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Guide to Cement-Based Integrated Pavement Solutions

IOWA STATE UNIVERSITY
Institute for Transportation

National Concrete Pavement Technology Center
Tech Center

PCA Portland Cement Association

Cement-Based Integrated Pavement Solutions

This page illustrates the land-use applications for the cement-based integrated pavement solutions described in this guide.

For more information on these applications, please see the table of contents to locate page numbers for each application.

LAND USE


Heavy Industrial


Light Industrial


Airports


Commercial


Residential


Recreation

CEMENT-BASED INTEGRATED PAVEMENT SOLUTIONS

VIBRATORY COMPACTION

①

Conventional

②

Overlays

③

CRCP

EXTERNAL COMPACTION

④

Roller-Compacted Concrete

⑤

Full-Depth Reclamation

⑥

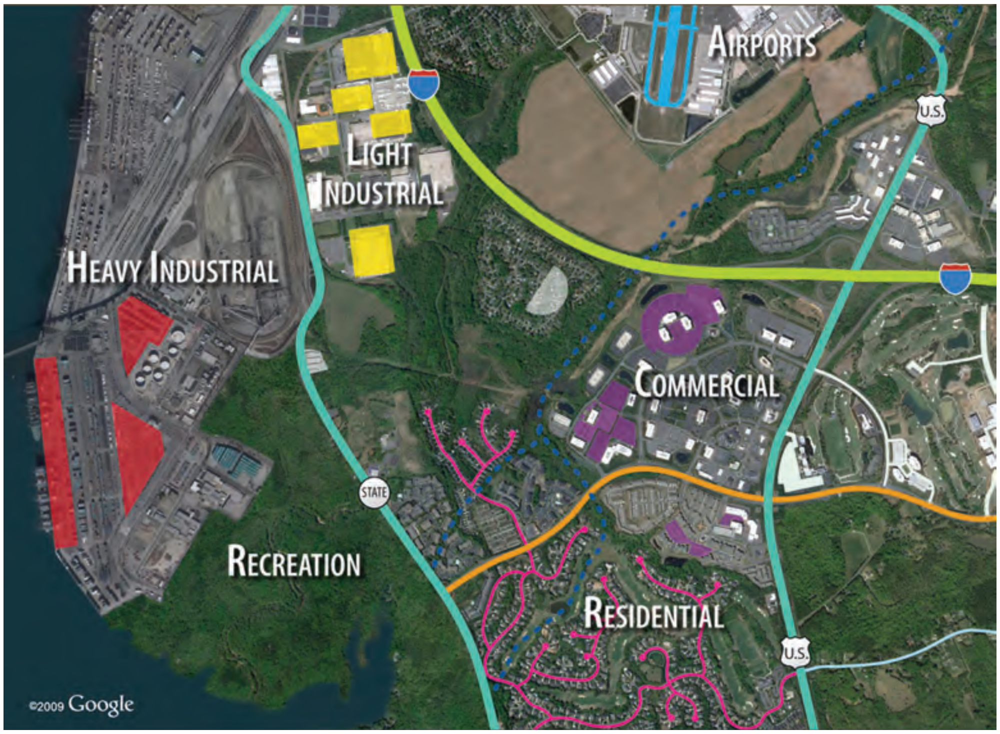
Pervious Concrete

⑦

Cement-Treated Base

⑧

Cement-Modified Soils



Heavy Industrial 🟥 ①④
Light Industrial 🟨 ①④
Residential 🟪 ①④⑥

Airports 🟦 ①②④
Interstates 🟩 ①②③

Highways 🟩 ①②④
Arterials 🟧 ①④

Country Roads 🟦 ①②④⑦
Commercial 🟪 ①④⑥

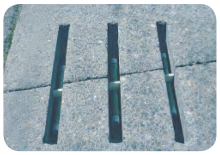
** The use of ⑦&⑧applies to all uses depending on quality of soil and need for stabiliaztion

SUSTAINABLE PRACTICE - PRESERVATION OF THE SYSTEM'S EQUITY

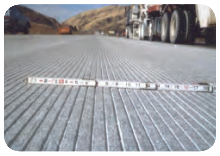

Concrete Recycling


Full-Depth Repair


Partial-Depth Repair


Dowel Bar Retrofit


Slab Stabilization


Diamond Grinding

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16. Abstract

This guide provides a clear, concise, and cohesive presentation of cement-bound materials options for 10 specific engineering pavement applications: new concrete pavements, concrete overlays, pervious concrete, precast pavements, roller-compacted concrete, cement-treated base, full-depth reclamation with cement, cement-modified soils, recycled concrete aggregates, and repair and restoration. Each application is presented as a method for meeting specific design and construction objectives that today's pavement practitioners must accomplish. The benefits, considerations, brief description, and summary of materials, design, and construction requirements, as well as a list of sustainable attributes, are provided for every solution. This guide is intended to be short, simple, and easy to understand. It was designed so that the most up-to-date and relevant information is easily extractable. It is not intended to be used as a design guide for any of the applications identified herein. Recommendations for additional information that can provide such details are given at the end of each solution discussion. The intended audience is practitioners, including engineers and managers who face decisions regarding what materials to specify in the pavement systems they design or manage. The audience also includes city and county engineers, along with the A/E firms that often represent them, and state DOT engineers at all levels who are seeking alternatives in this era of changing markets.

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About This Guide

This *Guide to Cement-Based Integrated Pavement Solutions* is a product of the National Concrete Pavement Technology Center (National CP Tech Center) at Iowa State University's Institute for Transportation, with funding from the Portland Cement Association. It provides a clear, concise, and cohesive presentation of cement-bound materials options for specific engineering pavement applications. Each application identified in this guide is presented as a method for meeting specific design and construction objectives that today's pavement practitioners must accomplish.

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Preface

How is this guide unique?

Portland cement is the fundamental ingredient in concrete. When you think of cement, it may be automatic to think of concrete; when you think of cement and pavements, you probably think of cement in conventional concrete used for pavement surface layers. But did you know that cement can be used in other pavement layers and for other applications? In fact, cement can be used in many other applications for pavement systems.

Pavement systems containing cement-bound layers have been used worldwide for over a century, with great success. Portland cement can be used in virtually every layer in a pavement system. Typical applications include improving the quality of subgrade soils and stabilizing base materials. Integrating multiple cement-based layers into a pavement design may provide a cost-effective method for achieving a stronger, more durable, sustainable pavement. For instance, using a cement-modified soil and cement-treated base as opposed to an unbound granular base placed on an unprepared subgrade can reduce the required thickness of the base material. In addition, a cement-treated base may decrease the thickness needed for the concrete or asphalt surface, resulting in less materials and overall reduced cost.

In addition to being the key constituent of new concrete pavement and concrete overlay surfaces, other unique surface applications of cement include roller-compacted concrete (RCC), precast pavements, and pervious concrete pavements. Cement is also used in numerous pavement repair techniques, as well as an array of pavement recycling and reclamation applications.

A great deal of research and effort by many sources has gone into developing literature about the individual pavement applications using cement. With so many applications, engineers and other practitioners could benefit from one publication that integrates and summarizes all cement-based pavement applications and helps them select and apply appropriate solutions for specific needs. This publication fills that need.

The *Guide to Cement-Based Integrated Pavement Solutions* provides a clear, concise, and cohesive discussion of 10 cement-bound material options for specific engineering pavement applications, or solutions: new concrete pavements, concrete overlays, pervious concrete, precast pavements, roller-compacted concrete, cement-treated base, full-depth reclamation with cement, cement-modified soils, recycled concrete aggregates, and repair and restoration. Each application is presented as a method for meeting specific design and construction objectives that today's pavement practitioners must accomplish. The benefits, considerations, brief description, and summary of materials, design, and construction requirements, as well as a list of sustainable attributes, are provided for every solution.

This guide is intended to be short, simple, and easy to understand. It was designed so that the most up-to-date and relevant information is easily extractable. It is not intended to be used as a design guide for any of the applications identified herein. Recommendations for additional information that can provide such details are given at the end of each solution discussion.

Who is this guide for?

It was developed for practitioners, including engineers and managers who face decisions regarding what materials to specify in the pavement systems they design or manage. The audience also includes city and county engineers, along with the A/E firms that often represent them, and state DOT engineers at all levels who are seeking alternatives in this era of changing markets.

Important Definitions

Highways

This symbol represents applications of highly trafficked roadways that experience high volumes of heavy truck traffic such as major highways and interstates.

Commercial / Lightweight

This symbol represents applications including commercial parking lots, driveways, and residential roadways.

Streets & Local Roads

This symbol represents applications for city streets and local roads that experience moderate levels of passenger vehicle traffic and maybe some heavy truck traffic.

Airfields

This symbol represents applications for general-purpose aviation and/or commercial or military airfield facilities.

Shoulders

This symbol represents roadway shoulder applications.

Heavy Industrial

This symbol represents applications for facilities that experience high volumes of heavy truck traffic and/or storage facilities, such as shipping yards, where heavy containers are stored for long periods of time.

ASTM

ASTM International, originally known as the American Society for Testing and Materials, is an international standards setting organization.

Base

The pavement layer constructed immediately beneath a hot-mix asphalt (HMA) surface and sometimes beneath a concrete surface. Material requirements for this layer are more stringent than those for most subbase and subgrade layers.

Concrete

An initially plastic (slumpable) mixture created by the combination of cement, coarse and fine aggregates, water, and various chemical admixtures that hardens to a solid material over time.

Concrete pavement

A pavement system in which the surface layer is concrete. Typical concrete pavement systems include a concrete surface over a subbase and subgrade layers.

Fine aggregate

Defined by ASTM C33 as sand with 95–100 percent of the total material passing a No. 4 (4.75 mm) sieve.

Fines

Portion of the soil finer than a No. 200 (75 µm) sieve.

Flexible pavement

A pavement system in which the surface layer is hot-mix asphalt (HMA). Typical flexible pavement systems include an HMA surface over a base, subbase, and subgrade layers.

Pavement system

The combination of surface, base/subbase, and improved subgrade layers constructed for the purpose of supporting traffic.

Portland cement

A commercial product that, when combined with water, forms a paste that over time becomes a hardened solid. It is typically combined with fine aggregates to form mortar or a combination of fine and coarse aggregates to form concrete.

Subbase

The pavement layer constructed between the base and subgrade in a flexible pavement system, or the layer often found beneath a concrete surface in a concrete pavement system.

Table of Solutions

Within an integrated pavement solutions system, numerous alternative paving materials and techniques are available. While their common link is the use of portland cement, there remain notable differences that must be recognized. To assist in the selection of the most appropriate solutions for a given project, Table 1 should be referenced.

Within this table, the various solutions are shown in the left column, along with a brief description of each. To assist in the selection of the most appropriate solutions, the challenges that a user might be facing are in the adjacent columns. This cross-referencing is intended to help narrow the selection of the available solutions. Complementing the table are both the benefits and typical applications. These too are intended to refine the selection of possible solutions.

Table 1. Table of solutions

Solution / Definition	Objectives	Benefits	Typical Applications
New Concrete Pavements New concrete pavements include both jointed and continuously reinforced concrete pavements. Thicknesses can range from 6 to 15 inches, depending on traffic, environment, and soils.	• Provide long life and reduced maintenance. • Improve the surface. • Provide high load-carrying capacity. • Expedite construction/renewal. • Reduce urban heat island effect. • Increase light reflectance. • Provide a sustainable option.	• Concrete pavements can withstand many environments. • Concrete pavements typically last much longer than their original design life. • Concrete pavement surfaces reflect light and reduce the urban heat island effect. • Vehicle fuel consumption for the driving public is reduced on concrete surfaces.	• Highways • Streets and Local Roads • Shoulders • Commercial/ Lightweight • Airfields • Heavy Industrial
Concrete Overlays Overlays are a method of rehabilitating and/ or increasing the structural capacity of existing pavements. *Bonded overlays* are thin (2- to 6-in.) layers of concrete bonded directly to a sound underlying pavement in order to increase structural capacity. *Unbonded overlays* are used principally when the underlying pavement is in fair to poor condition and are thick (4 to 11 in.) enough to support the traffic loads but recognizing the structural capacity of the underlying pavement.	• Extend pavement life. • Improve the surface. • Increase load-carrying capacity. • Expedite construction/renewal. • Reduce urban heat island effect. • Increase light reflectance. • Provide a sustainable option.	• Reconstruction costs are avoided. • Construction of an overlay is much faster than reconstruction. • Concrete pavement surfaces reflect light and reduce the urban heat island effect.	• Highways • Streets and Local Roads • Shoulders • Commercial/ Lightweight • Airfields • Heavy Industrial
Pervious Concrete Pervious concrete is a paving material consisting of almost exclusively coarse aggregate, but with sufficient cement paste to bind the mixture into a strong but open (porous) material with exceptional drainage properties.	• Satisfy EPA Storm Water Phase II regulations. • Earn LEED credits. • Improve safety. • Reduce tire-pavement noise. • Provide a sustainable option.	• Pervious concrete is an EPA Best Management Practice. • Stormwater runoff and flash flooding is minimized. • Hydroplaning and splash and spray are minimized. • Noise from the tire-pavement interaction is reduced. • Pervious concrete surfaces reflect light and help reduce the urban heat island effect.	• Streets and Local Roads • Shoulders • Commercial/ Lightweight
Precast Pavements Precast pavements are a technique for constructing or repairing a concrete pavement surface where casting and curing of panels are done in advance. Precast pavements are a highly durable finished pavement and not just a temporary fix. They are a repair option for jointed concrete pavements (JCP) or reconstruction option for both JCP and HMA pavements. Rapid placement of the hardened panels can then be conducted within short traffic closure windows.	• Provide long life. • Improve the surface. • Provide high load-carrying capacity. • Expedite construction/renewal. • Provide a sustainable option.	• Construction can be completed during short (overnight or weekend) closures. • Lane closures and associated user delays during construction are minimized. • Precast pavements are a highly durable finished pavement and not just a temporary fix. • Precast pavement surfaces reflect light and help reduce the urban heat island effect.	• Highways • Airfields • Heavy Industrial

Table 1. Table of solutions (Continued)

Solution / Definition	Objectives	Benefits	Typical Applications
Roller-Compacted Concrete Roller-compacted concrete (RCC) is a stiff and strong concrete mixture that is typically placed with asphalt pavers as either a surface or a support layer. Roller-compacted concrete surfaces can be used for low-speed or industrial applications. Roller-compacted concrete layers can also serve as a support layer to a thin (1.5- to 2-in.) HMA (or occasionally concrete) surface.	• Provide low-cost option. • Provide high load-carrying capacity. • Expedite construction. • Allow early opening to traffic. • Provide a sustainable option.	• Roller-compacted concrete provides a strong, dense, and durable material that can be quickly constructed. • Construction is fast with no forms or finishing. • No steel reinforcement and minimum labor make RCC economical. • For many applications, joint sawing is optional for aesthetic purposes resulting in additional cost savings. • Roller-compacted concrete pavement surfaces reflect light and help reduce the urban heat island effect.	• Highways • Streets and Local Roads • Shoulders • Airfields • Commercial/ Lightweight • Heavy Industrial
Cement-Treated Base Cement-treated base (CTB) is a mixture of aggregate material and/or granular soils combined with engineered amounts of portland cement and water that hardens after compaction and curing to form a stronger, stiffer, and more durable paving material. Cement-treated base is used as a pavement base for flexible pavements or a subbase for concrete pavements.	• Provide a strong, uniform base/ subbase for current and future loading conditions using in-place or locally available marginal soils and granular material. • Reduce stresses on the subgrade. • Stabilize a variety of soils with a single stabilizer. • Reduce rutting and deflections in a flexible pavement surface. • Improve the structural capacity of the existing soil. • Provide a sustainable option.	• A stiffer base reduces deflections due to traffic loads, thereby extending pavement life. • Subgrade failures, pumping, rutting, joint faulting, and road roughness are reduced. • Base thickness is reduced compared to unbound granular base thicknesses. • Marginal aggregates, including recycled materials, can be used, thus reducing the need for virgin, high-quality aggregates.	• Highways • Streets and Local Roads • Shoulders • Airfields • Commercial/ Lightweight • Heavy Industrial
Full-Depth Reclamation Full-depth reclamation (FDR) is a technique in which hot-mixed asphalt (HMA) material from the existing pavement is removed, combined with portland cement, and used to create a new and improved base. The FDR base is then topped with a new HMA or concrete surface layer.	• Provide a strong, uniform base/ subbase for current and future loading conditions using existing failed asphalt surface and base material. • Maintain existing grade with minimum material removal or addition. • Reduce or totally eliminate the need for virgin aggregates. • Reduce stresses on the subgrade. • Reduce rutting and deflections in a flexible pavement surface. • Improve the structural capacity of stabilized base over unstabilized base material. • Provide pavement reconstruction method that is fast and minimizes traffic disruption. • Provide a sustainable option.	• The performance of the base layer is improved over an unbound granular base. • Little, if any, material is hauled off or onto the site, resulting in less truck traffic, lower emissions, and less damage to local roads. Work can be completed quickly compared to removal and replacement techniques. • Full-depth reclamation process is economical compared to removal and replacement and thick overlays.	• Highways • Streets and Local Roads • Airfields • Commercial/ Lightweight • Heavy Industrial

