PORTLAND CEMENT CONCRETE (PCC) SURFACINGS

CELLULAR PCC

GENERAL INFORMATION

Generic Name(s): Cellular Portland Cement Concrete, Flexible Portland Cement Concrete, Concrete Infilled Geocells

Trade Names: Geoweb, Hyson Cells

Product Description: Cellular portland cement concrete (PCC) consists of a geosynthetic, honeycomb-like, cellular confinement system (geocells) that is filled with PCC. Once constructed, the cellular mat is composed of numerous individual concrete blocks. The confinement system is designed such that there is a high degree of interlock between adjacent concrete blocks. The geosynthetic acts as reinforcement for the system so there is no need for steel reinforcement. The resulting product is a flexible surfacing that can support heavy loads. The surfacing can be constructed with a thickness of 100 to 200 mm (4 to 8 in.). Individual cell sizes range from 150 mm x 150 mm (6 in. x 6 in.) to 500 mm x 500 mm (20 in. x 20 in.). Cellular PCC has been used for heavy duty roads as well as boat ramps and low water crossings. Because the constructed mat is flexible, it can be constructed off-site and installed at a later time using heavy-lifting equipment.

High slump ready mix concrete must be used. Plasticizers and retarders are often used to facilitate construction. The cellular confinement system includes polymer tendons that are used to support the geosynthetic until the PCC can be placed. Anchors are also used to hold the geosynthetic down before and during concrete placement; if not anchored properly, the geosynthetic can "float" on the PCC as it is placed.

Product Suppliers: GeoProducts, LLC, 8615 Golden Spike Lane, Houston, TX 77086, (281) 820-5493, www.geoproducts.org; and

Presto Products Company, P.O. Box 2399, Appleton, WI 54912-2399, (800) 548-3424, www.prestogeo.com.

Representative product suppliers and trade names are provided for informational purposes only. Inclusion of this information is not an endorsement of any product or company. Additional suppliers and geocell products are available.

APPLICATION

Typical Use: Road surfacing, channel erosion protection.

Traffic Range: Very Low to Medium.

Restrictions:

Traffic: Cellular PCC is suitable for heavy duty road applications.

Climate: None.

Weather: None.

Terrain: None.

Soil Type: N/A

Other: None.

Other Comments: None.

DESIGN

SLC: 0.25 to 0.30.

Other Design Values: Stiffness of cellular PCC mats can range from 100 to 1500 MPa (14,500 to 218,000 psi), depending on the slab thickness and level of subgrade support.

Base/Subbase Requirements: Roadway should be designed with adequate base and/or subbase support. For low volume applications, cellular PCC can be constructed directly on the subgrade unless heavy loads dictate the need for greater base support. Subgrade and base materials should be compacted and graded to provide a uniform working platform prior to geocell placement.

Other Comments: Cellular PCC can be constructed with a thickness of 100 to 200 mm (4 to 8 in.). PCC should generally have a compressive strength greater than 30 MPa (4300 psi).

CONSTRUCTION

Availability of Experienced Personnel: Cellular PCC is not a commonly used surfacing, so availability of experienced contractors may be limited.

Materials: The pre-fabricated cellular confinement system and PCC are required for cellular PCC construction.

Equipment: Equipment required for cellular PCC construction includes: concrete mixing trucks for hauling PCC and concrete finishing equipment. Equipment requirements are minimal and equipment is widely available.

Manufacturing/Mixing Process: PCC can be mixed at a central mix plant and hauled to the site or a mobile concrete batching plant can be set up on site.

Placement Process: The geocell sections are placed on the prepared subgrade/base, stretched out to their design length, and staked to hold the sections in place. Adjacent geocell sections are laid out and connected with adjoining sections. Once the geocell sections are in place, the geocells are infilled with ready mix PCC. The PCC should have a high plasticity to prevent the concrete from collapsing the cellular confinement system and to improve workability. Plasticizers and retarders are recommended. As an alternative, the geocells can be infilled with a uniformly graded aggregate and injected with cement grout. The geocell sections should be overfilled by 25 to 50 mm (1 to 2 in.). The surface is then finished by hand or machine, similar to conventional PCC.

Cellular PCC mats can be constructed off-site and hauled to the site for placement. In this case, heavy lifting equipment is required to place the cellular PCC mats.

Weather Restrictions: Do not place PCC if it is raining or if temperatures are near or below freezing. The Cellular PCC needs to be protected from freezing during the initial curing period (4 to 7 days). Do not place PCC on frozen base/subgrade soils. Special precautions are necessary if PCC is placed when temperatures are above about 35 ºC (94 ºF) or during high winds (rapid evaporation).

Construction Rate: Cellular PCC construction rates are in the range of 200 to 400 m^2/day (240 to 480 yd^2/day).

Lane Closure Requirements: The roadway lane should be closed during construction. Normal traffic loads can be allowed on the cellular PCC surface after initial curing and once an adequate PCC strength is reached, typically after 7 days. High strength PCC can be used to achieve design concrete strengths faster, so the road surfacing can be opened to traffic sooner. Cellular PCC can often be opened to light traffic after one day.

Other Comments: Construction defects are difficult to repair. For example, if the cellular confinement system collapses during concrete placement, it cannot be fixed; the area must be cleared and completely rebuilt.

SERVICEABILITY

Reliability and Performance History: Geocells were developed by the U.S. Army Corps of Engineers in the late 1970s. Cellular PCC has been used on projects where it will be used by occasional traffic, but it is not a commonly used road surfacing material. Research, design and construction information, and project experience are limited.

Life Expectancy: Life expectancy varies depending on traffic, subgrade support, and weather conditions. Typical design life for cellular PCC is 20 years.

Ride Quality: Cellular PCC with good base support can provide good ride quality. Ride quality deteriorates over the serviceable life.

Main Distress / Failure Modes: Faulting, depressions, spalling.

Preservation Needs: Cellular PCC generally requires little maintenance. Periodic crack sealing and patching may be required.

SAFETY

Hazards: None.

Skid Resistance: When high quality aggregates are used, cellular PCC provides good initial skid resistance. When lower quality aggregates are used, polishing of the PCC aggregates at the surface can reduce the skid resistance over time. Surface grinding or texturing can be used to increase the skid resistance of the cellular PCC.

Road Striping Possible?: Yes.

Other Comments: Surface texturing can be used to increase the skid resistance of cellular PCC. The type, spacing, width, and depth of the texturing affects skid resistance and tire/road noise. Numerous surface texturing options are available, including drag textures (broom, artificial turf, burlap), tine textures (transverse, longitudinal), exposed aggregate textures, and hardened concrete textures (diamond ground, diamond groove, abraded). For local roads where hydroplaning is not a primary concern, burlap or broom textures are commonly used.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: Geocells are manufactured from polyethylene. PCC is constructed of coarse and fine aggregates, portland cement, water, and chemical admixtures. Aggregates may be naturally occurring or quarried, but either requires mechanical processing (crushing, sizing) before they can be used. Fly ash, ground blast furnace slag, and silica fume, which are waste by-products, are sometimes included in the concrete mixture.

Portland cement is manufactured from limestone through a very energy intensive process. In addition to significant energy consumption during the manufacturing process, portland cement manufacturing produces large amounts of carbon dioxide (CO_2); various reports claim that cement manufacturing is responsible for 2% to 7% of CO_2 produced by humans.

Delivery and Haul Requirements: Geocells must be transported to the site from the distributor. Geocell sections collapse into a compact configuration to minimize the haul space required. Haul distances may be significant for remote sites. PCC must be hauled from the ready mix plant unless it is mixed on site, in which case the PCC mix components must be hauled to the site.

Potential Short-Term Construction Impacts: Construction process can damage vegetation adjacent to the road. Wash water from concrete equipment can damage vegetation and water quality; settling basins or designated wash out pits should be utilized to collect and contain the wash water.

