PCC Curing

An important aspect of PCC curing that is often overlooked is that it is not only important for the hydration of concrete but it also helps reduce shrinkage of concrete (Aitcin, 1998; Kovler and Jensen, 2005). External curing helps reduce the drying shrinkage portion of the total shrinkage which accounts for a bulk of the shrinkage in mixes with water-to-cementitious ratios above 0.4 (Kovler and Jensen, 2005). When ambient or PCC material factors point to the potential for excessive shrinkage, extra care should be taken to ensure that adequate curing is provided while the concrete has still not developed adequate strength. If possible, changes need to be made to the project specifications to allow for more effective curing techniques as needed. Besides decreasing the likelihood of early cracking, effective curing also improves the long-term pavement performance by improving concrete strength and durability as well as mitigating the effects of factors such as built-in curling and warping that are unquantifiable during pavement design.

4.4.4 PCC Slab Jointing

A significant factor that affects early-age concrete performance on stabilized and permeable bases is the timing of the initial sawcut, as well as the depth of sawcut. The variants that particularly sensitize the issue are base stiffness and the PCC slab/base restraint. The restraint increases the effective slab thickness and makes an otherwise adequate sawcut inadequate. While depth of initial sawcutting can be mandated in design, the timing to perform the sawcut cannot be specified.

The timing of the initial sawcut is a function of a variety of factors, including environmental conditions, equipment used, mixture properties, and temperature at time of PCC placement. There is no substitute to experience and vigilance when it comes to sawcutting.

4.4.5 Hot- and Cold-Weather Paving

The most common trigger situation leading to early-age cracking in rigid pavements built over stabilized or permeable bases is a large ambient temperature drop caused by an approaching cold front or a sudden rain shower during PCC placement. This is followed by hot-weather paving associated with high evaporation losses. Proper planning and execution of the construction to account for adverse climate conditions is a key to good performance. Most project specifications include provisions to deal with potential trigger conditions, but to achieve consistent success, an understanding of the consequences of trigger factors for a given set of variants and enforcement of the provisions is imperative.

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