Table 1. Table of solutions (Continued)

Solution / Definition	Objectives	Benefits	Typical Applications
Cement-Modified Soils Cement-modified soils (CMS) are soils and/or manufactured aggregates mixed with a small proportion of portland cement. Cement-modified soils exhibit reduced plasticity, minimized volumetric changes due to moisture changes, increased bearing strength, and improved stability.	• Reduce the plasticity and high-volume change characteristics of clay soils due to moisture variations. • Improve stability of a poorly graded sandy soil. Improve the properties of a sandy soil containing a high-plasticity clay. • Provide a method to dry out a wet subgrade. • Provide a firm construction platform to work on. • Provide a sustainable option.	• Cement-modified soils provide a weather-resistant work platform for construction operations. • Fatigue failures caused by repeated high deflections are controlled. • There is a reduction in moisture sensitivity and subgrade seasonal load restrictions. • No mellowing period is needed as required by other stabilizing agents.	• Highways • Streets and Local Roads • Shoulders • Airfields • Commercial/ Lightweight • Heavy Industrial
Recycled Concrete Aggregates Recycled concrete aggregates (RCA) are aggregates produced from the recycling of existing concrete. Existing concrete is removed, processed into appropriate aggregate sizes, and reused in various pavement applications.	• Recycle excavated concrete pavement. • Minimize construction cost. • Reduce dependence on good quality virgin aggregates, which may be hard to find or expensive to bring in. • Provide a sustainable option.	• Recycled concrete aggregates are versatile because they can be used in any pavement layer. • Material costs are reduced. • Construction time can be expedited with on-site recycling plants. • Pavement suffering from ASR or D-cracking can be recycled instead of discarded. • The need for old concrete disposal is reduced.	• Highways • Streets and Local Roads • Shoulders • Airfields • Commercial/ Lightweight • Heavy Industrial
Repair and Restoration Repair and restoration is a series of techniques including diamond grinding, dowel bar retrofit, full and partial depth repairs, joint sealing, patching, and slab stabilization that extend the life of a concrete pavement. These techniques can often be used in lieu of resurfacing or reconstructing.	• Extend life. • Improve the surface. • Expedite construction/renewal.	• Repair and restoration fixes distressed concrete pavement (Comment—areas may not be isolated, i.e., diamond grinding an entire roadway). • These are options for low-cost concrete pavement life extensions.	• Highways • Airfield • Streets and Local Roads

New Concrete Pavements

Objectives

- Provide long life and reduced maintenance.
- Improve the surface.
- Provide high load-carrying capacity.
- Expedite construction/renewal.
- Reduce urban heat island effect.
- Increase light reflectance.
- Provide a sustainable option.

Solution

- Construct a new concrete pavement.

Benefits

- Concrete pavements can withstand many environments.
- Concrete pavements typically last much longer than their original design life.
- Concrete pavement surfaces reflect light and reduce the urban heat island effect.
- Vehicle fuel consumption for the driving public is reduced on concrete surfaces.

Considerations

- The concrete mixture must be designed properly for the environment.
- Proper construction practices are essential to long-term performance.

Typical Applications

Concrete pavement applications include highways (mainline, shoulders, frontage roads), streets and local roads, as well as heavy industrial applications, airfields (runways, taxiways, roadways, aprons, parking facilities), and commercial/lightweight industrial applications such as driveways and parking lots.

Highways

Streets & Local Roads

Shoulders

Commercial / Lightweight

Airfields

Heavy Industrial

Description

A pavement structure is a combination of a surface course and base/subbase courses placed on a prepared subgrade. A new concrete pavement is one where the surface course is made of concrete (Figure 1-1).

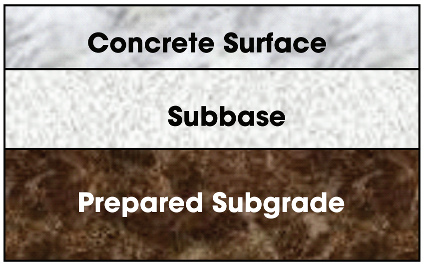

Figure 1-1. Schematic of typical concrete pavement cross-section

Concrete pavements have been built in the United States since the first concrete street was built in Bellefontaine, Ohio, in 1891. This pavement is still in service today. Concrete pavements can be very versatile; they can be designed to handle the freezing winters of Michigan's Upper Peninsula or the scorching heat of New Mexico in the Southwest. Concrete pavements can be a durable, economical, and sustainable solution for many applications if proper material mixtures are used and the pavement structure is both designed and constructed properly.

There are different types of concrete pavements built in the United States; however, the two most common ones are jointed concrete pavements (JCP) and continuously reinforced concrete pavements (CRCP). Each type is suitable for new construction, reconstruction, and overlays of existing roads.

Jointed concrete pavement can be either plain (JPCP) or reinforced (JRCP). Both have regularly spaced transverse contraction joints with dowels for load transfer and longitudinal construction joints held together with tie bars. Concrete will crack; joints are designed to control where these cracks occur. The idea is to design a joint spacing that ensures that cracks occur under the joints instead of randomly across the pavement. Jointed reinforced concrete pavement includes wire mesh and/or deformed steel bar reinforcement throughout each slab (the area bounded by transverse and longitudinal joints). The reinforcement is intended to hold tight any cracks that may form within the slab.

Continuously reinforced concrete pavements do not require transverse contraction joints, but do include transverse and longitudinal construction joints. Continuously reinforced concrete pavements contain continuous longitudinal and transverse reinforcement through the entire pavement (more than JRCP). Reinforcement in CRCP is designed to control transverse crack widths; reinforcement keeps cracks held tightly together and is not designed to help carry traffic loads. Standard CRCP designs are often chosen by states (like Texas, Virginia, and Illinois) to accommodate high traffic and heavy loads.

Figure 1-2 illustrates typical jointing and reinforcement for JPCP, JRCP, and CRCP designs.

Concrete pavements are often designed specifically for a given project; however, some agencies have adopted standard values for the geometric characteristics of

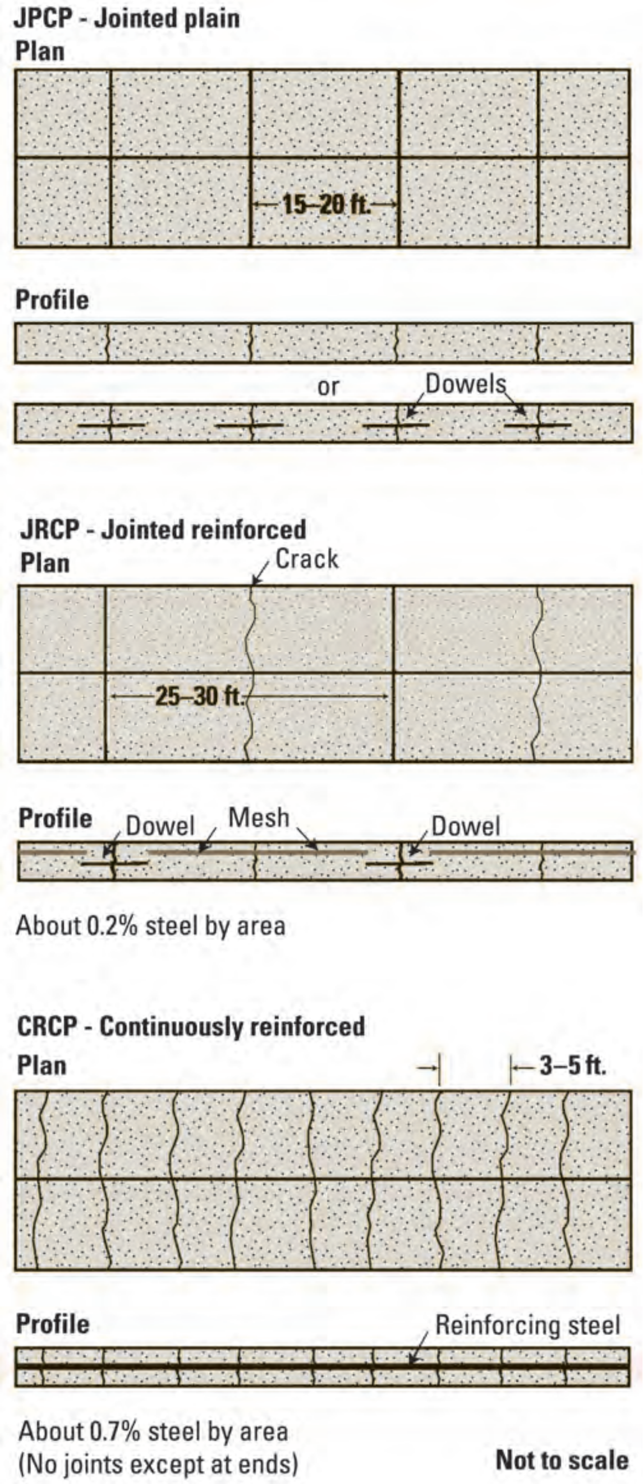

Figure 1-2. Schematic of the various types of new concrete pavements (from IMCP manual, Iowa State University, 2006)

pavements as well as for the materials' specifications so that designs become more practical.

The excellent performance of concrete pavements relies on the use of suitable materials, an adequate design, and sound construction practices. Both structural and functional performance is enhanced when all of these aspects are carefully identified and accounted for. The most influential design-related variables for structural performance (at a given level of traffic) are slab thickness, joint spacing, reinforcement, concrete strength, and support conditions. Functional performance of the pavement is often related to features like smoothness, texture, and noise. These are affected—in part—by the concrete pavement texture along with the concrete material used and, in particular, its durability.

Materials

Mixtures for concrete pavements typically incorporate the following constituents: a blend of coarse and fine aggregates, portland cement, water, and sometimes other cementitious materials such as fly ash and slag cement, and/or chemical admixtures (see Figure 1-3). The compatibility of materials in concrete pavements is important because it will affect long-term pavement performance.

A blend of coarse and fine aggregates is typically used in concrete paving mixtures. The aggregates are often natural but can also be manufactured. Coarse aggregates may even include a percentage of recycled aggregates. A fine aggregate is defined by ASTM C33 as having 95 percent or more material particles passing the #4 (4.75 mm) sieve. ASTM C33 also provides guidelines on typical aggregate gradations for concrete. Most states have standards and specifications that identify certain gradation limits for specific applications and further identify a limit for recycled aggregate content. Aggregates strongly influence concrete's fresh properties (particularly workability) and long-term durability. A well-graded blend of aggregates will further ensure long-term pavement performance. Achieving a well-graded aggregate supply can often be attained by adding an intermediate (#8 to 3/8 in. [2.36 to 9.5 mm]) aggregate.

Portland cement gives the material its strength and binds the aggregates together. There are different types of cement, but the most common for paving include Types I, II, I/II, and III. Type I is commonly used in normal concrete mixtures. Type II is similar to Type I but gives off less heat and is moderately sulfate resistant. It is common to use a Type I/II cement in paving applications, which meets the requirements as both a Type I and a Type II. Type III cements gain strength

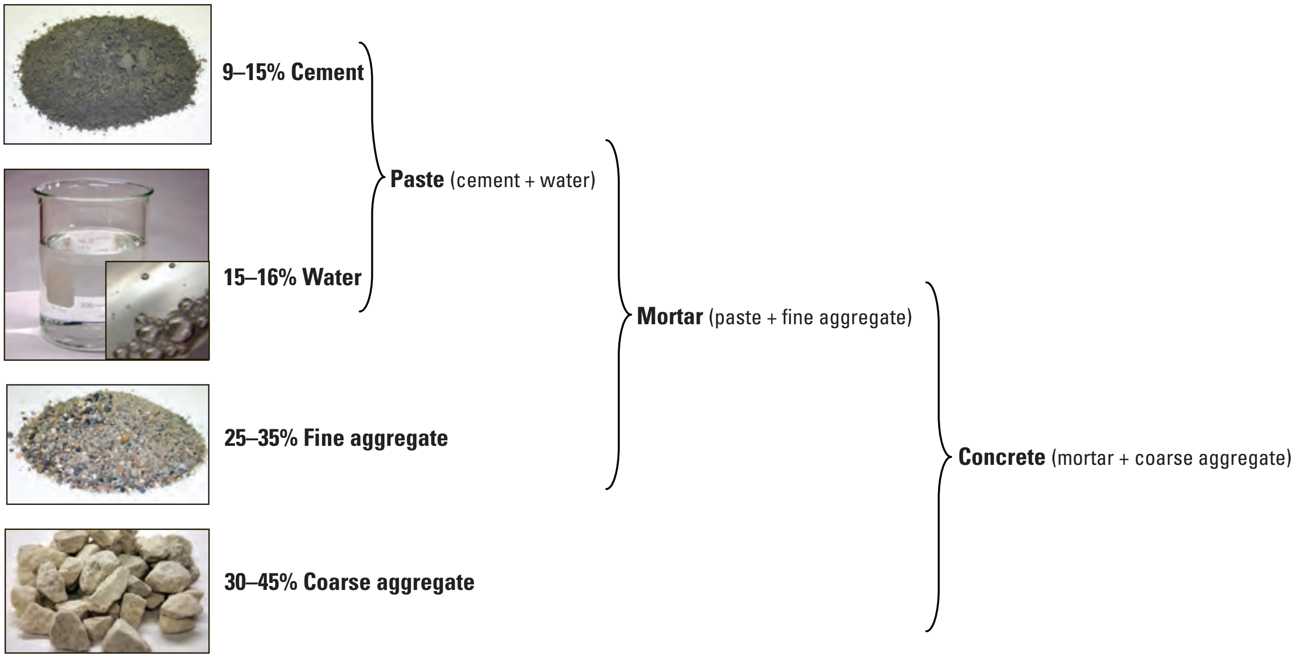

Figure 1-3. Concrete mixture constituents (from IMCP Manual, Iowa State University, 2006)

quickly and are often used in fast-track paving or repair. Blended cements such as Type IP (portland-pozzolan cement) or Type IS (portland blast-furnace slag) cements include other cementitious materials and are options for use in paving mixtures.

It is common for paving mixtures to include supplementary cementitious materials (SCMs) that are added to the mixture by replacing a percentage (either mass or volumetric) of the portland cement content. These may include industrial byproducts like fly ash or slag cement. The proportions in which the materials are used usually vary in every design and are typically selected to balance cost, strength requirements, workability, and durability.

Water for concrete should be potable (fit for human consumption). Some water recycled from returned concrete and plant washing can be acceptable. Specifications for mixing water in concrete mixtures can be found in ASTM C1602. Typical water-to-cementitious materials (w/cm) ratios for normal concrete paving mixtures range from 0.40 to 0.45. Higher w/cm ratios will result in increased workability but also lower strength and decreased long-term pavement performance.

Admixtures commonly used in concrete mixtures include air-entraining admixtures, water-reducing admixtures, retarders, and accelerators. Air-entraining admixtures are used to develop an air void system that is necessary for concrete durability, particularly in freeze-thaw environments. Water-reducing admixtures are used to reduce w/cm ratios while improving workability. Retarders decrease set time and are generally used in hot weather placements. Accelerators increase set times for cold weather concreting. The amount of admixture required for each depends on the amount and type of cementitious material used. It is a good practice to follow the manufacturer's recommendations for dosage. Several admixtures can be used in one mixture, but trial batches must be run in order to ensure compatibility.

If designed properly for the environment in which they will be placed, concrete pavements will last a long time. Various American Concrete Institute (ACI) international documents, the National Concrete Pavement Technology Center's (CP Tech Center) *Integrated Materials and Construction Practices for Concrete Pavement (IMCP) Manual*, and the Portland Cement Association's (PCA) *Design and Control of Concrete Mixtures* provide detailed recommendations of how to proportion a mixture and ensure good performance in a variety of environments. In general, compatible materials coupled with low permeability (i.e., low w/cm ratios and the use of SCMs) and a proper air void system will result in good long-term concrete performance.