Potential Long-Term Environmental Impacts:

Leachate: None.

Surface Runoff: Cellular PCC is impermeable, which promotes surface runoff. However, surface runoff water quality is not generally impacted by cellular PCC.

Erosion: None.

Water quality: None.

Aquatic species: None.

Plant quality: None.

Air Quality: None.

Other: None.

Ability to Recycle/Reuse: Cellular PCC cannot be economically recycled or reused.

Other Environmental Considerations: None.

AESTHETICS

Appearance: Cellular PCC has the general appearance of conventional PCC. The surface is normally light gray with a relatively smooth texture. The surface can be textured and/or colored to modify the surface appearance. The geosynthetic cellular support system is not visible in the completed surface.

Appearance Degradation Over Time: Cellular PCC will maintain its general appearance throughout its service life.

COST

Supply Price: N/A

Supply+Install Price: \$16.00 to \$20.00/m^2 (\$13.40 to \$16.70/yd^2).

EXAMPLE PROJECTS

Tesson Creek, Concord Village, MO.

SELECT RESOURCES

Visser, A.T., and Hall, S. (1999). "Flexible Portland Cement Concrete Pavement for Low-Volume Roads," *Transportation Research Record 1652*, TRB, National Research Council, Washington, D.C., pp. 121-127.

PORTLAND CEMENT CONCRETE PAVEMENT (PCCP)

GENERAL INFORMATION

Generic Name(s): Portland Cement Concrete Pavement (PCCP), Portland Cement Concrete (PCC), Concrete

Trade Names: N/A

Product Description: Portland cement concrete pavement (PCCP) is a mixture of aggregate, cementitious material, and water that forms a rigid, paved surfacing. Additives are used to help with production and paving and to improve durability. Typical additives include air entraining admixture, water reducing agents, and supplementary cementitious materials (e.g. fly ash, ground blast furnace slag, silica fume, and calcinated clay). Concrete pavements are designed and constructed as plain concrete, plain concrete with dowelled joints, or as continuously reinforced. PCCP have very good performance characteristics with respect to strength, durability, and ride quality.

Product Suppliers: Representative list of manufacturers, suppliers, and contractors can be obtained from: American Concrete Pavement Association, 5420 Old Orchard Road, Suite A-100, Skokie, IL, 60077-1059, (847) 966-2272, www.pavement.com.

APPLICATION

Typical Use: Road structure and surfacing.

Traffic Range: Very Low to High.

Restrictions:

Traffic: None.

Climate: None.

Weather: None.

Terrain: None.

Soil Type: N/A

Other: None.

Other Comments: None.

DESIGN

SLC: N/A; Rigid pavements, such as PCCP, are not designed using AASHTO SLC. Instead, pavement thickness is determined based on the following factors: modulus of subgrade reaction (k), modulus of rupture for the concrete, load transfer between joints, traffic loading, and other factors, such as drainage and reliability. Concrete pavement designs can be performed using the 1998 Supplement to the 1993 AASHTO Guide for Design of Pavement Structures or using the thickness design guides available through the American Concrete Pavement Association.

Other Design Values: Typical PCC compressive strength is 20 to 50 MPa (2,900 to 7,250 psi). High strength concrete, with compressive strengths above 50 MPa (7,250 psi) is also available for special applications. Minimum specified PCC flexural strength is typically 4.1 MPa (600 psi); typical flexural strengths are 4.5 to 5.5 MPa (650 to 800 psi).

Base/Subbase Requirements: Subgrade and base materials should be compacted and graded to provide a stable working surface prior to PCCP placement. Base/subbase should consist of unbound or stabilized granular material with sufficient drainage characteristics. The base thickness should be a minimum of 100 mm (4 in.) Open graded base is frequently used as a drainage medium to prevent pumping at the joints.

Other Comments: A properly designed joint pattern is necessary to prevent random slab cracking, except for continously reinforced PCCP (CRCP). To provide better load transfer across slab joints, dowel bars should be specified, especially on high speed roads with heavy traffic loading.

CONSTRUCTION

Availability of Experienced Personnel: PCCP is a commonly used surfacing and experienced contractors are, in general, widely available. Availability may be limited for projects in remote areas.

Materials: Portland cement concrete (PCC) is a mixture of aggregate, cementitious material, water, and additives used to help with production and paving and to improve durability. Steel reinforcing bars are used for crack control of CRCP and dowels for transferring wheel loads between slabs.

Equipment: Equipment required for PCCP construction includes: concrete mixing trucks for hauling PCC, construction forms for roadway edges and construction joints, concrete paver, water truck, vibratory equipment, finishing equipment, and concrete saws (single or multiple gang). Continuous slip form concrete pavers are used on high productivity or larger projects. Equipment is widely available in most areas, but availability may be limited in remote areas.

Manufacturing/Mixing Process: PCC can be mixed at a central mix plant and hauled to the site or a mobile concrete batching plant can be set up on site.

Placement Process: The concrete mix is discharged from mixing trucks and placed using automatic screeds or hand troweled. On large projects, continuous slip form concrete pavers can be used; if automatic dowel inserters are used, they should be checked to ensure proper placement and functioning of the equipment. The concrete is consolidated with vibrators to increase density and reduce voids. Thermal expansion joints are constructed at predetermined intervals. The concrete should be cured in place for 4 to 7 days or until a minimum strength is achieved, depending on exposure conditions. To facilitate curing, curing compounds can be applied, wet burlap can be used, or insulated sheets in low ambient temperatures can be used. Control joints must be saw-cut/formed before the stress in the concrete exceeds the strength to minimize random cracking. The time available to saw/form joints varies depending on concrete mix properties and ambient weather conditions.

Weather Restrictions: Do not place PCC if it is raining or if temperatures are near or below freezing. The PCCP needs to be protected from freezing during the initial curing period (4 to 7 days or until adequate strength is achieved). Do not place PCC on frozen base/subgrade soils. Special precautions are necessary if PCC is placed when temperatures are above about 35 ºC (94 ºF) or during high winds (rapid evaporation).

Construction Rate: Typical PCCP construction rates can be up to 2,300 m^3/day (3,000 yd^3/day).

Lane Closure Requirements: The roadway lane(s) being constructed is closed during construction and curing, so adequate traffic control is needed. Normal traffic loads can be allowed on the PCCP surface after initial curing and once an adequate PCC strength is reached, typically after 7 or 14 days. High strength PCC can be used to achieve design concrete strengths faster, so the road surfacing can be opened to traffic sooner, as soon as eight hours after placement. Road surface striping may be performed after the lane is opened.

Other Comments: Water/cement ratios are critical components in successful PCCP construction projects and should be monitored closely. Construction defects are generally difficult to repair. Mix designs and trial mixes should be prepared in advance of construction.

SERVICEABILITY

Reliability and Performance History: PCCP is a very common roadway surfacing and has been used on roadway projects for more than 100 years; an extensive amount of research, design and construction information, and project experience is available.

Life Expectancy: Life expectancy varies depending on construction materials used, environmental conditions, and traffic volumes. Typical PCCP design life is 30 to 40 years.

Ride Quality: PCCP provides very good ride quality after construction. Ride quality deteriorates over the serviceable life, partially due to cracking and faulting at the PCCP joints.

Main Distress / Failure Modes: Cracking, faulting, spalling.

Preservation Needs: In general, PCCP require relatively little preventative maintenance. Jointed PCCP require periodic joint resealing. Depending on the type of sealant used, resealing may be required every 5 to 10 years. Surface grinding may be required to maintain good frictional characteristics and for improving ride quality.

SAFETY

Hazards: Adequate surface grading and surface texture are required to prevent ponding of water on the surface that can cause reduced traction due to hydroplaning and icing. Road splash/spray can reduce visibility during periods of higher traffic volume.

Skid Resistance: When high quality aggregates are used, PCCP provide very good initial skid resistance. The use of lower quality aggregates leads to aggregate polishing at the surface that can reduce the skid resistance over time. Surface grinding or texturing can be used to increase the skid resistance of the PCCP.

Road Striping Possible?: Yes.

Other Comments: Because PCCP provides a high-quality road surfacing, there is a tendency for higher road usage and speeding. PCCP surface texturing is often used to increase the skid resistance of PCCP and decrease the level of vehicle skidding and hydroplaning. The type, spacing, width, and depth of the texturing affects skid resistance and tire/road noise. Numerous surface texturing options are available, including drag textures (broom, artificial turf, burlap), tine textures (transverse, longitudinal), exposed aggregate textures, and hardened concrete textures (diamond ground, diamond groove, abraded). For local roads where hydroplaning is not a primary concern, burlap or broom textures are commonly used. For high speed applications, such as highways, transverse tine texturing is the most commonly used texturing. Transverse tining provides a good, durable, skid resistant surface, reduces road splash/spray, reduces headlight glare from wet surfaces, reduces hydroplaning potential, and facilitates surface drainage.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: PCCP is constructed of PCC, which contains coarse and fine aggregates, portland cement, water, and, sometimes, chemical admixtures. Aggregates may be naturally occurring or quarried, but either requires mechanical processing (crushing, sizing) before they can be used. Continuously reinforced PCCP contains reinforcing bars that are manufactured from steel. Fly ash, ground blast furnace slag, and silica fume, which are waste by-products, are sometimes included in the concrete mixture.

Portland cement is manufactured from limestone through a very energy intensive process. In addition to significant energy consumption during the manufacturing process, portland cement manufacturing produces large amounts of carbon dioxide (CO_2); various reports claim that cement manufacturing is responsible for 2% to 7% of CO_2 produced by humans.

Delivery and Haul Requirements: PCC must be hauled from the mixing plant. The mixing plant must be located near the site because a limited amount of time (i.e. 90 minutes or less) is available after mixing to deliver, place, and consolidate the PCC.

Potential Short-Term Construction Impacts: Construction processes may impact vegetation adjacent to the roadway. Wash water from concrete equipment can damage vegetation and water quality; settling basins or designated wash out pits should be utilized to collect and contain the wash water. Wet sludge from sawcutting operations also needs to be contained and disposed of properly.

Potential Long-Term Environmental Impacts:

Leachate: None.

Surface Runoff: PCCP is impermeable, which promotes surface runoff. However, surface runoff water quality is not generally impacted by PCCP.

Erosion: None.

Water quality: None.

Aquatic species: None.

Plant quality: None.

Air Quality: None.

Other: None.

Ability to Recycle/Reuse: PCCP can be crushed for use as an unbound or stabilized material. PCCP can also be rubblized in-place and covered with an overlay.

Other Environmental Considerations: Light-colored PCCP can be used to reduce surface heat reflectivity and roadway lighting needs. For PCCP, tire/road noise is typically moderate to high with a higher noise level than HACP. The potential for tire/road noise is increased for high speed roadways. The type of surface texturing can affect tire/road noise levels.

AESTHETICS

Appearance: PCCP typically has a smooth surface texture and light gray color. The appearance can be influenced by aggregate type and source, so visual aesthetics can be improved by using select aggregates, when available. Surface appearance can also be modified by using pigments or stains to color the concrete or finishing techniques to change the surface texture. Special treatments are available to remove some of the cement paste and expose the PCC aggregate.

Appearance Degradation Over Time: The PCCP surface will maintain its general appearance throughout its service life. Over time it is not uncommon for cracks to develop that will require crack sealing.

COST

Supply Price: \$120 to \$140/m^3 (\$90 to \$110/yd^3).

Supply+Install Price: \$130 to \$180/m^3 (\$100 to \$135/yd^3).

EXAMPLE PROJECTS

PCCP is used extensively throughout the United States.

SELECT RESOURCES

American Concrete Institute, (248) 848-3700, www.aci-int.org.
American Concrete Pavement Association, (847) 966-2272, www.pavement.com.
Portland Cement Association, (847) 966-6200, www.cement.org.

EXPOSED AGGREGATE PCCP

GENERAL INFORMATION

Generic Name(s): Exposed Aggregate Portland Cement Concrete Pavement (PCCP)

Trade Names: N/A

Product Description: Portland cement concrete (PCC) is a mixture of aggregate, cementitious material, and water that forms a rigid, paved surfacing. In the construction of exposed aggregate PCC, a thin layer of cement paste is removed from around the aggregate at the pavement surface, exposing a portion of the aggregate. Additives are used to help with production and paving and to improve durability. Typical additives include air entraining admixture, water reducing agents, and supplementary cementitious materials (e.g. fly ash, ground blast furnace slag, silica fume, and calcinated clay). Concrete pavements are designed and constructed as plain concrete, plain concrete with dowelled joints or as continuously reinforced. PCCP have very good performance characteristics with respect to strength, durability, and ride quality.

Product Suppliers: Representative list of manufacturers, suppliers, and contractors can be obtained from: American Concrete Pavement Association, 5420 Old Orchard Road, Suite A-100, Skokie, IL, 60077-1059, (847) 966-2272, www.pavement.com.

APPLICATION

Typical Use: Road structure and surfacing.

Traffic Range: Very Low to High.

Restrictions:

Traffic: None.

Climate: None.

Weather: None.

Terrain: None.

Soil Type: N/A

Other: None.

Other Comments: None.

DESIGN

SLC: N/A; Rigid pavements, such as PCCP, are not designed using AASHTO SLC. Instead, pavement thickness is determined based on the following factors: modulus of subgrade reaction (k), modulus of rupture for the concrete, load transfer between joints, traffic loading, and other factors, such as drainage and reliability. Concrete pavement designs can be performed using the 1998 Supplement to the 1993 AASHTO Guide for Design of Pavement Structures or using the thickness design guides available through the American Concrete Pavement Association..

Other Design Values: Typical PCC compressive strength is 20 to 50 MPa (2,900 to 7,250 psi). High strength concrete, with compressive strengths above 50 MPa (7,250 psi) is also available for special applications. Minimum specified PCC flexural strength is typically 4.1 MPa (600 psi); typical flexural strengths are 4.5 to 5.5 MPa (650 to 800 psi).

Base/Subbase Requirements: Subgrade and base materials should be compacted and graded to provide a stable working surface prior to PCCP placement. Base/subbase should consist of unbound or stabilized granular material with sufficient drainage characteristics. The base thickness should be a minimum of 100 mm (4 in.) Open graded base is frequently used as a drainage medium to prevent pumping at the joints.

Other Comments: A properly designed joint pattern is necessary to prevent random slab cracking, except for continously reinforced PCCP (CRCP). To provide better load transfer across slab joints, dowel bars should be specified, especially on high speed roads with heavy traffic loading.

CONSTRUCTION

Availability of Experienced Personnel: PCCP is a commonly used surfacing and experienced contractors are, in general, widely available. Availability may be limited for projects in remote areas.

Materials: PCC is a mixture of aggregate, cementitious material, water, and additives used to help with production and paving and to improve durability. Retarders are used to prepare the exposed aggregate surface. Steel reinforcing bars are used for crack control of CRCP and dowels for transferring wheel loads between slabs.

Equipment: Equipment required for PCCP construction includes: concrete mixing trucks for hauling PCC, construction forms for roadway edges and construction joints, concrete paver, water truck, vibratory equipment, finishing equipment, and concrete saws (single or multiple gang). Continuous slip form concrete pavers are used on high productivity or very large projects. Equipment is widely available in most areas, but availability may be limited in remote areas.

Manufacturing/Mixing Process: PCC can be mixed at a central mix plant and hauled to the site or a mobile concrete batching plant can be set up on site.