Design

A concrete pavement design includes calculating a required pavement thickness, determining a joint layout, and identifying the required steel content (if applicable). The most nationally accepted method for concrete pavement design is the *American Association of State Highway and Transportation Officials (AASHTO) Design Guide* (1993). A major effort is currently underway to regionally calibrate and shift to the new AASHTO Mechanistic-Empirical Pavement Design Guide (M-E PDG).

Other design tools such as tables from the ACI Committee 330 report *Guide for the Design and Construction of Concrete Parking Lots*, the *Continuously Reinforced Concrete Pavement Design* and *Construction Guidelines* (Rasmussen, Rogers, and Ferragut 2009), and the American Concrete Pavement Association's StreetPave software program can be used to provide satisfactory results.

A concrete pavement needs to be thick enough to withstand the stress and fatigue caused by the environment in which it is constructed and the loads under which it must perform over an anticipated lifetime. Some critical design inputs for calculating thickness include the estimated traffic loading during the design life, failure criteria, concrete strength, and stiffness and drainage characterization of supporting layers.

For JCP, the spacing of contraction joints is designed at intervals such that potential volumetric changes of the concrete do not result in unintended damage to the pavement (i.e., uncontrolled cracking). The Federal Highway Administration's High Performance Concrete Paving (HIPERPAV) software can be used as an effective tool for designing proper joint spacing.

Jointed plain concrete pavement transverse contraction joints are typically spaced at 15 to 20 ft (5 to 6.1 m) in order to control cracking. Transverse contraction joints in JRCP can be spaced farther apart (typically about 30 to 40 ft [9 to 12 m]) because of the steel content. Contraction joints are not required in CRCP. Continuously reinforced concrete pavement is designed to have random transverse cracks that are held tightly together by the reinforcing steel. In all concrete pavements, longitudinal construction joints are placed between lanes and transverse construction joints are constructed at the end of each day's paving.

Reinforcement used in concrete pavements includes dowels, tie bars, and continuous steel bars throughout the slab. Dowels provide load transfer and vertical support for jointed pavements at the transverse joints. Tie bars promote aggregate interlock and are most often used along longitudinal joints. Wire or deformed steel bar reinforcement in JRCP keeps random cracks held tightly together. Designing the reinforcement includes identifying the type, size, and spacing. Most states already have standards and specifications for the design of pavement reinforcement. The critical design factors for reinforcement include pavement thickness, concrete material properties, and type of support.

A subbase is usually advisable for heavier trafficked pavements. A subbase in light duty pavements (e.g., residential and collector streets and parking lots) is not always necessary and depends on underlying soils, drainage needs, and loads.

Construction

The construction of a concrete pavement involves obtaining the materials, batching and mixing, placing, texturing, and curing.

Batching is the process of measuring the constituents by mass or volume according to a mixture design and introducing them into a mixer. The size of the batch depends on the capacity of the mixer. In most cases, either a stationary or a ready-mix plant is used for mixing paving concrete, which is then typically transported to the job in dump trucks for slipform paving. Truck mixers can also transport paving concrete but are used more often for fixed-form placements. When planning for equipment, it is important to consider the production capacity and typical haul times. Projects in congested areas, which do not allow for on-site production, may require a mix design that permits extended hauling and placement times.

Concrete is placed using slipform or fixed-form paving methods, depending upon the nature of the project. The concrete mixtures required by either placement method can vary significantly. Slipform paving operations require a low-slump mixture that will not slough after extrusion by the paving machine, while fixed-form paving operations rely on a higher slump mixture that will flow easily to fill the forms. Slipform paving is generally for placements that require high production rates, such as mainline paving. Fixed-form paving is adaptable to nearly any placement circumstance, but because it requires setting up side forms to hold the concrete, it is generally used in irregular sections where slipform paving is not practical.

Contraction joints should be formed or sawcut as soon as possible and are typically sawed to a depth of one-third that of the pavement thickness. Figure 1-4 depicts this process. Contractor experience and tools such as the Federal Highway Administration HIPERPAV computer software program can help identify proper sawcut times based on materials, design, and construction methods. Joints should be sealed with an appropriate material, although some states are

Figure 1-4. Sawcutting JPCP

experimenting with unsealed contraction joints. Local practice should govern accordingly.

When used, dowels can be placed in prefabricated dowel baskets and secured in place prior to paving. Figure 1-5 shows fresh concrete placed over dowel bars secured in dowel bar baskets. Alternatively, dowels can be inserted into the fresh concrete during placement using a dowel-bar inserter (see Figure 1-6).

There are several options for placing tie bars as well. A tie-bar inserter is commonly used to place tie bars between lanes when two lanes are constructed at the same time. For lane additions, single-piece tie bars can be drilled and inserted into the existing hardened concrete and epoxied into place. Bent tie bars can also be inserted during paving and pulled straight after the pavement has hardened. Finally, two-piece tie bars can be used, where one-half of the tie bar is inserted during placement and later the second half is screwed into the first half.

Reinforcing steel for JRCP and CRCP is placed before paving begins as seen in Figure 1-7 and Figure 1-8.

Texture is applied to the surface of the concrete after placement and before curing. The purpose is to increase friction and improve wet weather driving conditions. Two commonly used wet texture tech-


Figure 1-5. Concrete placed over dowel baskets


Figure 1-6. Dowel-bar inserter


Figure 1-7. JRCP reinforcement in place before paving


Figure 1-8. CRCP reinforcement placed before paving

niques include tining and drag. Tined surfaces are applied using a steel rake and can be applied longitudinally or in the transverse direction. Drag textures are applied by dragging a piece of artificial turf or heavy burlap on the surface (see Figure 1-9). Additional textures include diamond grinding and grooving. If used, grinding and grooving are done after curing and once the pavement is able to withstand the weight of the machine that must be used.

Proper curing measures prevent rapid water loss from the mixture and allow more thorough cement hydration. It is essential to apply curing as early as possible after placing concrete and to continue until enough hydration has taken place and the required hardened properties have been achieved. A variety of curing methods and materials is available for concrete pavement, including water spray or fog, wet burlap sheets, plastic sheets, and insulating blankets. Most commonly used, however, is the application of a liquid membrane-forming compound (see Figure 1-10).

Sustainability

- Concrete pavements have longevity.
- Industrial by-products (e.g., fly ash, slag cement, silica fume) can be used in mixture design.
- Concrete pavement surfaces are highly reflective, making them more visible at night. Better visibility improves safety. Brighter streets require less lighting; therefore, energy requirements are reduced.
- Concrete's light surface reduces the urban heat island effect.
- Studies suggest concrete surfaces reduce vehicle fuel consumption for the driving public.

For More Information

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Figure 1-9. Burlap drag on fresh concrete

Figure 1-10. Curing compound applied by spray nozzles on a cure cart

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2

Concrete Overlays

Objectives

- Extend pavement life.
- Improve the surface.
- Increase load-carrying capacity.
- Expedite construction/renewal.
- Reduce urban heat island effect.
- Increase light reflectance.
- Provide a sustainable option.

Solution

- Construct a concrete overlay.

Benefits

- Reconstruction costs are avoided.
- Construction of an overlay is much faster than reconstruction.
- Concrete pavement surfaces reflect light and reduce the urban heat island effect.

Considerations

- Proper assessment of existing pavement conditions is necessary to determine feasibility.
- Any loss of subgrade support or drainage problems must be corrected.

Typical Applications

Concrete overlays can be used for the rehabilitation of a variety of surfaces. However, various factors need to be taken into account before selecting the appropriate overlay system including the existing pavement condition, overlay design details, pre-overlay work, construction materials, and future maintenance and rehabilitation.

Highways

Streets & Local Roads

Shoulders

Commercial / Lightweight

Airfields

Heavy Industrial

Description

Concrete overlays are a durable and cost-effective maintenance and rehabilitation alternative when properly designed and constructed. Rehabilitation of the existing pavement is simplified by the fact that it does not need to be removed, and quite often, few pre-overlay repairs need to be carried out. Overlays preserve pavement serviceability for several decades beyond the original design life.

Overlays are constructed using conventional concrete paving procedures. Joint spacing, load transfer design, and reinforcement methods are similar to new pavements. In addition, typical concrete mixtures are used, which can be adjusted to allow for higher strengths or an expedited construction process.

Concrete overlays are able to restore the function of a facility very effectively. The construction of a new surface results in substantially improved surface characteristics including rideability, improved noise levels, and increased friction. Before placement of an overlay can occur, the existing pavement must be sufficiently evaluated in order to ensure it is a good candidate for overlay construction. There are two main types of concrete overlays: bonded and unbonded (see Figure 2-1).

Figure 2-1. Unbonded overlay

Both overlay types can be constructed over concrete, flexible, and composite pavements (see Figure 2-2).

Bonded overlays are relatively thin and constructed directly on top of existing pavements. Bonded overlays restore the surface and add some structural capacity to roadways that are somewhat to moderately distressed.

Unbonded concrete overlays are typically thicker than bonded overlays and require a separation layer (i.e., bond breaker). Unbonded overlays restore the structural capacity of existing pavements that are moderately to significantly deteriorated.

Materials

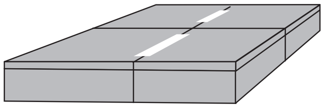
The type of project and the construction schedule dictate the concrete mixture materials. Conventional mixtures should be carefully selected to allow the resulting mixture to be dense, relatively impermeable, and resistant to environmental effects over the length of its service life. Most agencies specify a 28-day unconfined compressive strength requirement of 4,000 psi (28 MPa) for their pavements. On the other

Bonded Overlay Systems
(Resurfacing/Minor Rehabilitation)

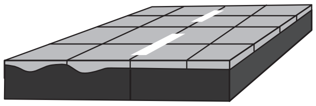
In general, bonded overlays are used to add structural capacity and/or eliminate surface distress when the existing pavement is in good structural condition.

Bonding is essential, so thorough surface preparation is necessary before resurfacing.

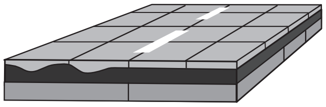
Bonded Concrete Overlays of Concrete Pavements
–previously called bonded overlays–



Bonded Concrete Overlays of Asphalt Pavements
–previously called ultra-thin whitetopping–



Bonded Concrete Overlays of Composite Pavements

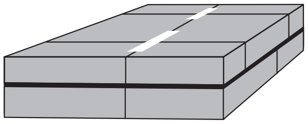


Unbonded Overlay Systems
(Minor/Major Rehabilitation)

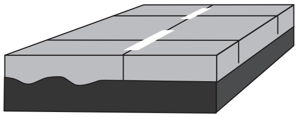
In general, unbonded overlays are used to rehabilitate pavement with some structural deterioration.

They are basically new pavements constructed on an existing, stable platform (the existing pavement).

Unbonded Concrete Overlays of Concrete Pavements
–previously called unbonded overlays–



Unbonded Concrete Overlays of Asphalt Pavements
–previously called conventional whitetopping–



Unbonded Concrete Overlays of Composite Pavements

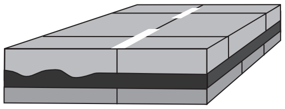


Figure 2-2. Overlay applications

hand, some states use rapid-strength concrete mixtures that have a high cementitious material content, a low water-to-cementitious materials (w/cm) ratio, and smaller top size aggregate. These types of mixtures can be used with accelerating admixtures to allow for faster opening times.

Type I and Type II cements are normally used in concrete mixtures for concrete overlays. Type III cement can be used when high early strength is desired. Various admixtures are commonly introduced as well and include water reducers, air entrainment, and SCMs. Supplementary cementing materials such as fly ash and slag cement improve the workability of the concrete, increase durability and long-term strength, and extend placement time during hot weather. A maximum w/cm ratio of 0.45 is common for pavements in a moist environment with many freeze-thaw cycles, although lower values are used to minimize drying shrinkage.

Aggregates used in overlays range from crushed stones and river gravels to recycled concrete aggregate and should possess adequate strength and be physically and chemically stable within the concrete mixture. The maximum coarse aggregate size should be used in order to minimize paste requirements, reduce shrinkage, minimize costs, and improve mechanical interlock properties at joints and cracks.

The separation layer in unbonded overlays is critical to their long-term performance (see Figure 2-3). A 1-in. (25 mm) thick conventional HMA surface mixture is most commonly used. However, the use of a nonwoven geotextile interlayer has been shown to be a promising alternative. Research and project experience has shown that nonwoven geotextiles provide uniform, elastic support of the concrete slab, reduce pumping processes, and prevent reflective cracking.

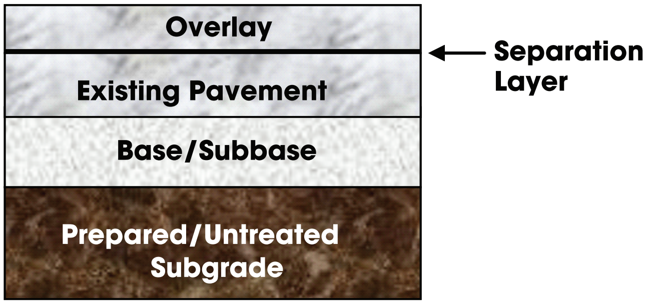


Figure 2-3. Typical cross-section of unbonded overlay

Concrete overlays have been shown to add 15 to 30 years of service life to a roadway. Long-term durability will result from proper materials selection, sufficient pre-overlay work, effective design methods, and successful construction practices. Pavement management and preservation activities such as routine and preventive maintenance and minor rehabilitation should be carefully considered as well in order to further increase the service life of a concrete overlay.

Design

The design of an overlay includes calculating a thickness, establishing a joint layout, and determining reinforcement content. There are several state-of-the-practice design methods that are listed in Table 2-1. In the case of an unbonded overlay, the overlay design must include an interlayer.

Bonded Overlays

The design of a bonded concrete overlay depends on the assumption that the overlay and existing pavement will be one monolithic structure.

For bonded overlays, typical thicknesses range from 2 to 5 in. (50 to 125 mm). For high-traffic roads, a 6 in. (150 mm) bonded overlay or greater can be constructed.

Table 2-1. Current state-of-the-practice overlay design methodologies

State-of-the-Practice Concrete Overlay Design Methods
Bonded concrete overlay of concrete pavements • 1993 AASHTO Guide • M-E PDG
Bonded concrete overlay of HMA and composite pavements • 1993 AASHTO Guide • M-E PDG • Modified ACPA method
Unbonded concrete overlay of all types • 1993 AASHTO Guide • M-E PDG

Typical joint design patterns are listed in Table 2-2. Recommendations for joint depth depend on the type of joint and existing pavement, as well as the equipment used for construction.

Overlay joint widths for bonded concrete pavements are equal to existing pavement joints. For conventional saws, transverse joints in bonded overlays of concrete pavements should be full depth plus 0.50 in. (13 mm). Similarly, longitudinal joints are cut either full depth or no less than half of the pavement thickness. Transverse joints in bonded overlays of HMA and composite pavements constructed using a conventional saw should be cut to a depth of one-fourth of the pavement thickness (T/4); longitudinal joints should be sawcut to a depth of one-third of the pavement thickness (T/3).

Reinforcement such as tie bars, dowel bars, and other embedded steel products are typically not used for overlays less than 6 in. (150 mm) thick.

Continuously reinforced bonded overlays have been constructed by some agencies, and in these cases steel is placed at sufficient depth to provide a minimum of 3 in. (75 mm) of concrete cover. The steel can be positioned directly on top of the old pavement, which has the added benefit of effectively restraining concrete volume changes at the interface.

Table 2-2. Joint pattern for bonded concrete overlays

Joint Pattern for Bonded Overlays	
Bonded Overlay of JPCP	Match joints with existing pavement joints.
Bonded Overlay of CRCP	Match longitudinal joints with existing pavement joints.
Bonded Overlay of HMA and Composites	Use small square patterns in the range of 3 to 8 ft. (0.9 to 2.4 m). Maximum dimensions of the square panels should be no greater than 1.5 times the thickness of the overlay. Avoid longitudinal joints in the wheel paths.

Unbonded Overlays

The design of an unbonded overlay is similar to designing a new concrete pavement over a stabilized subbase. An unbonded overlay design assumes there is no bond between the bottom surface of the overlay and the top surface of the existing pavement.

The design thickness of an unbonded overlay typically ranges from 6 to 11 in. (150 to 280 mm) but can be as thin as 4 in. (100 mm) for lower-volume roads or when overhead clearance is an issue and loading is light.

Unbonded overlays of concrete pavements require an interlayer as a separation layer. The design of the separation layer is critical to the long-term performance of the overlay because it helps prevent reflective cracking and allows the overlay and existing pavement structure to move independently of one another. Drainage must be considered during design of this interlayer.

The most common separation layer is a 1-in. (25-mm) HMA surface mixture; however, a nonwoven geotextile specifically manufactured for use as an interlayer between cementitious layers has also been used as an alternative. The thickness of the HMA interlayer is sometimes increased slightly for unbonded overlays of CRCP. An increase in interlayer thickness may also be required if the existing pavement experiences larger degrees of faulting. A geotextile is not a good alternative in such cases.

It should be noted that while unbonded overlays of HMA or composite pavements do not require an interlayer, if a full-depth concrete patch has been constructed in the existing pavement it must be isolated. One technique for isolating the patch is to apply a debonding agent or material (e.g., asphalt emulsion coating) to the surface of the patch before the construction of the overlay.

For an unbonded overlay of concrete, many states try to match the transverse joints in the overlay with those in the existing pavement. However, some states intentionally design transverse joints in the overlay at an offset from those in the existing pavement. Joint spacings are designed based on the thickness of the overlay. Typical joint patterns for unbonded overlays are listed in Table 2-3 and Table 2-4. Joint depths depend on the type of saw used for construction.

Unbonded overlays of concrete, HMA, or composite pavements should include transverse joints that, when cut with conventional saws, are constructed at depths of T/4 to T/3. Longitudinal joints should be at depths of T/3.

Dowels are used in joints when the overlay's design thickness is greater than 8 in. (200 mm) and expected to carry heavy truck traffic. Tie bars may be appropriate in open-ditch (or shoulder) sections if the design thickness is greater than 5 in. (125 mm). Tied shoulders are the approved method for providing overlay edge support. Tie bars at confined curb-and-gutter sections should be considered if the overlay design thickness is greater than 6 in. (150 mm).

Construction

The construction of an overlay (see Figure 2-4) is a process similar to conventional concrete pavement and includes concrete production, preparation of the existing surface, and the placement, curing, and saw-cutting of new concrete.

Table 2-3. Joint pattern for unbonded concrete overlays of concrete pavements

Unbonded Overlays of Concrete Pavements	
Design Thickness	**Joint Pattern**
<5 in. (125 mm)	Use square panels measuring 6 x 6 ft (1.8 x 1.8 m) panels
5 – 7 in. (125 – 175 mm)	Maximum joint spacing in feet = 2 times thickness in inches
> 7 in. (175 mm)	Maximum joint spacing =15 ft. (4.6 m)

Table 2-4. Joint pattern for unbonded concrete overlays of HMA and composite pavements

Unbonded Overlays of Concrete Pavements	
Design Thickness	**Joint Pattern**
<6 in. (150 mm)	Maximum joint spacing in feet = 1.5 times thickness in inches
6 – 15 in. (150 – 380 mm)	Maximum joint spacing in feet = 2 times thickness in inches
> 15 in. (380 mm)	Maximum joint spacing =15 ft. (4.6 m)

While mixing and placing are the same for both bonded and unbonded overlays, there are subtle differences in the other steps of the process based on the type of overlay to be constructed and the type of existing pavement.

Bonded Overlays

For bonded overlays of any kind, repairs need to be made to place the existing pavement in good condition or at least in fair condition. For existing concrete pavement, that would include repairing wide cracks and subsurface voids. For existing HMA and composite pavements, repairs include addressing potholes, moderate to severe alligator cracking, and loss of subgrade support. Methods for addressing the vertical movement of concrete in composite pavements are explained in the National Concrete Pavement Technology Center's *Guide to Concrete Overlays*.

After repair, the surface of an existing pavement is prepared and cleaned of any loose debris. Surface preparation and cleaning promotes a bond between the overlay and existing pavement. The most common method used to prepare a concrete surface is shotblasting. The surface is then cleaned by sweeping and/or using compressed air. Milling HMA and/or composite surfaces can also be an appropriate method of repair; however, too much milling (for either repair or preparation) will reduce structural capacity. The

Figure 2-4. Unbonded concrete overlay construction over a nonwoven geotextile interlayer

minimum remaining HMA needs to be at least 3 in. (75 mm), preferably 4 in. (100 mm) Milling needs to be done to the top of the nearest HMA lift line to prevent fracturing of the HMA. Hot-mix asphalt and composite pavements are then swept clean or blown with compressed air.

Placement of concrete over existing pavements should follow standard conventional concrete paving practices (see Figure 2-5). Placement over HMA or composite pavements can be accomplished using fixed-form or slipform construction techniques. When HMA surface temperatures are greater than 120°F (49°C), the surface should be cooled by applying water in front of the paver; however, no standing water should be allowed at the time of paving. If the surface cannot be cooled sufficiently, placement may need to be rescheduled for another part of the day.

Curing a bonded overlay and properly timed sawcuts are critical factors no matter what type of existing pavement lies beneath it. The new concrete layer has a high surface-to-volume ratio that makes it vulnerable to rapid moisture loss. Curing compounds should be applied at twice the rate typical for conventional concrete practices and should coat the surface and edges evenly. Joints must be cut as soon as possible and can be constructed with conventional or early-entry saws. It may be necessary to have multiple saws on hand in order to sawcut joints fast enough to prevent uncontrolled cracking. Joint sealants may not be required.

Figure 2-5. Bonded overlay construction

Unbonded Overlays

Before an unbonded overlay is constructed over any existing pavement type (i.e., concrete, HMA, or composite), distresses that cause a major loss of structural integrity will require repair. Hot-mix asphalt and composite pavements may be milled to correct surface defects that are 2 in. (50 mm) or deeper. A minimum of 3 to 4 in. (75 to 100 mm) of HMA must remain in place after milling if the overlay design thickness is 6 in. (150 mm) or greater. If less than 6 in. (150 mm), an overlay of at least 6 in. (150 mm) of remaining HMA is recommended; otherwise, a bonded overlay should be designed.

After repair, if any are necessary, the surface is swept or air blown. If the existing pavement is concrete, the surface must be void of any loose debris before the bond-breaker interlayer is constructed. Hot-mix asphalt and composite surfaces can be simply swept clean; small remaining debris is not an issue.

Like bonded overlays, placement of unbonded overlays over existing concrete should follow standard conventional concrete paving practices. Placement over HMA or composite pavements can be accomplished using fixed-form or slipform construction techniques. The pavement needs to be cooled prior to paving, when surface temperatures are greater than 120°F (49°C). Dowel baskets must be secured properly to the existing pavement unless a dowel bar inserter is used.

Curing and sawcutting follows the same logic as that for bonded overlays: quick, thorough, even application of curing and properly timed saw cuts are critical to long-term performance.

Sustainability

- Concrete overlays make use of the existing pavement, eliminating the need for removal and disposal.
- Concrete overlays can be constructed and opened to traffic within a day, reducing user costs and driver frustration.
- Concrete overlays possess a low life-cycle cost, with long lives and minimal maintenance costs.

- Industrial by-products (e.g., fly ash, slag cement, silica fume) can be used in mixture design.
- Concrete pavement surfaces are highly reflective, making them more visible at night. Better visibility improves safety.
- Concrete's light surface reduces the urban heat island effect.

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3

Pervious Concrete

Objectives

- Satisfy EPA Storm Water Phase II regulations.
- Earn LEED credits.
- Improve safety.
- Reduce tire-pavement noise.
- Provide a sustainable option.

Solution

- Use pervious concrete.

Benefits

- Pervious concrete is an EPA Best Management Practice.
- Stormwater runoff and flash flooding is minimized.
- Hydroplaning and splash and spray are minimized.
- Noise from the tire-pavement interaction is reduced.
- Pervious concrete surfaces reflect light and help reduce the urban heat island effect.

Considerations

- Pervious concrete may require periodic maintenance to prevent clogging.
- Pervious concrete may cause raveling and abrasion problems on higher-speed roadways.

Typical Applications

Streets & Local Roads

Shoulders

Commercial / Lightweight

Organizations such as the Green Highways Partnership are actively facilitating the redevelopment of many inner-city landscapes in an effort to make them more sustainable. Pervious concrete pavements are becoming more attractive alternatives for a variety of new construction and urban retrofit applications. Figure 3-1 shows pervious concrete installed at a park to meet Americans with Disabilities Act (ADA) accessibility requirements. Figure 3-2 shows pervious concrete installed at a park to minimize impervious

Figure 3-1. Miller Park in Fair Oaks, California

Figure 3-2. Imperial Beach Sports Park, California

surface runoff. Figure 3-3 shows a Chicago, Illinois, neighborhood alley constructed of pervious concrete to minimize runoff. The ability to manage stormwater runoff makes pervious concrete a common choice for applications, including city streets and local roads, shoulders, pedestrian walkways, alleys, and parking lots.

Pervious pavement can also be used as a subbase for conventional concrete, at low-water crossings, and for recreational areas such as tennis courts and greenhouses.

Figure 3-3. Pervious concrete for alley in Chicago, Illinois

Description

Pervious concrete (see Figure 3-4) is used in a highly permeable pavement that captures rainwater and allows it to pass through the surface and percolate into the underlying layer. Pervious concrete pavements minimize stormwater runoff, flash flooding, and standing water; they can reduce or even eliminate the need for on-site holding ponds or buried stormwater retention structures. Figure 3-5 shows a parking lot made of pervious concrete.

Pervious concrete can be placed directly on a drainable aggregate base, above sand, or on soils with sufficient drainage properties. Pervious concrete may also be placed over impermeable soils such as clay; however, provisions need to be made for adequate water storage and retention time for egress and percolation of water into the subgrade. The mix design is composed of narrow specially graded coarse aggregate, cement, water, and a small amount of fine aggregate. The result is a material with interconnected air voids of between 15 to 25 percent, depending on the mix design. When compared to conventional concrete pavements, the exposed aggregate surface of pervious concrete can provide enhanced traction for both pedestrians and vehicles. The potential for vehicles hydroplaning during wet weather conditions is also reduced. If not cured properly, surface particles may become loose or ravel. With proper compaction and curing, raveling can be prevented.

Figure 3-4. Pervious concrete

Figure 3-5. Pervious concrete pavement parking lot

Pervious concrete pavements can last for more than 20 years with nominal maintenance. To ensure adequate drainage, routine maintenance is typically required. The amount of routine maintenance depends on the rate of soil loading. Sweeping, vacuuming, or power spraying can be used to mitigate clogging and restore permeability. These pavements have been successful in freeze-thaw and sulfate environments when designed and constructed properly. The ability for pervious concrete pavements to drain water quickly minimizes the saturation within the voids that could otherwise freeze and cause damage. Pervious concrete is more susceptible to sulfate environments; however, if kept isolated from sulfate rich soils or produced with SCMs, pervious pavements can perform satisfactorily.

Materials

See Table 3-1 for typical values of material properties for pervious concrete.

Pervious concrete uses basically the same materials as conventional concrete. One exception is that the fine aggregate content is limited and the coarse aggregate is kept to a narrow gradation (see Figure 3-6). Commonly used gradations of coarse aggregate include ASTM C33 No. 67, No. 8, or No. 89. Number 89 is typically used in mixtures for parking lots and pedestrian walkways. Rounded or angular (i.e., crushed) aggregates can be used for pervious concrete mixtures. Maximum aggregate size and the type of aggregate will affect the final surface texture.

Table 3-1. Typical values for material properties

Property	Typical Values
Unit Weight	70-80% of conventional concrete mixtures
Density	100-125 lb/ft^3 (1600-2000 kg/m^3) – this is dependent on mix design and construction procedures
Percent Voids	15-25%
Permeability	100 in./hr – over 2000 in/hr (2.5-50 m/hr)
Compressive Strength	2500 psi (17 MPa) but this can range from 500 – 4000 psi (3.5 – 28 MPa)

Pervious concrete mixes contain minimal amounts of water, with water-to-cementitious materials (w/cm) ratios around 0.30; however, ratios as high as 0.34 to 0.40 have been used successfully with the proper inclusion of chemical admixtures, such as retarders.

Portland cements and blended cements may be used in pervious concrete applications. In addition, SCMs such as fly ash, pozzolans, and slag cement can be used to improve material properties such as workability and strength. In freeze-thaw environments, air-entraining admixtures are recommended.

Figure 3-6. Fresh pervious concrete

Design

A pervious pavement is designed as either an active or a passive system. An active system is designed to handle much more rainfall than is expected to fall on just the pavement itself. A passive system is a pervious concrete pavement that handles rainfall that falls directly on the pavement surface. A passive mitigation system can capture much, if not all, of the "first flush," but it is not intended to offset excess runoff from adjacent impervious surfaces. An active mitigation system is designed to maintain runoff at a site at specific levels. For either system (active or passive), a proper thickness must be designed. Pervious pavement thickness is designed based on the calculation of hydrologic and mechanical properties including the amount of expected rainfall, pavement characteristics, and underlying soil properties. Standard design procedures include ACI 522R, ACI 325.9R, or ACI 330R. See Figure 3-7 for pervious concrete subjected to rainfall.

Designs for pervious concrete pavement surfaces must consider permeability and storage capacity. Designers should ensure that permeability is sufficient to accommodate all rain falling on the surface of or running onto pervious concrete. While the permeability of pervious concretes is a factor in design, the flow rate through the subbase and subgrade may be more restrictive and control the amount of water leaving the system. The total storage capacity of the pervious concrete system includes the capacity of the pervious concrete pavement, the capacity of any subbase used, and the amount of water that leaves the system by infiltration into the underlying soil.

In freeze-thaw climates, pervious concrete systems should not be designed to store water in the concrete itself because of the expansive nature of water when it freezes. For typical designs, the storage capacity and infiltration rate of the subbase and subgrades are significant.

Typical design thicknesses include 5- to 6-in. (125- to 150-mm) thick pervious concrete with a drainable aggregate base generally 6- to 12-in. (150- to 300-mm) thick. The base layer should allow a percolation rate of 0.5 in./hr (13 mm/hr) if no overflow piping is

Figure 3-7. Pervious concrete pavement in the rain

installed. In freeze-thaw environments, a minimum of 12 in. (300 mm) of a drainable aggregate base, such as 1-in. (25-mm) crushed stone, is typically constructed. A thicker pavement system may need to be used if heavier loads and higher traffic are anticipated, or if the percolation rate of the base layer is inadequate.

Figure 3-8, Figure 3-9, and Figure 3-10 show typical schematics of pervious pavement designs. Full exfiltration designs are only used where the natural soil has a high infiltration rate or good lateral permeability. Partial exfiltration designs are the most common and typically used to control the water quality volume. No exfiltration designs are used where problem soils are a concern or where it is not desirable to introduce water into adjacent locations.

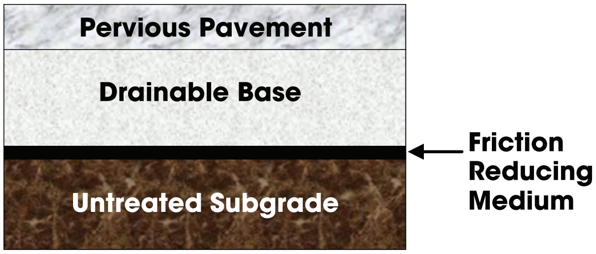

Figure 3-8. Schematic of pervious full exfiltration pavement design

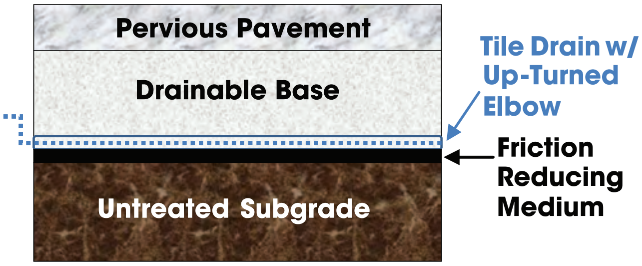

Figure 3-9. Schematic of pervious partial exfiltration pavement design

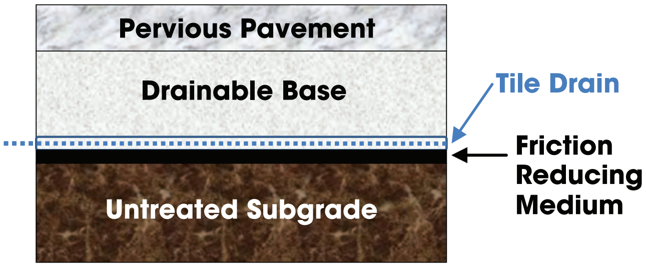

Figure 3-10. Schematic of pervious no exfiltration pavement design

Construction

The construction of pervious concrete pavement includes production of concrete, placement, compaction, and curing.