Placement Process: The concrete mix is discharged from mixing trucks and placed using automatic screeds or hand troweled. On large projects, continuous slip form concrete pavers can be used; if automatic dowel inserters are used, they should be checked to ensure proper placement and functioning of the equipment. The concrete is consolidated with vibrators to increase density and reduce voids. Thermal expansion joints are constructed at predetermined intervals. For exposed aggregate concrete pavements, a retarder is spread over the pavement surface while the PCC is still wet; once the underlying PCC hardens, the still wet cement paste at the pavement surface is brushed or washed away, exposing the aggregate at the pavement surface. Control joints must be saw-cut/formed before the stress in the concrete exceeds the strength to minimize random cracking. The time available to saw/form joints varies depending on concrete mix properties and ambient weather conditions.

Weather Restrictions: Do not place PCC if it is raining or if temperatures are near or below freezing. The PCCP needs to be protected from freezing during the initial curing period (4 to 7 days or until adequate strength is achieved). Do not place PCC on frozen base/subgrade soils. Special precautions are necessary if PCC is placed when temperatures are above about 35 ºC (94 ºF) or during high winds (rapid evaporation).

Construction Rate: Typical PCCP construction rates can be up to 2,300 m^3/day (3,000 yd^3/day).

Lane Closure Requirements: The roadway lane(s) being constructed is closed during construction and curing, so adequate traffic control is needed. Normal traffic loads can be allowed on the PCCP surface after initial curing and once an adequate PCC strength is reached, typically after 7 or 14 days. High strength PCC can be used to achieve design concrete strengths faster, so the road surfacing can be opened to traffic sooner, as soon as eight hours after placement. Road surface striping may be performed after the lane is opened.

Other Comments: Water/cement ratios are critical components in successful PCCP construction projects and should be monitored closely. Construction defects are generally difficult to repair. Mix designs and trial mixes should be prepared in advance of construction.

SERVICEABILITY

Reliability and Performance History: PCCP is a very common roadway surfacing and has been used on roadway projects for more than 100 years; an extensive amount of research, design and construction information, and project experience is available. Exposed aggregate PCCP is less common, but information is available.

Life Expectancy: Life expectancy varies depending on construction materials used, environmental conditions, and traffic volumes. Typical PCCP design life is 30 to 40 years.

Ride Quality: PCCP provides very good ride quality after construction. Ride quality deteriorates over the serviceable life, partially due to cracking and faulting at the PCCP joints.

Main Distress / Failure Modes: Cracking, faulting, popouts, spalling

Preservation Needs: In general, PCCP require relatively little preventative maintenance. Jointed PCCP require periodic joint resealing. Depending on the type of sealant used, resealing may be required every 5 to 10 years. Surface grinding may be required to maintain good frictional characteristics and for improving ride quality.

SAFETY

Hazards: Adequate surface grading and surface texture are required to prevent ponding of water on the surface that can cause reduced traction due to hydroplaning and icing. Road splash/spray can reduce visibility during periods of higher traffic volume.

Skid Resistance: When high quality aggregates are used, PCCP provide very good initial skid resistance. The use of lower quality aggregates leads to aggregate polishing at the surface that can reduce the skid resistance over time.

Road Striping Possible?: Yes.

Other Comments: Because PCCP provides a high-quality road surfacing, there is a tendency for higher road usage and speeding. PCCP surface texturing is often used to increase the skid resistance of PCCP and decrease the level of vehicle skidding and hydroplaning. The type, spacing, width, and depth of the texturing affects skid resistance and tire/road noise.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: PCCP is constructed of PCC, which contains coarse and fine aggregates, portland cement, water, and, sometimes, chemical admixtures. Aggregates may be naturally occurring or quarried, but either requires mechanical processing (crushing, sizing) before they can be used. Reinforced PCCP contains reinforcing bars that are manufactured from steel. Fly ash, ground blast furnace slag, and silica fume, which are waste by-products, are sometimes included in the concrete mixture.

Portland cement is manufactured from limestone through a very energy intensive process. In addition to significant energy consumption during the manufacturing process, portland cement manufacturing produces large amounts of carbon dioxide (CO_2); various reports claim that cement manufacturing is responsible for 2% to 7% of CO_2 produced by humans.

Delivery and Haul Requirements: PCC must be hauled from the mixing plant. The mixing plant must be located near the site because a limited amount of time (i.e. 90 minutes or less) is available after mixing to deliver, place, and consolidate the PCC.

Potential Short-Term Construction Impacts: Construction processes may impact vegetation adjacent to the roadway. Wash water from concrete equipment can damage vegetation and water quality; settling basins or designated wash out pits should be utilized to collect and contain the wash water. Wet sludge from sawcutting operations and brushing the pavement surface also needs to be contained and disposed of properly.

Potential Long-Term Environmental Impacts:

Leachate: None.

Surface Runoff: PCCP is impermeable, which promotes surface runoff. However, surface runoff water quality is not generally impacted by PCCP.

Erosion: None.

Water quality: None.

Aquatic species: None.

Plant quality: None.

Air Quality: None.

Other: None.

Ability to Recycle/Reuse: PCCP can be crushed for use as an unbound or stabilized material. PCCP can also be rubblized in-place and covered with an overlay.

Other Environmental Considerations: Light-colored PCCP can be used to reduce surface heat reflectivity and roadway lighting needs. For exposed aggregate PCCP, tire/road noise is typically moderate with a lower noise level than conventional PCCP or HACP, but a higher noise level than porous PCCP. The potential for tire/road noise is increased for high speed roadways. The size and shape of aggregates at the pavement surface and depth of aggregate exposure affects tire/road noise levels.

AESTHETICS

Appearance: The appearance will be influenced by the gray cement paste and the aggregate type and source, so visual aesthetics can be improved by using select aggregates, when available.

Appearance Degradation Over Time: The exposed aggregate PCCP surface will maintain its general appearance throughout its service life. Over time it is not uncommon for cracks to develop that will require crack sealing.

COST

Supply Price: \$120 to \$140/m^3 (\$90 to \$110/yd^3)

Supply+Install Price: \$145 to \$200/m^3 (\$110 to \$150/yd^3)

EXAMPLE PROJECTS

Colonial Parkway, Williamsburg, VA.
Exposed aggregate PCCP is used extensively for driveways throughout the United States.

SELECT RESOURCES

American Concrete Institute, (248) 848-3700, www.aci-int.org.
American Concrete Pavement Association, (847) 966-2272, www.pavement.com.
Portland Cement Association, (847) 966-6200, www.cement.org.
Artcrete Concrete Products Intl., www.exposedaggregate.com.

PIGMENTED PCCP

GENERAL INFORMATION

Generic Name(s): Pigmented Portland Cement Concrete Pavement (PCCP), Pigmented Concrete, Colored Concrete

Trade Names: N/A

Product Description: Portland cement concrete (PCC) is a mixture of aggregate, cementitious material, and water that forms a rigid, paved surfacing. Additives are used to help with production and paving and to improve durability. Typical additives include air entraining admixture, water reducing agents, and supplementary cementitious materials (e.g. fly ash, ground blast furnace slag, silica fume, and calcinated clay). Concrete pavements are designed and constructed as plain concrete, plain concrete with dowelled joints or as continuously reinforced. PCCP have very good performance characteristics with respect to strength, durability, and ride quality.

There are three methods available for coloring a PCCP surface: (1) The color (pigment) is incorporated into the concrete mix during mixing; (2) Pigment is sprinkled onto a freshly poured PCC surface and mixed into the surface as part of the concrete finishing process; or (3) pigmented sealers or stains are applied to a hardened concrete surface.

Product Suppliers: Representative list of manufacturers, suppliers, and contractors can be obtained from: American Society of Concrete Contractors, 2025 S. Brentwood Blvd., Saint Louis, MO 63114, (314) 962-0210, www.ascconline.org.

APPLICATION

Typical Use: Road surfacing.

Traffic Range: Very Low to High.

Restrictions:

Traffic: None.

Climate: None.

Weather: None.

Terrain: None.

Soil Type: N/A

Other: None.

Other Comments: Any light-colored surface finish can be disfigured by stains, such as from oil spills.

DESIGN

SLC: N/A; Rigid pavements, such as PCCP, are not designed using AASHTO SLC. Instead, pavement thickness is determined based on the following factors: modulus of subgrade reaction (k), modulus of rupture for the concrete, load transfer between joints, traffic loading, and other factors, such as drainage and reliability. Concrete pavement designs can be performed using the 1993 AASHTO Guide for Design of Pavement Structures or using the thickness design guides available through the American Concrete Pavement Association..

Other Design Values: Compressive strength: 20 to 50 MPa (2,900 to 7,250 psi). High strength concrete, with compressive strengths above 50 MPa (7,250 psi) is also available for special applications.

Base/Subbase Requirements: Subgrade and base materials should be compacted and graded to provide a stable working surface prior to PCCP placement. Base/subbase should consist of unbound or stabilized granular material with sufficient drainage characteristics. The base thickness should be a minimum of 100 mm (4 in.) Open graded base is frequently used as a drainage medium to prevent pumping at the joints.

Other Comments: A properly designed joint pattern is necessary to prevent random slab cracking, except for continously reinforced PCCP (CRCP). To provide better load transfer across slab joints, dowel bars should be specified, especially on high speed roads with heavy traffic loading.

The effect of color pigments on PCCP performance is generally none to minimal.

CONSTRUCTION

Availability of Experienced Personnel: When the pigment is added during mixing, pigmented PCCP construction is identical to conventional PCCP construction. PCCP is a commonly used surfacing and experienced contractors are, in general, widely available. Availability may be limited for projects in remote areas. For pigments added during finishing, an experienced concrete finishing contractor is required; they are widely available near large urban areas and regionally available in other areas. For colored surface coatings, experienced specialty contractors are required; they are widely available near large urban areas and regionally available in other areas.

Materials: PCC is a mixture of aggregate, cementitious material, water, and additives used to help with production and paving and to improve durability. Steel reinforcing bars are used for crack control of CRCP and dowels for transferring wheel loads between slabs.Many of the dry pigments obtain their color from the use of mineral oxides, such as iron or chromium. A variety of pigmented sealers are available, including acrylic, epoxy, and polyurethane products.

Equipment: Equipment required for PCCP construction includes: concrete mixing trucks for hauling PCC, construction forms for roadway edges and construction joints, concrete paver, water truck, vibratory equipment, finishing equipment, and concrete saws (single or multiple gang). Continuous slip form concrete pavers are used on high productivity or very large projects. Equipment is widely available in most areas, but availability may be limited in remote areas.

Manufacturing/Mixing Process: PCC can be mixed at a central mix plant and hauled to the site or a mobile concrete batching plant can be set up on site. The pigment can be added to the PCC mix at the plant.

Placement Process: The concrete mix is discharged from mixing trucks and placed using automatic screeds or hand troweled. On large projects, continuous slip form concrete pavers can be used; if automatic dowel inserters are used, they should be checked to ensure proper placement and functioning of the equipment. The concrete is consolidated with vibrators to increase density and reduce voids. Thermal expansion joints are constructed at predetermined intervals. The concrete should be cured in place for 4 to 7 days or until a minimum strength is achieved, depending on exposure conditions. To facilitate curing, topical curing compounds are recommended. Control joints must be saw-cut/formed before the stress in the concrete exceeds the strength to minimize random cracking. The time available to saw/form joints varies depending on concrete mix properties and ambient weather conditions.

If a dry-shake color hardener is used, the pigment is sprinkled onto a freshly poured PCC surface and mixed into the surface as part of the concrete finishing process. If pigmented sealers or stains are used, they are applied to the concrete surface after it has hardened and fully cured.

Weather Restrictions: Do not place PCC if it is raining or if temperatures are near or below freezing. The PCCP needs to be protected from freezing during the initial curing period (4 to 7 days or until adequate strength is achieved). Do not place PCC on frozen base/subgrade soils. Special precautions are necessary if PCC is placed when temperatures are above about 35 ºC (94 ºF) or during high winds (rapid evaporation). Different pigmented sealers and stains may have different weather restrictions regarding application; restrictions for a particular product should be reviewed before it is applied.

Construction Rate: Typical pigmented PCCP construction rates can be up to 2,300 m^3/day (3,000 yd^3/day).

Lane Closure Requirements: The roadway lane(s) being constructed is closed during construction and curing, so adequate traffic control is needed. Normal traffic loads can be allowed on the PCCP surface after initial curing and once an adequate PCC strength is reached, typically after 7 or 14 days. High strength PCC can be used to achieve design concrete strengths faster, so the road surfacing can be opened to traffic sooner, as soon as eight hours after placement. Road surface striping may be performed after the lane is opened. Colored surface coatings have varying cure times, but typically range from a few minutes to a few hours.

Other Comments: Water/cement ratios are critical components in successful PCCP construction projects and should be monitored closely. Construction defects are generally difficult to repair. Mix designs and trial mixes should be prepared in advance of construction.

SERVICEABILITY

Reliability and Performance History: Pigmented PCCP performs identically to conventional PCCP. PCCP is a very common roadway surfacing and has been used on roadway projects for more than 100 years; an extensive amount of research, design and construction information, and project experience is available. For pigmented sealers and stains, product specific information should be collected regarding performance and durability.

Life Expectancy: Life expectancy varies depending on construction materials used, environmental conditions, and traffic volumes. Typical PCCP design life is 30 to 40 years. Surface applied pigments and coatings will commonly last 3 to 6 years or more.

Ride Quality: PCCP provides very good ride quality after construction. Ride quality deteriorates over the serviceable life, partially due to cracking and faulting at the PCCP joints.

Main Distress / Failure Modes: Cracking, faulting, spalling, color fading or wearing (for surface applied coatings).

Preservation Needs: In general, PCCP require relatively little preventative maintenance. Jointed PCCP require periodic joint resealing. Depending on the type of sealant used, resealing may be required every 5 to 10 years. Surface grinding may be required to maintain good frictional characteristics and for improving ride quality.

SAFETY

Hazards: Adequate surface grading and surface texture are required to prevent ponding of water on the surface that can cause reduced traction due to hydroplaning and icing. Road splash/spray can reduce visibility during periods of higher traffic volume.

Skid Resistance: When high quality aggregates are used, PCCP provide very good initial skid resistance. The use of lower quality aggregates leads to aggregate polishing at the surface that can reduce the skid resistance over time. Surface grinding or texturing can be used to increase the skid resistance of the PCCP.

Pigmented sealers can obscure the natural aggregate texture and can create slippery surface conditions; however, some coatings include skid resistant materials that provide good to excellent skid resistance.

Road Striping Possible?: Yes.

Other Comments: Because PCCP provides a high-quality road surfacing, there is a tendency for higher road usage and speeding. PCCP surface texturing is often used to increase the skid resistance of PCCP and decrease the level of vehicle skidding and hydroplaning. The type, spacing, width, and depth of the texturing affects skid resistance and tire/road noise. Numerous surface texturing options are available, including drag textures (broom, artificial turf, burlap), tine textures (transverse, longitudinal), exposed aggregate textures, and hardened concrete textures (diamond ground, diamond groove, abraded). For local roads where hydroplaning is not a primary concern, burlap or broom textures are commonly used. For high speed applications, such as highways, transverse tine texturing is the most commonly used texturing. Transverse tining provides a good, durable, skid resistant surface, reduces road splash/spray, reduces headlight glare from wet surfaces, reduces hydroplaning potential, and facilitates surface drainage.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: PCCP is constructed of PCC, which contains coarse and fine aggregates, portland cement, water, and, sometimes, chemical admixtures. Aggregates may be naturally occurring or quarried, but either requires mechanical processing (crushing, sizing) before they can be used. Fly ash, ground blast furnace slag, and silica fume, which are waste by-products, are sometimes included in the concrete mixture. Reinforced PCCP contains reinforcing bars that are manufactured from steel. Pigments, sealers, and stains are manufactured products; many of the products obtain their coloring from mineral oxides. A variety of pigmented sealers are available, including acrylic, epoxy, and polyurethane products.