Pervious concrete production requires tighter control of mixture proportioning. It is also important to maintain aggregate moisture at saturated surface dry moisture content during production. Water absorbed by the mixture from aggregates that are too dry will result in a mix that is too dry for placement and compaction. Too much water in aggregates will increase w/cm and decrease strength and durability.

A low slump and stiffer consistency may discharge slower from transit mixers than conventional concrete. Water reducers and viscosity-modified admixtures can be used to increase flowability and maintain stability of the concrete during discharge and placement. Unit weight or bulk density tests provide the best routine test to monitor quality, as well as seven-day cores to evaluate thickness and strength.

Conventional formwork is typically used to place pervious concrete, and placement should be continuous with spreading and strike off activities performed in a rapid manner. Compaction and finishing is generally accomplished by a weighted roller-screed that spins as it is pulled across the fresh concrete. The spinning tube provides some surface compaction and creates a smooth uniform surface (Figure 3-11). Recommended joint spacings of 20 ft (6 m) have been suggested, although some installations have had joint spacings of 45 ft (13.5 m) or more without

Figure 3-11. Compacting the placed pervious concrete

uncontrolled cracking. Because setting time and shrinkage are accelerated in pervious concrete construction, joints are usually tooled into the concrete soon after consolidation with a rolling joint tool.

The open structure and relatively rough surface of pervious concrete expose more surface area of the cement paste to evaporation, making curing extremely important. Curing for pervious slabs and pavements begins before the concrete is placed—the subgrade must be moistened to prevent it from absorbing moisture from the concrete. After placement, fog misting followed by plastic sheeting is the recommended curing procedure, and sheeting should remain in place until the concrete achieves adequate strength to support the traffic load without damaging the surface (see Figure 3-12). Curing should be started as soon as practically possible after placing, compacting, and jointing.

Sustainability

- Heat and light is reflected due to its lighter color and lower density, decreasing the impact of heat island effects.

Figure 3-12. Curing pervious concrete with plastic sheeting

- Pervious concrete reduces runoff and thus helps prevent pollution of natural bodies of water.
- The need for on-site holding ponds or expensive irrigation systems is reduced or eliminated, resulting in decreased costs and more useable land space.
- Safety is improved because the potential for hydroplaning is reduced since water is able to escape from the surface.
- Noise is reduced, improving traveling experience.

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4

Precast Pavements

Objectives

- Provide long life.
- Improve the surface.
- Provide high load-carrying capacity.
- Expedite construction/renewal.
- Provide a sustainable option.

Solution

- Use precast concrete pavement systems.

Benefits

- Construction can be completed during short (overnight or weekend) closures.
- Lane closures and associated user delays during construction are minimized.
- Precast pavements are a highly durable finished pavement and not just a temporary fix.
- Precast pavement surfaces reflect light and help reduce the urban heat island effect.

Considerations

- Initial costs are generally higher than conventional PCC pavement.
- The learning curve for production, placement, and testing can be steep.

Typical Applications

Precast concrete pavements are typically used for highway, airfield, and heavy industrial applications.

Highways

Airfields

Heavy Industrial

Description

Precast pavements are constructed using prefabricated concrete slabs installed over a prepared subbase or existing pavement (see Figure 4-1). Precast panels are fabricated off site at established precast concrete facilities prior to construction, transported to the jobsite, and then installed on site and opened to traffic. Precast pavements have been used primarily for reconstruction and repair of JCP—but have also been used for new construction—and have the potential to be used for reconstruction of HMA pavements. Precast pavement systems can also be used as an unbonded overlay, a cost-effective solution to add structural capacity and extend the life of an existing roadway.

The benefits of precast pavement are primarily realized through reconstruction of existing facilities

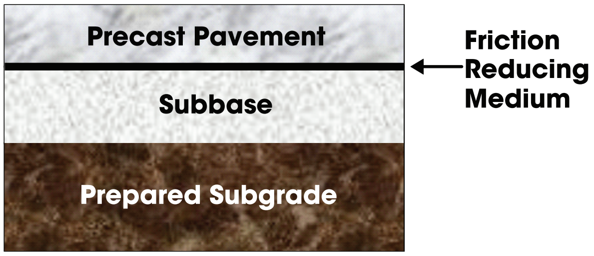

Figure 4-1. Precast pavement system cross-section

during short closures, as shown in Figure 4-2 during the nighttime reconstruction of Interstate 66 in Virginia. Precast pavement has also been used successfully for new construction of highways, like that shown in Figure 4-3 in Indonesia. For this project, up to 0.6 miles (1.0 km) of precast pavement was placed daily.

Repair or reconstruction of JCP and HMA pavements using precast pavement systems can be accomplished quickly, during short overnight or weekend closures, thus reducing user delay and associated costs. Precast panels can be used for isolated full-depth repairs, such as joint replacements, for single or multiple consecutive slab replacements, or for total reconstruction of an entire section.

There are two primary types of precast pavement systems used in the United States to date. The first type of system uses prestressed concrete panels that are pretensioned in one direction during fabrication and posttensioned together in the other direction after placement on site. The other type of system is a jointed system, which replicates conventional JCP using precast panels. For the prestressed system, load transfer between panels is provided by posttensioning; dowels are used for the jointed system. Deciding on which system to use will depend primarily on the type of application but also on issues such as cost and contractor expertise.

Figure 4-2. Nighttime placement of precast panels in Virginia

Figure 4-3. Precast pavement system in Indonesia

Unless they are to be used as a temporary patch, precast pavements are designed to perform equal to or better than new concrete pavement. While the ride quality of the surface as installed is acceptable for opening to traffic, diamond grinding can be used to ensure the final riding surface meets the stringent requirements for high-speed roadways.

Materials

Precast concrete has been proven a durable high-performance product for bridge and commercial building construction. The concrete mixtures used are similar to those utilized for other precast elements and are not restricted to "paving" mixtures. However, consideration must be given to pavement-specific requirements, such as requirements for skid resistance and durability in potentially aggressive environments. High strength, low permeability concrete mixtures with a low w/cm ratio and uniform aggregate gradation are used routinely by precast fabrication plants and will generally be suitable for pavement panels as well.

Strength requirements are typically not difficult to achieve due to the need for rapid production of precast panels by turning over the casting beds every day or every other day. Typical precast pavement mixtures are designed for average 28-day compressive strengths between 4,000 and 6,000 psi (28–41 MPa), and higher strengths usually achieved. For prestressed precast panels, strengths of 3,000 to 4,000 psi (21–28 MPa) are typically required for release of pretensioning. Low permeability prevents chlorides and other corrosive agents from penetrating the concrete and reaching the reinforcement and prestressing steel in the panels. Aggregates must meet specified skid- and abrasion-resistance requirements typical for pavements.

Design

For prestressed precast pavement systems, the premise for design is to first calculate the thickness that would be required for conventional concrete pavement, then to reduce that thickness, as much as practical, by adjusting the prestress levels such that stresses in the precast pavement will be equivalent to the conventional concrete pavement. Additional prestress can be added to further increase the design life of the pavement. Precast panels are typically a minimum of 8 in. (200 mm) thick, but they can be adjusted as necessary to match the thickness and cross-section of the existing pavement.

Jointed precast pavement systems are typically designed to replicate conventional JCP. For repair or reconstruction projects, the precast panels are designed to match the thickness of the slab being removed minus 1/4–1/2 in. (6–13 mm) to accommodate irregularities in the base beneath the pavement slab being removed. For new construction, the panels are designed to match the thickness that would be specified for a conventional concrete pavement design based on project conditions.

For prestressed systems, there are two types of joints: (1) the intermediate joints between the individual panels, and (2) the expansion joints at the ends of each posttensioned section of precast panels. The intermediate joints are "nonworking" joints that are posttensioned together and sealed with epoxy applied to the abutting faces of the precast panels during construction. The expansion joints are designed to accommodate or "absorb" movement due to expansion and contraction of the posttensioned slabs.

For jointed systems, doweled joints are used similar to conventional JCP. However, it should be noted that there is not any significant contribution to load transfer from aggregate interlock, as is the case for conventional JCP. Grout or mortar is typically used to ensure full bedding of the dowel bars in the precast panels after installation and to fill the joint between the panels.

Prestressed panels are typically designed with minimal nonprestressed reinforcement. This is because prestressing helps to minimize or even eliminate cracking through so-called "elasto-plastic" behavior, which helps keep any cracks that do form tightly closed. Jointed precast panels are typically heavily reinforced with two mats of mild steel reinforcement to prevent any cracks that may form during handling or from widening over the life of the pavement.

Subbase layers, if included in the precast pavement design, should be designed to provide uniform support. Typical base materials include HMA, crushed stone, stone dust, and lean concrete.

Construction

Precast pavement construction encompasses prefabrication of the concrete panels and subsequent placement at the jobsite.

The prefabrication process includes setting up the forms to very strict tolerances, securing reinforcement, prestressing, and adding other embedments within the forms. Next in the prefabrication process is placing concrete into the forms (Figure 4-4 and Figure 4-5), screeding, texturing, and curing the concrete. Finally, removing the panels from the forms, completing any additional steps required before placement, and stockpiling the panels for shipment to the project concludes the process.

A primary benefit of prefabrication is the high degree of quality control that exists in precast concrete facilities along with the controlled environment under which the panels can be produced. This helps to ensure uniformity of materials, workmanship, and adequate curing for the precast panels. Good construction practices recommend that an established prefabrication facility be used, as opposed to a temporary plant set up near the jobsite.

Delivery of the precast panels to the site is a critical aspect of the installation process, and care must be taken to ensure that the panels are not damaged in any way during handling or shipping. Figure 4-6 and Figure 4-7 show typical placement methods for precast pavement systems. Providing a flat, uniform, and stable platform for the precast panels to rest on is important, regardless of the subbase material used. For prestressed precast systems, some form of friction-reducing material is needed between the precast pavement and underlying subbase material to reduce frictional restraint stresses that can accumulate during posttensioning and daily expansion and contraction cycles. To help ensure full support beneath the panels, grout or urethane foam is typically injected beneath the slabs after installation to fill any voids that may exist.

The construction process varies with each job, but based on the type of precast pavement system used, common steps include the following:

- Sawcutting and removing existing pavement (repair/reconstruction) or ensuring the subbase is properly prepared (new construction)


Figure 4-4. Concrete poured into form for precast panel


Figure 4-5. Vibrators for consolidation of concrete around reinforcement in precast prestressed panel

Figure 4-6. Placement of precast panel for precast JCP system


Figure 4-7. Placement of a prestressed precast panel

- Sawcutting and jackhammering dowel slots or drilling and epoxying dowels (jointed systems)
- Final leveling and grade adjustment of the subbase
- Installation of the precast panel(s)
- Applying temporary posttensioning to pull adjacent panels together (prestressed system)
- Applying final posttensioning after a full section of panels have been installed (prestressed system)
- Backfilling of the dowel slots (jointed systems) and posttensioning blockouts (prestressed system)
- Grouting of posttensioning tendons (prestressed system)
- Grouting or foam injection beneath the panels
- Filling joints around the perimeter of the panels (jointed systems)
- Sealing joints
- Diamond grinding for smoothness (as necessary)

Sustainability

- Material usage is optimized through minimizing the thickness of the precast panels.
- Construction waste is reduced because the exact amount of necessary components is delivered to the site—there is no additional "incidental" thickness to the slab.
- There is significant user cost savings including fuel consumption and lost work time due to delays.
- Any spare components/panels can be recycled, and their materials used again in another product.
- Mixtures for precast systems use locally derived materials and can incorporate recycled SCMs like fly ash and slag cement.

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5

Roller-Compacted Concrete

Objectives

- Provide a low-cost pavement option.
- Provide a strong, durable pavement that will support heavy loads.
- Minimize traffic disruption and provide for required early-opening to traffic.
- Widen a lane or add a shoulder in a cost-effective manner.
- Provide a sustainable option.

Solution

- Construct with roller-compacted concrete (RCC).

Benefits

- Roller-compacted concrete provides a strong, dense, and durable material that can be quickly constructed.
- Construction is fast, with no forms or finishing.
- No steel reinforcement and minimum labor make RCC economical.
- For many applications, joint sawing is optional for aesthetic purposes resulting in additional cost savings.
- Roller-compacted concrete pavement surfaces reflect light and help reduce the urban heat island effect.

Considerations

- A mixer with adequate energy is required to mix RCC.
- Typically, an asphalt-type paver is used for placement.
- Surface typically is not as smooth or consistent in appearance as conventional concrete.
- For higher traffic speeds, the surface may need to be diamond ground or topped with a concrete or HMA overlay.

Typical Applications

Roller-compacted concrete pavement applications include streets and local roads, highways and shoulders, airfields, heavy industrial, and commercial/light industrial. Roller-compacted concrete is an ideal candidate in situations where surface smoothness and appearance are secondary to high durability, low maintenance, early trafficking, and low initial cost.

Roller-compacted concrete with a surface treatment such as diamond grinding or an overlay can be used for pavements that experience high-speed traffic, including highways. In such applications, RCC acts as a base or subbase.

Highways

Streets & Local Roads

Shoulders

Commercial / Lightweight

Airfields

Heavy Industrial

Description

Roller-compacted concrete has a similar strength to conventional concrete, yet it can be more economical. Pavements with RCC can resist rutting and span soft localized subgrades. They will not deform under heavy, concentrated wheel loads, will resist deterioration from fuel or hydraulic fuel spills, and will remain rigid under high temperatures. The compressive strength of RCC is comparable to that of conventional concrete, ranging from 4,000 to 6,000 psi (28 to 41 MPa), with flexural strength ranging in values from 500 to 1,000 psi (3.4 to 6.9 MPa). The strength makes it able to withstand high concentrated loads and impacts from heavy industrial, military, and mining applications, as well as support light vehicle traffic shortly after placement.

Roller-compacted concrete can be used as a pavement surface layer for low-speed roads and industrial facilities where surface smoothness and appearance are not a major concern as compared to high durability, low maintenance, and low initial cost (see Figure 5-1). Diamond-ground RCC had been used successfully on urban arterials without any additional surface treatment. Roller-compacted concrete can also be a base or subbase for highways and other high-speed traffic roadways (see Figure 5-2 and Figure 5-3).

Roller-compacted concrete combines various aspects of conventional concrete pavement materials practices with some construction practices typical of flexible pavements. It has the same basic ingredients as conventional concrete: cement, water, and aggregates (such as gravel or crushed stone), but it is typically placed with asphalt-type paving equipment and compacted by vibratory steel drum rollers to a specific density (see Figure 5-4).

Unlike conventional concrete, RCC is a “drier” mix and stiff enough to be compacted by vibratory rollers. Since the paste content in RCC is lower, less concrete shrinkage and reduced cracking from shrinkage-related stresses result. In addition, non-air-entrained RCC pavements can provide reliable and durable performance in freeze-thaw environments as long as the mix is properly proportioned with adequate cement content and sound aggregates. The concrete must also be thoroughly mixed, adequately compacted, and properly cured.

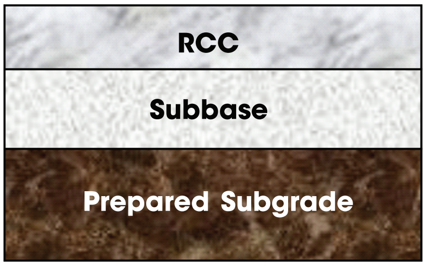

Figure 5-2. Pavement cross-section with RCC surface

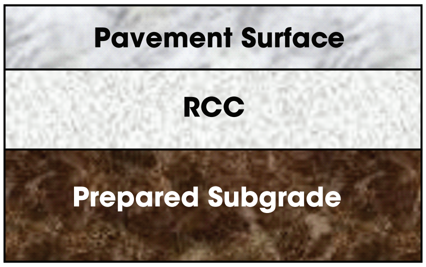

Figure 5-3. Pavement cross-section with RCC base

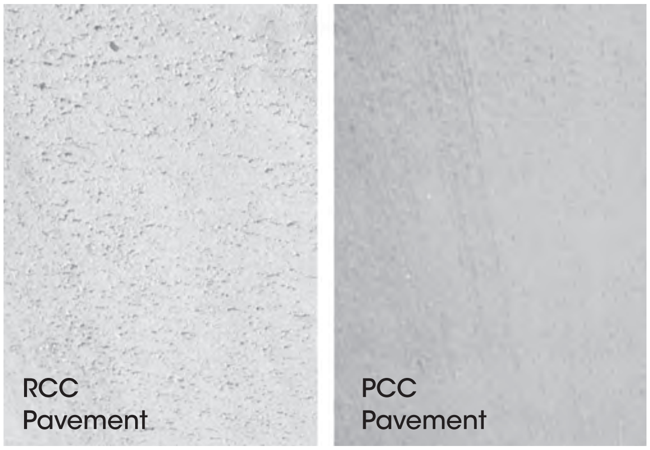

Figure 5-1. Typical RCC versus PCC surface

Figure 5-4. RCC construction for commercial and heavy industrial applications

Materials

The goal in selecting the appropriate quantity of materials for RCC is to proportion the mix so that there is enough paste to cover the aggregates and fill the voids (see Figure 5-5). Primary differences in proportions between RCC pavement mixtures and conventional concrete pavement mixtures are the following:

- Roller-compacted concrete is generally not air entrained.
- Roller-compacted concrete typically has a lower water content.
- Roller-compacted concrete typically has a lower paste content.
- Roller-compacted concrete generally requires a larger fine aggregate content in order to produce a combined aggregate that is well graded and stable under the action of a vibratory roller.
- Roller-compacted concrete usually has a nominal maximum size of aggregate not greater than 3/4 in. (19 mm) in order to minimize segregation and produce a relatively smooth surface texture.