Portland cement is manufactured from limestone through a very energy intensive process. In addition to significant energy consumption during the manufacturing process, portland cement manufacturing produces large amounts of carbon dioxide (CO_2); various reports claim that cement manufacturing is responsible for 2% to 7% of CO_2 produced by humans.

Delivery and Haul Requirements: PCC must be hauled from the mixing plant. The mixing plant must be located near the site because a limited amount of time (i.e. 90 minutes or less) is available after mixing to deliver, place, and consolidate the PCC.

Potential Short-Term Construction Impacts: Construction processes may impact vegetation adjacent to the roadway. Wash water from concrete equipment can damage vegetation and water quality; settling basins or designated wash out pits should be utilized to collect and contain the wash water. Wet sludge from sawcutting operations also needs to be contained and disposed of properly.

Potential Long-Term Environmental Impacts:

Leachate: None.

Surface Runoff: Pigmented PCCP is impermeable, which promotes surface runoff. However, surface runoff water quality is not generally impacted by pigmented PCCP

Erosion: None.

Water quality: None.

Aquatic species: None.

Plant quality: None.

Air Quality: None.

Other: None.

Ability to Recycle/Reuse: Pigmented PCCP can be crushed for use as an unbound or stabilized material. Pigmented PCCP can also be rubblized in-place and covered with an overlay.

Other Environmental Considerations: Light-colored PCCP can be used to reduce surface heat reflectivity and roadway lighting needs. For PCCP, tire/road noise is typically moderate to high with a higher noise level than HACP. The potential for tire/road noise is increased for high speed roadways. The type of surface texturing can affect tire/road noise levels.

AESTHETICS

Appearance: Pigmented PCCP can be a highly decorative surfacing. Numerous colors are available; earth tones such as red, brown, green, and tan (and numerous variations) are most common. Pigmented PCCP can be used to blend in with the surrounding environment (earth tone colors in a wilderness area) or to contrast the surrounding environment (e.g. pedestrian crosswalk, fire lane, or handicap parking area colored in bright, contrasting colors), depending on the application and designer's intent.

Appearance Degradation Over Time: Over time, some color wear and fading is possible. For surface coatings, non-uniform wear is possible and will expose the underlying PCC color. Additional applications of colored surface coating can be used to maintain the appearance of the surface. When the entire PCCP surfacing layer is colored by pigment, surface wear will not affect the color. Surfaces can also become discolored by tire marks and oil leakage. Pigmented crack sealants and patching products must be used for preventative and corrective maintenance to maintain the uniform appearance of the surfacing.

COST

Supply Price: $2.20 to $4.40/kg ($1.00 to $2.00/lb) for pigment only.

Supply+Install Price: $6.50 to $105/$m^2$ ($5.00 to $80/$yd^2$) for pigment only.

EXAMPLE PROJECTS

Desert View Entrance Station, Grand Canyon National Park, AZ.

SELECT RESOURCES

American Concrete Institute, (248) 848-3700, www.aci-int.org.
American Society of Concrete Contractors, (314) 962-0210, www.ascconline.org.
Portland Cement Association, (847) 966-6200, www.cement.org.

POROUS PCCP

GENERAL INFORMATION

Generic Name(s): Porous Portland Cement Concrete Pavement (PCCP), Pervious Concrete Pavement, Porous Concrete

Trade Names: N/A

Product Description: Porous PCCP is a paved surface and subbase comprised of PCC and gravel or crushed aggregate, formed in a manner that results in a permeable surface. The various layers have the potential for stormwater detention. Stormwater that passes through the pavement may completely or partially infiltrate the underlying soil, the excess being collected and routed to an overflow facility through perforated underdrain pipes.

A typical porous concrete pavement consists of a porous concrete surface, a filter course, a reservoir course (designed to temporarily retain infiltrated water and for frost protection), and existing soil or subbase material. The top porous concrete layer is an open graded PCC, typically 100 to 150 mm (4 to 6 in.) thick, consisting of 12.5 to 19 mm (0.5 to 0.75 in.) diameter gravel or crushed aggregate and very little to no sand. Water and portland cement are added as in conventional PCC. Using little to no sand in the mixture creates an open cell structure (with about 15 to 25% air voids) that allows stormwater to flow through the concrete and into the base layers. The filter course is a 25 to 50 mm (1 to 2 in.) thick layer of 12.5 mm (0.5 in) crushed stone aggregate designed to provide filtration and stability for the reservoir course during placement of the porous concrete layer.

Porous concrete pavement helps to reduce the amount of untreated runoff discharging into storm sewers, rivers, and streams.

Product Suppliers: Representative list of manufacturers, suppliers, and contractors can be obtained from: American Concrete Pavement Association, 5420 Old Orchard Road, Suite A-100, Skokie, IL, 60077-1059, (847) 966-2272, www.pavement.com.

APPLICATION

Typical Use: Road surfacing.

Traffic Range: Very Low to Medium.

Restrictions:

Traffic: Porous concrete is not recommended for applications with significant heavy truck traffic.

Climate: The use of porous concrete in areas requiring intensive winter maintenance is limited, because of a risk of the pores clogging with winter road sanding material. Porous concrete is not recommended for windy climates where wind erosion would provide windblown sediment that can clog the porous concrete pores.

Weather: None.

Terrain: Porous concrete is not recommended for roadway gradients steeper than 5%; roadway gradients as flat as possible are desired so as to increase water residence time.

Soil Type: Porous concrete is mainly used in areas with permeable soils with an infiltration rate greater than 1.3 cm/hr (0.5 in./hr). Where soils have low permeability, the reservoir thickness should be increased to provide additional storage. With soils composed of clay or silt, additional drainage may be required.

Other: Depth to seasonal high groundwater levels and bedrock should be greater than 1.2 m (4 ft.).

Other Comments: Porous concrete use is usually limited to applications with drainage areas less than 6.1 hectares (15 acres). Porous concrete has mainly been used for low volume parking lots and roads and recreational areas.

DESIGN

SLC: N/A; Rigid pavements, such as porous concrete, are not designed using AASHTO SLC. Instead, pavement thickness is determined based on the following factors: modulus of subgrade reaction (k), modulus of rupture for the concrete, load transfer between joints, traffic loading, and other factors, such as drainage and reliability. Concrete pavement designs can be performed using the 1993 AASHTO Guide for Design of Pavement Structures or using the thickness design guides available through the American Concrete Pavement Association.

Other Design Values: Compressive strength: 20 to 30 MPa (2,900 to 4,350 psi).

Base/Subbase Requirements: The reservoir course (base) should be deep enough to provide sufficient water storage volume and provide frost protection if the soils are frost susceptible and in a climatic zone subject to freezing temperatures. Additional granular thickness, over and above that normally used in the design of rigid pavements, will be required.

Other Comments: The depth of the stone reservoir should be such that it drains completely within 72 hours. This allows the underlying soils to dry out between storms and also provides capacity for the next storm. If frost penetrates deeper than the thickness of the pavement and reservoir course, and the subgrade has potential for frost heaving, additional material should be added to the reservoir course to below the frost zone. The reservoir (base) course should be deep enough to provide sufficient water storage volume. A minimum residence time of 12 hours should be a target for the design storm to provide exfiltration for pollutants removal. Concerns about clogging of porous concrete pavements should be addressed at the design stage by reducing erosion and sediment runoff through strategic design and water retaining ground cover.

When fine-grained natural soils are present, a geosynthetic separation/filtration layer is typically placed at the bottom of the reservoir layer.