Aggregate selection is very important. Natural or manufactured aggregates can be used. Mineral aggregates constitute up to 85 percent of the volume of RCC and play an influential role in achieving the required workability, specified density in the field under vibratory compaction, compressive and flexural strengths, thermal properties, long-term performance, and durability. Aggregate fines are typically in the range of 2–8 percent, passing the #200 (75 μm) sieve. Silts and clays, however, should be avoided.

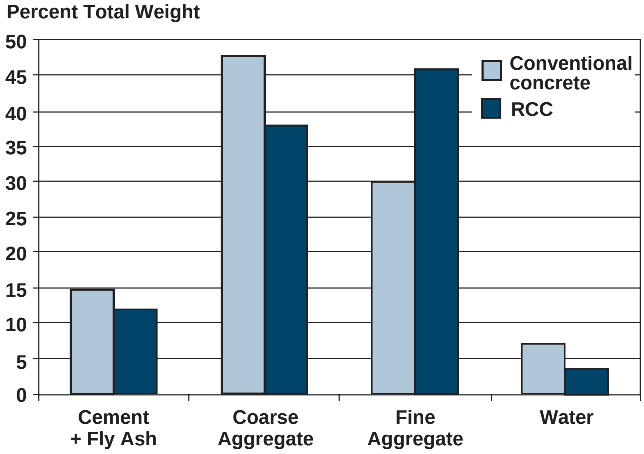

Figure 5-5. Typical mix design constituents

Cementitious materials used in RCC pavement mixtures include portland cement or blended hydraulic cement and may include pozzolans such as fly ash and slag cement. Types I and II cements are commonly used in RCC pavements. Type III can be used when early strength gain is required, and Type V can be used in areas that have specific soil conditions calling for this type of cement.

The use of a blended cement, pozzolans, or slag cement may help improve workability, reduce the potential for alkali-aggregate reaction, extend the compaction time, and help in freeze-thaw conditions. The use of fly ash in RCC is an effective means of providing additional fine material needed to ensure adequate compaction, particularly in those RCC mixtures that contain standard graded concrete fine aggregate.

Water content should be just enough to ensure even distribution of the paste but dry enough to support the vibratory roller (see Figure 5-6). Chemical admixtures can be used. Higher dosages of chemical admixtures than in conventional concrete may be required, and material compatibility should be established through trial batches.

Design

Roller-compacted concrete pavements fall into two main categories: (1) heavy-duty industrial pavements (e.g., ports and multimodal terminals), and

Figure 5-6. RCC material looks drier than conventional concrete

(2) pavements carrying mixed-vehicle traffic (e.g., trucks and passenger vehicles). Table 7 shows a list of design methodologies. Thickness design for RCC pavements employs the same basic strategy as for conventional concrete pavements; however, there are no dowels or steel reinforcement in RCC to accommodate load transfer. The pavement should be thick enough to allow for flexural stresses and fatigue damage caused by wheel loads within allowable limits. Fatigue due to flexural stress is used to calculate the required pavement thickness. The minimum thickness of an RCC pavement is typically 4 in. (100 mm). A single lift should be no thicker than 10 in. (250 mm).

Base and subbase layer requirements are similar to those required for conventional concrete; however, RCC can be more sensitive to the moisture content of granular subbases.

Historically, RCC is constructed without joints. When RCC is allowed to crack naturally, aggregate interlock usually provides adequate load transfer across the cracks. Cracks typically occur at 20- to 60-ft (6.1- to 18.3-m) intervals, depending on the RCC's properties and pavement thickness. The primary reason joints are used in RCC pavements is to initiate crack locations or to improve aesthetics in parking lots, access roads, or areas of channelized traffic at speeds greater than 30 mph. Figure 5-7 shows flexural beam testing.

Table 5-1. List of design methodologies

Property	Heavy Industrial Applications	Conventional Roadway Applications
RCC-Pave Computer Software (PCA)	✓	
U.S. Army Corps of Engineers (USACE)	✓	
StreetPave (ACPA)		✓
Guide for Design of Jointed Concrete Pavements for Streets and Local Roads (ACI 325.12R-02)		✓
Guide for the Design and Construction of Concrete Parking Lots (ACI 330R-08)		✓

When joints are constructed in RCC, they are fewer in number and spaced farther apart than in conventional concrete pavements. Dowels or tie bars are not used in RCC pavements for load transfer the way they are used in conventional concrete; therefore, the designer needs to consider the absence of load transfer devices in the design. Figure 5-8 shows a typical RCC design crack.

Where concentrated lane traffic is not common, joints can be sawed in square patterns using the transverse spacing of 15- to 20-ft (4.6- to 6.1-m) intervals for pavements less than 8 in. (200 mm) thick and 3 to 4 times (in feet) the pavement thickness (in inches) for

Figure 5-7. Flexural beam testing

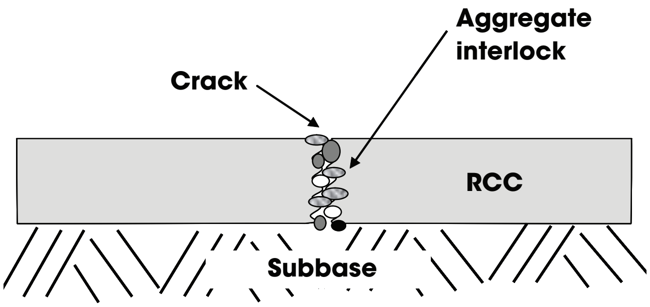

Figure 5-8. Typical RCC design relies on aggregate interlock at cracks

pavements 8 in. (200 mm) thick or greater. In areas with concentrated lane loading, the longitudinal spacing should be 20 ft (6.1 m) for pavements less than 8 in. (200 mm) thick and 2.5 times (in feet) the pavement thickness (in inches) for pavements 8 in. (200 mm) thick or greater.

Construction

A continuous supply of fresh RCC material to the pavement placement machinery is necessary for producing a quality product. Therefore, the rate of RCC production and transportation capability should match the speed of construction at the site (see Figure 5-9). An RCC mixing facility must have the efficiency to evenly disperse the relatively small amount of water present in the stiff, dry mix. Consequently, the relatively dry RCC requires rigorous mixing energies and batching times to provide a uniform mixture, which can reduce the plant's mixing capacity when compared to conventional concrete.

The right mixing equipment is vital to ensuring a continuous and consistent quality supply to the paver. There are two types of mixers for RCC: batch type and continuous mixers. Most concrete batch-type mixers consist of a tilt (Figure 5-10) or fixed drum and transit mixers (dry batch ready-mix trucks) (Figure 5-11). These mixers are typically used for smaller projects because of the reduced mixing capacity and longer mixing time. Continuous mixers are typically used for larger projects because they can produce RCC at a faster rate than batch mixers. Typically, RCC is blended in continuous horizontal shaft mixers such as pugmills. High-output pugmills have the mixing efficiency needed to evenly disperse the cement and relatively small amount of water used in this drier mix (see Figure 5-12). Roller-compacted concrete is typically delivered in dump trucks, but transit mixers can sometimes be used for small projects.

During placement, it is important that the subbase and/or subgrade be uniformly moist. In general, RCC pavements are constructed using both asphalt and conventional concrete pavement construction techniques. Roller-compacted concrete is typically placed with an asphalt-type paver. When configured with a high-density screed, rolling compaction is reduced, thus minimizing variations in surface tolerance and improving surface smoothness. A high-density paver is often used to accommodate the relatively large amount of material moving through the paver. For pavement thicknesses greater than 10 in. (250 mm), multiple lifts are used.


Figure 5-9. RCC delivered to jobsite

Figure 5-10. Tilt-drum mixer


Figure 5-11 Ready-mix transit trucks dumping into haul trucks

Compaction is the most important stage of construction, as it plays a large role in density, strength, durability, smoothness, and surface texture. Since RCC mixtures are relatively dry and stiff (zero slump), a 10-ton (10.2-t) vibratory steel drum and rubber-tired rollers are generally used during placement operations (see Figures 5-13 through 5-16 for the RCC placement through curing process). When using high-density pavers, higher compaction is accomplished primarily by the paver and paving screeds. Rolling begins soon after placement and continues until the density of the pavement meets a minimum of 98 percent of the modified Proctor density. Final compaction is generally achieved within one hour of mixing.

Proper curing and hydration of the RCC mixture is critical to the long-term durability of the pavement. Because RCC has a low water content and exhibits no bleed water, proper curing techniques are important to prevent evaporation and premature drying of the surface. Lack of adequate moisture for curing can result in scaling, dusting, and raveling of the hardened surface.

For most projects, a white concrete curing compound conforming to ASTM C309 (Specification for Liquid Membrane-Forming Compounds for Curing Concrete) is used. A water cure can also be implemented, where the pavement is sprayed or irrigated to keep it moist. However, moisture curing of RCC requires a continuous application of water for the entire curing period.

Sustainability

- Long service life with minimal maintenance, low initial costs, incorporation of by-product materials, and improved safety make RCC a sustainable option.

Figure 5-12. Mobile RCC pugmill mixing plant and mixing chamber

Figure 5-13. RCC placement

Figure 5-14. Compacting RCC using both vibratory and pneumatic-tired rollers

- The ability to use some fines allows RCC to incorporate material that would otherwise not be acceptable for conventional concrete.

Figure 5-15. RCC in-place density measurement

Figure 5-16. Curing RCC

- Roller-compacted concrete surfaces reflect heat, which reduces the heat island effect.
- Roller-compacted concrete has a high albedo, making for better night visibility and improved safety.

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6

Cement-Treated Base

Objectives

- Provide a strong, uniform base/subbase for current and future loading conditions using in-place or locally available marginal soils and granular material.
- Reduce stresses on the subgrade.
- Stabilize a variety of soils with a single stabilizer.
- Reduce rutting and deflections in a flexible pavement surface.
- Improve the structural capacity of the existing soil.
- Provide a sustainable option.

Solution

- A cement-treated base (CTB) using existing soils or locally available borrow material.

Benefits

- A stiffer base reduces deflections due to traffic loads, thereby extending pavement life.
- Subgrade failures, pumping, rutting, joint faulting, and road roughness are reduced.
- Base thickness is reduced compared to unbound granular base thicknesses.
- Marginal aggregates, including recycled materials, can be used, thus reducing the need for virgin, high-quality aggregates.

Considerations

- The potential for reflective cracking and increased friction between the CTB and surface need to be considered.

Typical Applications

Cement-treated base provides a durable, long-lasting base in all types of climates. It is often used in highway, street and local road, shoulder, commercial, and heavy industrial applications. Cement-treated base is also common in airfield applications, particularly large airport runway applications. The Federal Aviation Administration requires CTB for runways that experience high volumes of heavy aircraft traffic.

Highways

Streets & Local Roads

Shoulders

Commercial / Lightweight

Airfields

Heavy Industrial

Description

Cement-treated base consists of native soils, gravels, or manufactured aggregates blended with measured amounts of portland cement and water that hardens after curing to form a durable paving material. The versatility of cement is critical to the success of the stabilization operation, because site conditions can easily change during a project and the stabilizer needs to adapt to the changing conditions. Cement is known as a "universal stabilizer" because it works well over a wide range of different soil types.

Pavements with CTB will be much stronger than an unstabilized, granular base. Thicknesses for CTB are less than those required for unstabilized granular bases carrying the same traffic. Cement-treated base can distribute loads over a wider area (see Figure 6-1), reducing the stresses on the subgrade. It has a high load-carrying capacity, does not consolidate further under load, reduces rutting in HMA pavements, and is resistant to freeze-thaw deterioration.

In a pavement system, CTB is generally constructed over the subgrade (see Figure 6-2). An HMA or concrete wearing surface is placed on the CTB to complete the pavement structure. The design of a concrete surface layer must take into account increased friction values between the layers. In some instances, an interlayer is used to reduce restraint stresses and the potential for reflective cracking. See Figure 6-3 for a completed CTB section of roadway.

Materials

Cement-treated base is a mixture of aggregate material, portland cement, and water. The mixture should be designed based on strength and resistance to freeze-thaw and wet environments.

The aggregate material used in a CTB mixture can be a variety of materials or combinations thereof. These materials include existing or borrowed stone, gravel, sand, silt, and caliche. Recycled concrete aggregates (RCA) and recycled asphalt pavement can also be incorporated. A well-graded sandy and gravelly aggregate material blend typically requires the least amount of cement for adequate hardening, whereas an aggregate material that is classified as either a poorly graded sandy material deficient in fines or a silty and/or clayey material both require more cement for hardening. Many state specifications require that aggregates used in CTB meet typical gradation and Atterberg limit requirements.

Any portland cement type can be used, but Types I and II are the most common. Cement content depends on the type of aggregate material used;

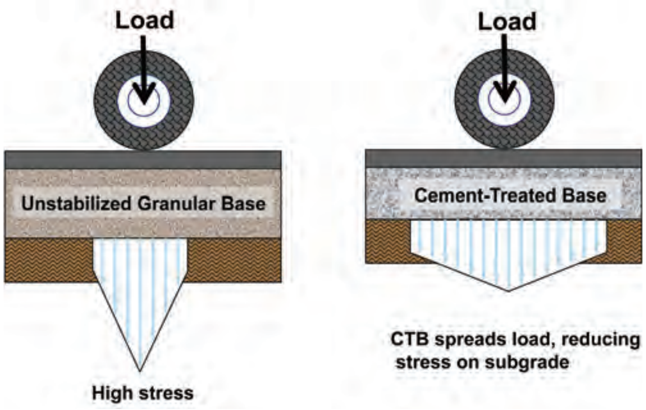

Figure 6-1. Load distribution of CTB compared to unstabilized granular base

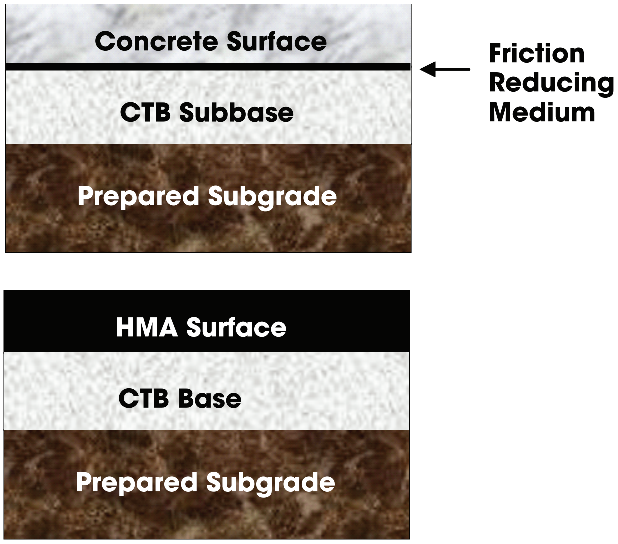

Figure 6-2. Typical pavement cross-sections showing CTB layers

Figure 6-3. Completed CTB for new pavement construction in Oklahoma

however, it usually ranges from 3 to 8 percent for most applications. In general, a cement content that will provide a seven-day unconfined compressive strength of between 300 and 400 psi (2.1 and 2.8 MPa) is satisfactory for most CTB applications.

The engineering properties of the CTB mixture are dependent on individual constituent materials that make up the mixture (i.e., aggregate material and cement type), curing conditions, and age. Age makes a difference because cement will continue to hydrate over time, which will increase strength. General ranges for compressive strength, modulus of rupture, modulus of elasticity, and Poisson's ratio are listed in Table 6-1.