CONSTRUCTION

Availability of Experienced Personnel: Porous concrete pavement construction requires experienced contractors. Porous concrete is not a commonly used surfacing and experienced contractors are, in general, not widely available. Specialized concrete mix design will also be needed.

Materials: PCC is a mixture of aggregate, cementitious material, water, and additives used to help with production and paving and to improve durability. The filter course is constructed of 12.5 mm (0.5 in) diameter open graded crushed stone aggregate. The reservoir course is constructed of 37.5 to 75 mm (1.5 to 3 in.) diameter open graded crushed stone aggregate.

Equipment: Equipment required for PCCP construction includes: concrete mixing trucks for hauling PCC, construction forms for roadway edges and construction joints, water truck, grading equipment, compaction equipment, vibratory equipment, finishing equipment, and concrete saws (single or multiple gang). Equipment is widely available in most areas, but availability may be limited in remote areas.

Manufacturing/Mixing Process: PCC can be mixed at a central mix plant and hauled to the site or a mobile concrete batching plant can be set up on site.

Placement Process: If needed, the site is excavated to design subgrade depth and graded using light equipment to minimize compaction of the subgrade surface. If the subgrade soils are fine-grained, a geosynthetic separation/filtration layer is placed on the subgrade prior to construction of the reservoir layer. Then, the base reservoir and filtration layers are placed and compacted. After the base is constructed, the porous concrete surface layer can be placed. The concrete mix is discharged from mixing trucks and placed using automatic screeds or hand troweled. The concrete is lightly consolidated with vibrators and finished. The concrete should be cured in place for 4 to 7 days or until a minimum strength is achieved, depending on exposure conditions. To facilitate curing, curing compounds can be applied, wet burlap can be used, or insulated sheets can be used in low ambient temperatures. Control joints must be saw-cut/formed before the stress in the concrete exceeds the strength to minimize random cracking. The time available to saw/form joints varies depending on concrete mix properties and ambient weather conditions.

Weather Restrictions: Do not place porous concrete if it is raining or if temperatures are near or below freezing. The porous concrete needs to be protected from freezing during the initial curing period (4 to 7 days or until adequate strength is achieved). Do not place porous concrete on frozen base soils. Special precautions are necessary if porous concrete is placed when temperatures are above about 35 ºC (94 ºF) or during high winds (rapid evaporation). The aggregate base materials should not be constructed on wet or frozen soils.

Construction Rate: Typical porous concrete pavement construction rates can be up to 750 m^3/day (980 yd^3/day).

Lane Closure Requirements: The roadway lane(s) being constructed is closed during construction and curing, so adequate traffic control is needed. Normal traffic loads can be allowed on the porous concrete surface after initial curing and once an adequate PCC strength is reached, typically after 7 or 14 days. Road surface striping may be performed after the lane is opened.

Other Comments: Water/cement ratios are critical components in successful porous concrete construction projects and should be monitored closely. Construction defects are generally difficult to repair. Mix designs and trial mixes should be prepared in advance of construction by experienced personnel.

SERVICEABILITY

Reliability and Performance History: In the past, performance reliability of porous concrete pavements has been very low, with failure rates on the order of 75%. Failure has been caused by poor design, poor construction, heavy vehicle traffic, low permeability soils, and resurfacing with impermeable materials. There is now a better understanding of the construction and design features and reliability is improving.

Life Expectancy: Life expectancy varies depending on construction materials used, environmental conditions, and traffic volumes. Typical porous concrete design life is 20 years.

Ride Quality: Porous concrete pavement provides very good ride quality after construction. Ride quality deteriorates over the serviceable life.

Main Distress / Failure Modes: Cracking, faulting, spalling, clogging of pores.

Preservation Needs: Vacuum sweeping, followed by high pressure jet hosing to clean pores, should be performed periodically to clean out the concrete pores. Periodic crack and joint sealing is required.

SAFETY

Hazards: None.

Skid Resistance: When high quality aggregates are used, PCCP provide very good initial skid resistance. The use of lower quality aggregates leads to aggregate polishing at the surface that can reduce the skid resistance over time.

Road Striping Possible?: Yes.

Other Comments: Because porous concrete provides a high-quality road surfacing, there is a tendency for higher road usage and speeding. Because porous concrete has an open structure, it can freeze sooner than conventional PCCP and so may be more of a hazard for winter driving. Porous concrete can significantly reduce water spray compared to conventional PCCP.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: Porous concrete is constructed of PCC, which contains aggregate, portland cement, water, and, sometimes, chemical admixtures. Aggregates may be naturally occurring or quarried, but either requires mechanical processing (crushing, sizing) before they can be used. Fly ash, ground blast furnace slag, and silica fume, which are waste by-products, are sometimes included in the concrete mixture.

Portland cement is manufactured from limestone through a very energy intensive process. In addition to significant energy consumption during the manufacturing process, portland cement manufacturing produces large amounts of carbon dioxide (CO_2); various reports claim that cement manufacturing is responsible for 2% to 7% of CO_2 produced by humans.

Delivery and Haul Requirements: PCC must be hauled from the concrete batch plant. The batch plant must be located near the site because a limited amount of time (i.e. 90 minutes or less) is available after mixing to deliver, place, and consolidate the PCC.

Potential Short-Term Construction Impacts: Construction processes may impact vegetation adjacent to the roadway. Wash water from concrete equipment can damage vegetation and water quality; settling basins or designated wash out pits should be utilized to collect and contain the wash water. Wet sludge from sawcutting operations also needs to be contained and disposed of properly. Significant excavation and disposal of existing soils may be required to install the reservoir and filter layers.

Potential Long-Term Environmental Impacts:

Leachate: None.

Surface Runoff: The pavement surface is permeable, allowing infiltration of stormwater, which is temporarily stored in the reservoir course until it can infiltrate into the ground. Contaminants in the surface runoff that are not easily trapped or reduced can flow through the pavement structure and become a potential source of groundwater contamination. Therefore, porous concrete pavements are not recommended for areas near groundwater drinking supplies or other sensitive bodies of water. However, local infiltration of storm water is generally preferable to large stormwater collection and disposal systems.

Erosion: Porous concrete is a bound material and is not susceptible to surface erosion.

Water quality: The filter layer below porous concrete removes particulate matter and so improves stormwater quality. However, if the surface water infiltrating the pavement surface contains contaminants that are not easily trapped or reduced, the contaminants will flow through the pavement structure and be introduced into the surrounding soil.

Aquatic species: Porous concrete does not impact aquatic species. However, porous concrete can be a pathway for contaminants to be introduced into nearby bodies of water. Therefore, porous concrete pavements are not recommended for areas near sensitive bodies of water.

Plant quality: None.

Air Quality: None.

Other: None.

Ability to Recycle/Reuse: Porous concrete can be crushed for use as an unbound or stabilized material. Porous concrete can also be rubblized in-place and covered with an overlay.

Other Environmental Considerations: Pre-treatment of stormwater is recommended where oil and grease or other potential groundwater contaminants are expected. The possible environmental benefits of porous concrete pavement include: removal of fine particulates and soluble pollutants through soil infiltration, attenuation of peak flows, reduction in the volume of runoff leaving the site and entering storm sewers, reduction in soil erosion, and groundwater recharge.

Light-colored porous concrete can be used to reduce surface heat reflectivity. Porous concrete pavements are less able to absorb and store heat than conventional PCCP (high air voids content reduces heat storage capacity). The open void structure in the porous concrete pavements allows cooler earth temperatures to cool the pavement. Porous concrete pavements typically reduce tire/road noise compared to conventional PCCP surfaces.

AESTHETICS

Appearance: Porous concrete typically has a coarse surface texture and light gray color. The appearance can be influenced by aggregate type and source, so visual aesthetics can be improved by using select aggregates, when available. Surface appearance can also be modified by using pigments or stains to color the concrete.

Appearance Degradation Over Time: The porous concrete surface will maintain its general appearance throughout its service life.