Table 6-1. Typical CTB properties

Property	7-Day Value
Compressive Strength	300 – 800 psi (2.1 – 5.5 MPa)
Modulus of Rupture (Flexural Strength)	100 – 200 psi (0.7 – 1.4 MPa)
Modulus of Elasticity	600,000 – 1,000.000 psi (4,100 – 6,900 MPa)
Poisson's Ratio	0.15

Design

A CTB serves as an integral component of the pavement system. It needs to be strong enough to withstand the stress and fatigue caused by the environment in which it is constructed and the loads under which it must perform over an anticipated lifetime. Some critical design inputs for calculating CTB thickness include the estimated traffic loading during the design life, subgrade strength, and CTB strength.

The most common approach for determining CTB thickness is to follow the American Association of State Highway and Transportation Officials (AASHTO) Design Guide (1993) procedure for pavement design, which uses a structural layer coefficient to model base material. A major effort is currently underway to regionally calibrate and shift to the new AASHTO Mechanistic-Empirical Pavement Design Guide (M-E PDG). Another approach is to use the Portland Cement Association procedure given in the PCA publication *"Thickness Design for Soil-Cement Pavements."*

The ability of a pavement base to carry loads depends on the strength of the base material and the thickness of the base layer. Although a thin, strong base can theoretically carry the same load as a thick, weaker base, the thicker, weaker base is usually preferred. This is because the thin, stronger base is more brittle and more likely to crack, resulting in potential reflective cracking in the surface pavement. On major highways, typical thicknesses range from 6 to 12 in. (150 to 300 mm).

Construction

Construction includes initial preparation, processing, compaction, finishing, and curing. The following paragraphs give a brief summary of CTB construction.

Initial preparation includes the following steps: (1) Shape area to crown and grade; (2) Correct unstable subgrade areas; (3) If necessary, scarify, pulverize, and prewet the soil (in general, not much pulverization is required for CTB); and (4) Reshape crown and grade.

Processing is continuous and accomplished in one day. There are two methods for processing CTB: mixed-in-place or central-plant-mixed.

For CTB mixed-in-place, cement is placed dry onto the surface of the in-place aggregate using a mechanical spreader attached to a dump truck or bulk cement truck. The cement may also be placed on the surface in slurry form. The in-place aggregate can be either the existing material or borrowed material. A single-shaft pulvermixer combines the aggregate and cement. If necessary, water is applied on the surface or directly into the mixing chamber. The single-shaft mixer then mixes the cement, water, and aggregate until a uniform, thoroughly mixed material is achieved (see Figure 6-4, Figure 6-5, and Figure 6-6).

The central-plant-mixed method requires mixing cement, aggregate material, and water in a stationary plant. Mixing at a central plant is generally done by pugmills or rotary-drum mixers. Rotary-drum mixers work well for mixing coarse, nonplastic aggregate material. High-speed rotary shaft pugmills work well for coarse aggregate material and nonplastic fine-grained material like sands and silts. For plants with rotary-drum or batch-type pugmills, material is

Figure 6-4. Spreading dry cement on grade prior to mixing

Figure 6-5. Applying cement slurry on grade prior to mixing (cement slurry is applied the same way for FDR and CMS applications)

batched by weight, mixed, dumped into haul trucks, and delivered to the site. At plants with continuous-flow-type pugmills, the most common type of central plant, materials are individually metered by weight or volume and fed into the mixer by an auger screw, belt, or rotary-vane feeder. After mixing at the plant, the CTB material is dumped into trucks, hauled to the site, and spread evenly over the area (see Figure 6-7). An aggregate spreader is commonly used to place the CTB mixture over the subgrade.

The CTB mixture should be compacted at optimum moisture to maximum dry density as determined by preliminary laboratory testing per AASHTO T134 or ASTM D558, or as defined by project specifications. Vibratory-steel rollers, sheepsfoot rollers, or pneumatic-tire rollers are typically used, depending on the type of aggregate material used in the CTB mixture.

The finishing operations follow immediately after adequate compaction is obtained. The goal of the finishing process is to produce a high-quality surface that has adequate compaction and is void of any soft areas or surface compaction planes. The steps for finishing CTB also depend on the type of aggregate material used in the CTB mixture. In general, finishing a CTB mixture includes a combination of shaping, scratching the surface, applying a broom drag, lightly applying water, and rolling with a pneumatic steel roller.

After finishing, the CTB must be adequately cured, allowing cement to hydrate and the cement-aggregate

Figure 6-6. Constructing CTB using mixed-in-place method

Figure 6-7. Placement of plant-mixed CTB on prepared subgrade

mixture to harden. The newly constructed base should be kept continuously moist (by lightly watering or misting) for a 3- to 7-day period, or a moisture-retaining cover or curing compound can be placed over the CTB soon after completion.

Sustainability

- In-situ or local marginal aggregates can be used in CTB. This will minimize the need to haul in costly select granular aggregates.
- Cement-treated base may require the use of industrial by-products such as fly ash.
- Recycled asphalt pavement mixed with cement makes an excellent CTB.
- Cement-treated base provides a stronger base than unbound granular material; therefore, for the same load-carrying capacity, less material is required.
- Hauling less material reduces the number of trucks and possible damage to surrounding roads, resulting in fuel savings, lower emissions, and premature future roadway maintenance.

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Full-Depth Reclamation with Cement (FDR)

Objectives

- Provide a strong, uniform base/subbase for current and future loading conditions using existing failed asphalt surface and base material.
- Maintain existing grade with minimum material removal or addition.
- Reduce or totally eliminate the need for virgin aggregates.
- Reduce stresses on the subgrade.
- Reduce rutting and deflections in a flexible pavement surface.
- Improve the structural capacity of stabilized base over unstabilized base material.
- Provide pavement reconstruction method that is fast and minimizes traffic disruption.
- Provide a sustainable option.

Solution

- Full-depth reclamation with cement to recycle and reuse the existing pavement material ecycle and reuse the existing pavement material.

Benefits

- The performance of the base layer is improved over an unbound granular base.
- Little, if any, material is hauled off or onto the site, resulting in less truck traffic, lower emissions, and less damage to local roads. Work can be completed quickly compared to removal and replacement techniques.
- Full-depth reclamation process is economical compared to removal and replacement and thick overlays.

Considerations

- The potential for reflective cracking and increased friction between the FDR and surface pavement needs to be considered.
- Underground utilities need to be considered during the design and construction phase.

Typical Applications

Recycled materials and recycling techniques are used in highway, street and local road, commercial/lightweight industrial, airfield, and heavy industrial applications.

Description

Highways

Streets & Local Roads

Commercial / Lightweight

Airfields

Heavy Industrial

Full-depth reclamation with cement is a technique in which an existing HMA pavement and base material is reclaimed (pulverized as necessary), combined with portland cement, and then recompacted to create a new and improved base. The FDR base is then topped with a new HMA or concrete surface layer.

Full-depth reclamation is appropriate under the following conditions:

- The pavement is damaged and cannot be rehabilitated with simple resurfacing methods.
- The existing pavement distress indicates that a problem likely exists in the surface, base, and/or subgrade.
- The existing pavement distress would otherwise require full-depth patching over more than 15–20 percent of the surface area.
- The pavement structure is inadequate for the current or future traffic.

Materials

Materials used for FDR include the existing HMA surface that has been pulverized and blended with the underlying base, subbase, and/or subgrade, cement, and water. Laboratory testing and trial mixes allow selecting the best proportions of cement for the job. The amount of water and cement required in the mix will depend upon the project-specified strength and gradation of the final blend obtained from pulverizing the HMA during construction and mixing it with the base material. Typical specifications for pulverizing call for a minimum of 100 percent passing the 3-in. (75-mm) sieve, 95 percent passing the 2-in. (50-mm) sieve, and 55 percent passing the No. 4 (4.75-mm) sieve. In general, a cement content that provides a seven-day unconfined compressive strength between 300 to 400 psi (2.1 to 2.8 MPa) is satisfactory for most FDR applications.

Design

Full-depth reclamation design is a process that involves (1) determining the type of existing pavement layers and their respective thicknesses, and (2) identifying which material will be combined with cement in order to create a stable base for a new pavement structure. The thickness design is similar to a CTB and is calculated based on strength of the material, strength and stiffness characterizations of additional layers, anticipated loads, and performance requirements (i.e., life, serviceability, reliability). The AASHTO procedure for pavement design or PCA thickness design procedure can be used. Typical thickness values for FDR range from 6 to 12 in. (150 to 300 mm).

Construction

Full-depth reclamation requires a reclaimer mixer, grader, cement spreader, water truck, and roller. A reclaimer machine typically makes an initial pass over the existing flexible pavement, pulverizing the HMA surface and blending it with the base and/or subgrade material (see Figure 7-1 and Figure 7-2). Water may be added during this mixing stage to bring the material up to optimum moisture content. The material is then graded accordingly. Next, cement is spread either dry or in slurry form in a controlled manner onto the surface (see Figure 7-3 and Figure 7-4). The reclaimer then mixes the cement into the pulverized material.

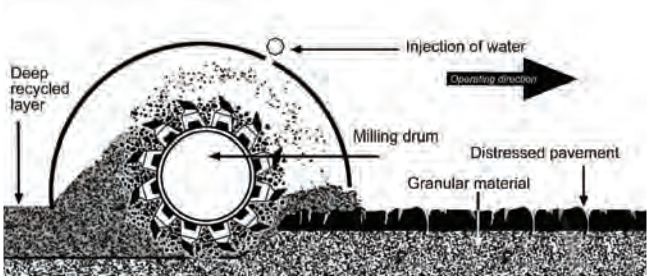

Figure 7-1. Schematic of the mixing chamber of a reclaimer machine

Figure 7-2 Reclaimer pulverizing existing asphalt pavement and base material

Mixing continues until the material is thoroughly mixed. This is followed by compaction, final grading, curing, and surfacing. Smooth-wheeled rollers are used for compaction. The FDR should be cured for from three to seven days. Surface treatments include chip seals, HMA, or concrete. The whole process can be performed under traffic (see Figure 7-5). Figure 7-6 shows the equipment used for compaction and finishing.

Sustainability

- Existing materials are reused, reducing the exploitation of virgin material.
- Damage is reduced to surrounding roads from hauling existing base materials out and bringing virgin materials in.
- Costs related to the processing, purchasing, and transportation of virgin aggregates are minimized.
- Truck traffic is reduced, resulting in fuel savings and lower emissions.

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Figure 7-3. Dry cement placed on pulverized material

Figure 7-4. Applying cement slurry on grade prior to mixing (cement slurry is applied the same way for CTB applications)

Figure 7-5. Mixing the cement into the pulverized material

Figure 7-6. Equipment for compaction and finishing

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Cement-Modified Soils (CMS)

Objectives

- Reduce the plasticity and high-volume change characteristics of clay soils due to moisture variations.
- Improve stability of a poorly graded sandy soil. Improve the properties of a sandy soil containing a high-plasticity clay.
- Provide a method to dry out a wet subgrade.
- Provide a firm construction platform to work on.
- Provide a sustainable option.

Solution

- Add a small amount of cement to the soil to create a cement-modified soil.

Benefits

- Cement-modified soils provide a weather-resistant work platform for construction operations.
- Fatigue failures caused by repeated high deflections are controlled.
- There is a reduction in moisture sensitivity and subgrade seasonal load restrictions.
- No mellowing period is needed as required by other stabilizing agents.

Considerations

- Cement-modified soils are not intended to withstand the same CTB durability and compressive strength requirements.

Typical Applications

Cement-modified granular soils can be used as a treated subgrade and working platform beneath a base or subbase.

Highways

Streets & Local Roads

Shoulders

Commercial / Lightweight

Airfields

Heavy Industrial

Description

Cement-modified soils are soils and/or manufactured aggregates mixed with a small proportion of portland cement. By combining small amounts of cement with soils, plasticity is reduced, volumetric changes due to moisture content are minimized, bearing strength is increased, and stability is improved. As a result, a weather-resistant work platform for construction operations and a stronger, permanent pavement layer for enhanced support and capacity can be constructed.

Cement-modified soils are normally used to improve material properties in the subgrade. They can eliminate the need for extensive removal and replacement of existing soils, saving considerable time and money. The most common application of CMS is as an option for subgrade material when existing or available soils are of poor quality (see Figure 8-1).

The primary difference between CMS and CTB is that CTB typically contains more cement and is required to meet certain strength values per specifications and to serve as a durable, freeze-thaw resistant material. Cement-modified soils typically do not have to meet the same requirements for strength and durability; instead, small amounts of cement are added to mitigate expansion due to moisture variations and improve cohesion caused by poor soils. An additional benefit is an improvement in strength and stiffness.

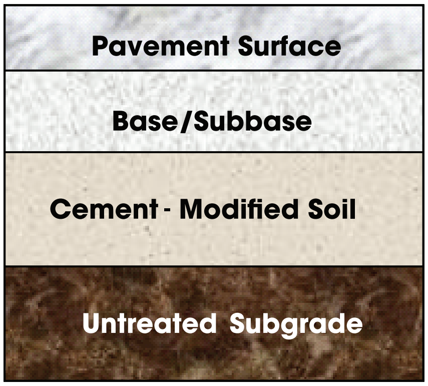

Figure 8-1. Typical cross-section with CMS

Materials

Cement-modified soils are principally used to modify fine-grained soils such as silts and clays and granular soils having a high plasticity and/or fine content. Cement content for each is typically based on identifying the appropriate amount necessary to meet specifications.

Most CMS involves high plasticity soils such as clays. Specifications will often require enough cement content to reduce the plasticity index (PI) to within a range of 12 to 15. Typically, a cement content of 3 to 4 percent will reduce the PI sufficiently and increase the California bearing ratio (CBR) and resistance values. The cement-modified soil should provide a firm foundation for compaction of the base/subbase layer above it.

Design

The design of a CMS layer focuses on creating a working platform for the construction of base/subbase and, subsequently, the surface layer. The CMS layer, however, does not contribute appreciably to the structural capacity of the pavement. According to most state and/or job-specific specifications, a CMS layer is designed to meet certain Atterberg limit requirements as determined by proper laboratory testing methods. Cement-modified soils are typically not designed to meet a compressive strength requirement, but rather designed to meet reduced plasticity requirements and increased CBR values. The design will vary, depending on existing soil properties. A common thickness of 6 in. (150 mm) has been shown to provide an adequate working platform for construction of base or subbase layers.

Construction

Cement-modified soils are produced in place using existing soils. Cement-modified soils construction consists of mixing the cement into the soil using mixed-in-place methods. However, because of the cohesiveness of the soil some additional effort may be required for the pulverization and mixing operations. Wet soils may require multiple mixing passes. If the soil is dry, pre-wetting and allowing the water to soak in may facilitate pulverization (see Figure 8-2). In contrast to normal CTB construction, the time limit between mixing and compacting is not as stringent,

Figure 8-2. Cement slurry added to subgrade material (cement slurry is applied the same way for CTB and FDR applications)

although all operations, including compaction, should be completed in the same day.

In general, in-place mixing and construction sequence follows these steps:

- For initial preparation, shape the area to crown and grade and correct any soft or unsuitable areas.
- If necessary, prewet dry soils to aid pulverization or dry back wet soils by aeration with disc harrow or rotary mixer with its hood open.
- Distribute cement in dry form with mechanical spreader or in slurry form from distributor truck.
- Mix with pulvermixer, adding water if necessary, until a homogeneous, friable mixture is obtained that will meet the specified pulverization requirements (see Figure 8-3).
- Compact with tamping (sheepsfoot) roller (see Figure 8-4).
- Complete surface compaction with a steel drum, pneumatic tire, or other appropriate type of roller.
- With grader, shape area to final crown and grade.
- Seal surface with pneumatic-tire roller.

Unlike cement-treated bases, CMS is often not cured. However, curing with a light water spray or bituminous coating will provide the maximum benefit from the cement.

Figure 8-3. Pulvermizer used for in-place mixing of CMS

Sustainability

- CMS reduces waste by allowing the use of existing material.
- In-situ marginal subgrade soils can be improved, minimizing the need to haul in costly select granular aggregates.
- CMS provides a stronger more stable subgrade, which may reduce the quantity of base material needed.

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Figure 8-4. Sheepsfoot roller used for compaction

Recycled Concrete Aggregates

Objectives

- Recycle excavated concrete pavement.
- Minimize construction cost.
- Reduce dependence on good quality virgin aggregates, which may be hard to find or expensive to bring in.
- Provide a sustainable option.

Solution

- Use old concrete as aggregates in new pavement layers.

Benefits

- Recycled concrete aggregates (RCA) are versatile because they can be used in any pavement layer.
- Material costs are reduced.
- Construction time can be expedited with on-site recycling plants.
- Pavement suffering from ASR or D-cracking can be recycled instead of discarded.
- The need for old concrete disposal is reduced.

Considerations

- If ASR or D-cracking exists in recycled pavement material, special attention must be given to mixture design.
- Recycled concrete aggregates in HMA may increase binder content requirements.
- Concrete mixture designs will have to be adjusted for strength.
- Additional quality control measures may be necessary to ensure concrete workability.

Typical Applications

Recycled concrete aggregates are used in highway, street and local road, shoulder, airfield, commercial/lightweight industrial, and heavy industrial applications.

Highways

Streets & Local Roads

Shoulders

Commercial / Lightweight

Airfields

Heavy Industrial

Description

Recycled concrete aggregates are aggregates produced from the recycling of existing concrete. Existing concrete is removed, processed into appropriate aggregate sizes, and reused in various pavement applications. The benefits of using RCA in pavements include reduced material costs, minimized use of depleting virgin aggregate sources, and decreased landfill content.

Recycled concrete aggregates are primarily used in bases and subbases. According to a 2008 Federal Highway Administration national review, 84 percent of states are recycling concrete aggregate. While most states use RCA as a base material, 22 percent use RCA as aggregate for new concrete pavements.

Recycled concrete aggregates are ideal for the bottom lift of a two-lift paving mixture design. Two-lift paving is a construction technique that involves placing a concrete surface layer in two consecutive lifts. The process is sometimes referred to as "wet-on-wet" because the top layer is placed immediately after the bottom layer, before the bottom layer hardens. The advantage to this kind of construction is that good quality aggregates are only required in the top lift, whereas aggregates such as RCA can then be used for the lower lift.

The quality of RCA is very dependent on the quality of the material from which it was processed. Old concrete pavement is broken down in-place, removed, and crushed to produce RCA. Recycled concrete aggregates produced from all but the poorest quality original concrete can be expected to pass the same tests required of virgin conventional aggregates.

Materials

Recycled concrete aggregates (see Figure 9-1) produced from concrete pavement recycling contains both the original aggregates and hydrated cement paste. Recycled concrete aggregates can be processed to exhibit properties that meet the same gradation requirements as virgin aggregates used for similar applications. Recycled concrete aggregates may improve early strength properties in some applications because of the continued hydration of exposed cement particles in the RCA. There are some material characteristics specific to RCA in some applications that should be understood and accounted for in either design or construction.

Figure 9-1. Recycled concrete aggregates

Concrete pavements containing RCA can result in increased porosity and absorption, higher coefficient of thermal expansion and shrinkage, lower strengths, and reduced specific gravity when compared to the use of only virgin aggregates. The chloride content of recycled aggregates should be investigated if the material will be used in reinforced concrete. To achieve the same workability, slump, and w/cm ratio as in conventional concrete, mixtures incorporating RCA typically require higher paste content and/or greater amounts of water reducer. In an HMA surface and asphalt-stabilized base and/or subbase layers, RCA can help to improve stability and friction but typically requires an increase in binder content.

As an aggregate in CTB layers, RCA requires no special consideration and performs similar to virgin aggregate. Recycled concrete aggregates can be more susceptible to abrasion. Therefore, when used as an aggregate in unbound base and/or subbase layers, the construction process should be adjusted as needed for proper handling.

Pavements suffering from ASR or D-cracking can be recycled, but special attention must be given to concrete mixture design. Supplementary cementitious materials that mitigate ASR must be incorporated into concrete mixture designs when ASR-distressed RCA is used. D-cracked RCA must be processed to proper aggregate sizes for the prevention of further D-cracking distress.

When designed and constructed appropriately, pavements built with recycled materials can be durable. The key is to design a mixture with proper material proportions for the intended application.

Design

It is common to combine RCA with virgin aggregate in mixtures for new concrete or HMA surface layers. In concrete surface applications, up to 30 percent of natural crushed coarse aggregate can be replaced with coarse RCA without significantly affecting any of the mechanical properties of the concrete. As replacement amounts increase, drying shrinkage and creep will increase and tensile strength and modulus of elasticity will decrease; however, compressive strength and freeze-thaw resistance are not significantly affected. Special care is necessary when using fine RCA in concrete mixtures. Only a maximum of 10 to 20 percent fine RCA has been shown to be beneficial. Recycled concrete aggregates content in HMA surface layers is not limited if the mixture design properties adhere to all specified performance requirements (e.g., abrasion).

Recycled concrete aggregates content for base and subbase applications is not as strict. In general, a well-graded RCA can result in a very stable subbase, and RCA content in CTB should be such that it still meets all performance requirements.

Construction

The steps required for the RCA production process are crushing and removing existing pavement material, removing any reinforcement and/or other contaminants, and processing the reclaimed material down to appropriate aggregate sizes. In general, equipment used for RCA production includes the following:

- Hand-operated or vehicle-mounted crushing devices (e.g., hand-held tools, drop hammers/blades, impact breakers/hammers, etc.) (see Figure 9-2)
- A backhoe or bulldozer with a rhino horn attachment for loosening the crushed material from the layer beneath it and any reinforcement
- Front-end loaders or dump trucks for transporting (see Figure 9-3)
- A recycling plant that can be stationary, portable, or mobile

Figure 9-4 shows existing concrete recycled in-place and reused for base material.

When used in new concrete, it is recommended that RCA be prewetted and close to a saturated surface dry

Figure 9-2. Example of equipment used to break existing concrete

Figure 9-3. Broken concrete pavement is removed for recycling

Figure 9-4. Existing concrete recycled in-place and reused for base material on the Tri-State Tollway in Illinois

condition before batching. Additional quality control measures may be necessary to ensure good moisture control. Concrete and HMA mixtures containing RCA can be transported, placed, and compacted in the same manner as conventional mixtures.

The construction of CTB and unbound base/subbase layers follows typical standard procedures. If RCA is used in what is intended to be a drainable base or subbase layer, it is advised that handling (i.e., shaping) the material is kept to a minimum; the tendency for fine particulates to break off from the surface of the RCA is increased, otherwise.

In a drainable layer, increased fines decrease the ability for water to escape out of the layer. It is also recommended that RCA base and subbase drainage layers are daylighted for this reason.

Recycled concrete aggregates used in unbound base and/or subbase layers can contain very small percentages of contaminants (such as HMA binder) without adversely affecting performance.

Sustainability

- Existing materials are reused, reducing the exploitation of virgin material and minimizing landfill material.
- Costs related to the processing, purchasing, and transportation of virgin aggregates are minimized.
- In-place recycling reduces truck traffic and fuel consumption, and also reduces local road damage from haul trucks.
- Using RCA, particularly in applications that expose it to the atmosphere (e.g., embankment fill, gravel roads, and railroad ballast), results in a process called carbon sequestering. The process essentially recaptures CO_2 from the atmosphere.

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10

Repair and Restoration

Description

The repair and restoration of concrete pavements are tasks conducted to improve a distressed pavement by restoring both function and structural capacity. The various techniques that fall into this category can be conducted one or more times during the life of the pavement. The type of repair depends on the condition of the pavement at the time. Quite often, prompt repairs are more effective and less expensive than delayed repairs or rehabilitation. The following summarizes some of the more common repairs and rehabilitation techniques used on concrete pavements in order to extend performance.

Full-Depth Repairs

Full-depth repairs are used to address an area of major distress in a pavement. This could be a localized event or extended throughout the pavement section.

A full-depth repair can provide good long-term performance (more than 10 to 15 years) if the quality of the repair is good and the right materials are used.

In concrete pavements, full-depth repairs most often consist of cast-in-place concrete that replaces the full depth of the existing slab. Figure 10-1 shows the process for full-depth repair of a JPCP panel (from top to bottom): identify candidate slabs, remove existing pavement, and replace with new concrete.

A similar technique is used for jointed pavements, where part or all of a slab panel can be replaced with the joint reinforcement being replaced at the same time.

Figure10-1. Full-depth repair of a concrete pavement slab

Partial-Depth Repairs

A partial-depth repair consists of the removal and replacement of small, shallow areas of deteriorated concrete pavement at spalled or distressed joints. For a partial-depth repair to be practical, the distress typically had not extended deeper than one-third of the depth of the slab. However, due to the recent availability of joint milling machines as a "U" mill, partial depth repairs have extended to T/2. The load transfer devices, if present, should be fully functional. Figure 10-2 shows a pavement showing spalling. Spalling can cause ride and noise problems for the traveling public, and thus partial-depth repairs can remedy functional performance. A partial-depth repair begins with the removal of distressed concrete by sawing, chipping, and/or milling until sound concrete is exposed. Repair material is then applied and the surface texture restored. Finally, curing should be conducted per the recommendations specific for the patch material used.

Figure10-2. Partial-depth repair process at joint

Stitching

Stitching is a repair method for restoring load transfer at longitudinal cracks (see Figure 10-3). This type of repair is an option when slabs are not severely distressed. Holes are drilled at a diagonal from one side of the crack to the other. The angle of the diagonal should be consistent and measure between 35 and 45 degrees. Epoxy followed by a tie bar fill the hole. The tie bar should pass through the crack at mid-depth. It is important not to damage the surface of the concrete while performing this type of repair. Surface damage can be avoided by choosing appropriate drilling equipment such as a hydraulic-powered drill and a bit that is 0.375 in. (10 mm) greater than the diameter of the tie bar that will be inserted. The size of the tie bar depends on slab thickness, angle of hole, and hole's distance from the crack.

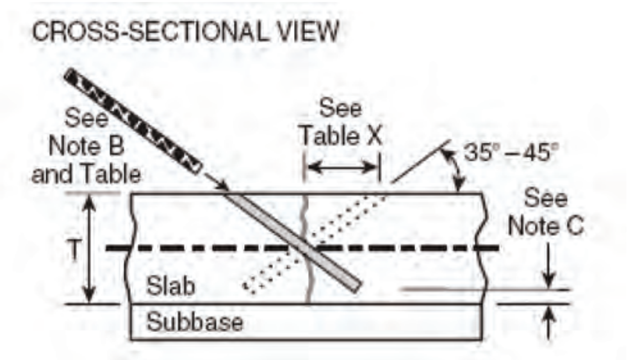

Figure 10-3. Cross-section of concrete pavement showing stitching

Slab Stabilization

Slab stabilization is a repair technique for concrete pavement in which a flowable material is inserted beneath the pavement slabs in order to restore their support. During the process, voids are filled that lie between the slab and the supporting layer. These are often caused by water infiltration and subsequent pumping of fines to the surface. Voids weaken the structure and without repair can lead to breaking up of the slabs due to traffic loads. The material that is inserted should fill the voids but should not lift the slab.

Slab stabilization restores slab support, reduces pavement deflections, and minimizes the progression of further distress. The success of the repair depends, in part, on identifying the areas with loss of support. Furthermore, the injection of material under the slab must be performed in such a way that the void is adequately filled, which encourages the use of an experienced contractor. Figure 10-4 shows typical tasks during a slab stabilization repair, where holes are drilled into the concrete slab, which is then filled with grout material.

Slab Jacking

Slab jacking is a repair procedure in which a concrete pavement slab is raised by applying pressurized grout beneath the slab. Slab jacking is used to fix localized spots of settlement often found near fill areas, culverts, and bridge approaches. When done properly, this technique can restore the ride quality of a pavement, although it does not correct faulted joints. The grout mixture or polyurethane used in the repair should be certified for this purpose. The procedure is similar to slab stabilization in that the locations should first be carefully identified. Holes are drilled, and a pumping sequence is identified to achieve the desired effect. Material is then injected—in sequence—so that the slab is raised no more than 0.25 in. (6 mm). This process continues until the slab reaches the desired grade. Success in slab jacking is more likely when performed on structurally sound pavement with localized depressions. A proven process and durable materials should be used.

Figure 10-4. Drilling operation as part of slab stabilization

Joint Resealing

Joint resealing consists of placing a sealing material in an existing joint or crack to reduce moisture infiltration and minimize intrusion of incompressibles. When cracks and joints are not properly sealed, water can sometimes infiltrate and saturate the lower layers of the pavement. This, in turn, can cause various pavement distresses. Sealing material is typically a liquid (hot or cold) but can also be an expansion joint filler (preformed). The joint design typically dictates the type of sealant to be used. The desired properties of the sealant are durability to traffic and environment, extensibility that allows joint/crack movement without rupture, and adhesiveness that permits adherence to the crack or joint walls. A joint resealing procedure follows five basic steps: old sealant removal, joint refacing, joint reservoir cleaning, backer rod installation, and new sealant installation. The key factors for the success of this repair are the proper selection of joints/cracks, selection of sealing material, restoration of the joint reservoir and shape factor, reservoir preparation, and proper sealant application. Figure 10-5 shows the application of joint sealant.

Dowel Bar Retrofit

Load transfer across transverse joints has always been a factor contributing to the life of a concrete pavement. Steel dowels are often used to ensure load transfer. However, problems can sometimes arise over time, including corrosion and high bearing stresses that can erode the surrounding concrete. On older concrete pavements, or those that were designed for lower traffic, load transfer may be provided by aggregate interlock only. Over time, the loss of load transfer can manifest itself into joint faulting and slab cracking and thus should be remedied.

Load transfer restoration is defined as the installation of mechanical devices in an existing pavement. Along

Figure 10-5. Application of joint sealant

transverse joints, the load transfer is usually accomplished by installing dowel bars. To define whether or not load transfer is adequate, a falling weight deflectometer can be used to assess the load transfer efficiency. A good candidate for repair is a pavement in good structural condition but with poor load transfer (less than 50 to 60 percent). Pavements with faulting between 0.12 and 0.5 in. (3 and 13 mm) are also good candidates, as are those with less than 10 percent of slabs with multiple cracks.

Dowel bar retrofit begins with slotting, typically by sawing and chipping. The joint is prepared and the dowel bar affixed to a joint insert. The repair material is then placed and cured as needed. Quite often, diamond grinding can be conducted after all dowel bar retrofits are complete. Figure 10-6 displays a concrete pavement where slots have been cut and cleaned to retrofit dowel bars. Note that retrofitting is often done in the wheel paths only.

Diamond Grooving and Grinding

Diamond grooving and grinding are surface treatments performed to improve the functional characteristics of a pavement. Diamond grinding consists of removing a very thin layer of the surface using a set of closely spaced diamond saw blades. The result of this technique includes improvements to smoothness, friction, and noise. Grinding is recommended when the pavement is structurally sound, and before conducting this repair the hardness of the concrete aggregate should be determined so that the diamond blades are selected, sized, and spaced accordingly. The need for

Figure 10-6. Contiguous concrete slabs prepared for dowel bar retrofitting

Figure 10-7 Diamond grinding concrete pavement for surface restoration

associated treatments (e.g., load transfer restoration) should also be considered prior to this treatment. Figure 10-7 displays the typical appearance of a concrete pavement that has been diamond ground.

Diamond grooving is usually done to minimize the hydroplaning effect in a pavement. Channels are grooved onto the surface to accomplish this goal. Diamond saw blades are used to cut these parallel grooves in either longitudinal (more common) or transverse patterns. Other benefits of this repair are improved wet weather friction and the reduction in splash and spray when the pavement is wet.

Candidate pavements for diamond grooving are often based on historical crash rates. This surface treatment is generally performed at localized areas and on pavements that are structurally sound. The success of this repair depends on the selection of proper candidate projects and the proper selection of groove dimensions.

Figure 10-8 illustrates a concrete pavement where diamond grooving is being performed. In this case, the grooving pattern is longitudinal.

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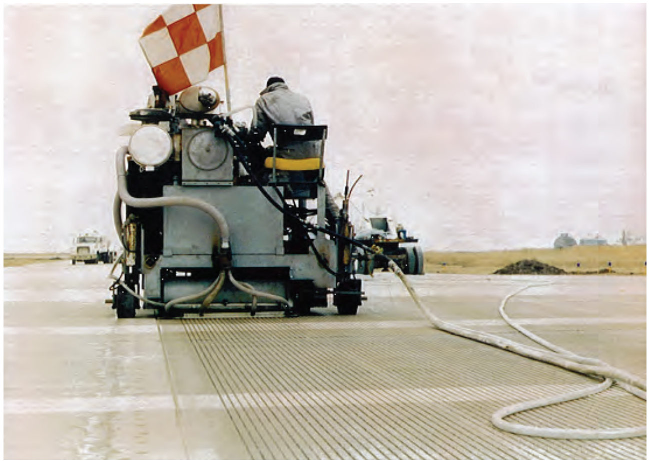

Figure 10-8. Longitudinal grooving of a concrete pavement to restore macrotexture

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