COST

Supply Price: N/A

Supply+Install Price: \$44 to \$70/m^2 (\$37 to \$59/yd^2).

EXAMPLE PROJECTS

Local Streets, Indian Rocks Beach, FL.

SELECT RESOURCES

U.S. Environmental Protection Agency (1999). *Stormwater Technology Fact Sheet: Porous Pavement*, EPA 832-F-99-023, U.S. EPA, Office of Water, Washington, D.C., 6 pp.

STAMPED PCCP

GENERAL INFORMATION

Generic Name(s): Stamped Portland Cement Concrete Pavement (PCCP), Stamped Concrete, Pattern Imprinted Concrete

Trade Names: N/A

Product Description: Portland cement concrete (PCC) is a mixture of aggregate, cementitious material, and water that forms a rigid, paved surfacing. Additives are used to help with production and paving and to improve durability. Typical additives include air entraining admixture, water reducing agents, and supplementary cementitious materials (e.g. fly ash, ground blast furnace slag, silica fume, and calcinated clay). Concrete pavements are designed and constructed as plain concrete, plain concrete with dowelled joints or as continuously reinforced. Stamped PCCP are typically used in low traffic volume applications and so would typically be plain concrete construction. PCCP have very good performance characteristics with respect to strength, durability, and ride quality.

In stamped concrete, the surface of freshly placed PCC is patterned to resemble brick, slate, flagstone, tile, stone, or other traditional materials. The stamped concrete surface is covered with a coating product consisting of cement-modified acrylic resins and/or epoxy-based polymers and a blend of aggregates. The coating system can be designed to provide a wide range of colors and textures.

Product Suppliers: Representative list of manufacturers, suppliers, and contractors can be obtained from: American Society of Concrete Contractors, 2025 S. Brentwood Blvd., Saint Louis, MO 63114, (314) 962-0210, www.ascconline.org.

APPLICATION

Typical Use: Road surfacing.

Traffic Range: Very Low to High (less than 1200 AADT).

Restrictions:

Traffic: Stamped concrete is not recommended for heavy industrial loading applications (i.e. slow moving trucks, frequent braking, etc.). Stamped concrete is not recommended for high speed traffic applications because the imprinted pattern can create a rough surface.

Climate: None.

Weather: None.

Terrain: None.

Soil Type: N/A

Other: None.

Other Comments: Stamped concrete is mainly used for decorative purposes, since it simulates a wide range of other, more expensive, pavement types, such as flagstones, brick pavers, etc. Stamped concrete has been used most frequently in areas with high pedestrian traffic.

DESIGN

SLC: N/A; Rigid pavements, such as stamped PCCP, are not designed using AASHTO SLC. Instead, pavement thickness is determined based on the following factors: modulus of subgrade reaction (k), modulus of rupture for the concrete, load transfer between joints, traffic loading, and other factors, such as drainage and reliability. Concrete pavement designs can be performed using the 1993 AASHTO Guide for Design of Pavement Structures or using the thickness design guides available through the American Concrete Pavement Association.

Other Design Values: Compressive strength: 20 to 50 MPa (2,900 to 7,250 psi)

Base/Subbase Requirements: Subgrade and base materials should be compacted and graded to provide a stable working surface prior to PCCP placement. Base/subbase should consist of unbound or stabilized granular material with sufficient drainage characteristics. The base thickness should be a minimum of 100 mm (4 in.) In high traffic volume applications, open graded base is frequently used as a drainage medium to prevent pumping at the joints.

Other Comments: A properly designed joint pattern is necessary to prevent random slab cracking, except for continously reinforced PCCP (CRCP).

CONSTRUCTION

Availability of Experienced Personnel: PCCP is a commonly used surfacing and experienced contractors are, in general, widely available. Certified stamped concrete installers are available locally in most large urban areas and regionally in more remote areas. Availability may be limited for projects in remote areas.

Materials: PCC is a mixture of aggregate, cementitious material, water, and additives used to help with production and paving and to improve durability. Steel reinforcing bars are used for crack control of CRCP and dowels for transferring wheel loads between slabs. The surface coating applied to the stamped surface is composed of cement-modified acrylic resins and/or epoxy-based polymers, and a blend of aggregates.

Equipment: Equipment required for PCCP construction includes: concrete mixing trucks for hauling PCC, construction forms for roadway edges and construction joints, concrete paver, water truck, vibratory equipment, imprinting templates, finishing equipment, and concrete saws (single or multiple gang). Equipment is widely available in most areas, but availability may be limited in remote areas.

Manufacturing/Mixing Process: PCC can be mixed at a central mix plant and hauled to the site or a mobile concrete batching plant can be set up on site.

Placement Process: The concrete mix is discharged from mixing trucks and placed using automatic screeds or hand troweled. The concrete is consolidated with vibrators to increase density and reduce voids. Thermal expansion joints are constructed at predetermined intervals. Before the PCC sets, the imprinting templates, constructed of specially woven wire cable welded to a desired pattern, are placed on the PCC surface and pressed into the concrete using standard compaction equipment. The imprint depth is typically 9 mm (0.375 in.). The template is then removed from the PCCP surface and the process is repeated for the next area. Once the stamped concrete is imprinted and allowed to set, a surface coating, consisting of a release agent and clear seal, or cement-modified acrylic resins, or epoxy-based polymers and a blend of fine aggregates, is applied to the surface to seal the surface, add color, and improve surface performance characteristics. The concrete should be cured in place for 4 to 7 days or until a minimum strength is achieved, depending on exposure conditions. Control joints must be saw-cut/formed before the stress in the concrete exceeds the strength to minimize random cracking. The time available to saw/form joints varies depending on concrete mix properties and ambient weather conditions.

Weather Restrictions: Do not place PCC if it is raining or if temperatures are near or below freezing. The PCCP needs to be protected from freezing during the initial curing period (4 to 7 days or until adequate strength is achieved). Do not place PCC on frozen base/subgrade soils. Special precautions are necessary if PCC is placed when temperatures are above about 35 ºC (94 ºF) or during high winds (rapid evaporation). The surface coating should not be applied if it is raining or if rain is expected within 2 hours of coat application. Air temperatures should be above 10 ºC (50 ºF) at the time the surface coating is applied and for at least 8 hours after the coating is applied.

Construction Rate: Typical stamped concrete construction rates can be 335 to 500 m^2/day (400 to 600 yd^2/day).

Lane Closure Requirements: The roadway lane(s) being constructed is closed during construction and curing, so adequate traffic control is needed. Normal traffic loads can be allowed on the PCCP surface after initial curing and once an adequate PCC strength is reached, typically after 7 or 14 days. Road surface striping may be performed after the lane is opened.

Other Comments: Water/cement ratios are critical components in successful PCCP construction projects and should be monitored closely. Construction defects are generally difficult to repair. Mix designs and trial mixes should be prepared in advance of construction.

SERVICEABILITY

Reliability and Performance History: PCCP is a very common roadway surfacing and has been used on roadway projects for more than 100 years; an extensive amount of research, design and construction information, and project experience is available. Stamped concrete is a relatively new surfacing, emerging as a surfacing alternative within the past 15 years. Design and construction information and extensive project experience is available.

Life Expectancy: Life expectancy varies depending on construction materials used, environmental conditions, and traffic volumes. Typical stamped concrete design life is 30 to 40 years, depending on traffic.

Ride Quality: Stamped concrete provides fair to good ride quality after construction, depending on the imprint pattern. Ride quality deteriorates over the serviceable life, partially due to cracking and faulting at the PCCP joints.

Main Distress / Failure Modes: Cracking, faulting, spalling, color fading.

Preservation Needs: In general, PCCP require relatively little preventative maintenance. Jointed PCCP require periodic joint resealing. Depending on the type of sealant used, resealing may be required every 5 to 10 years. Color coating needs to be reapplied every 3 to 5 years.

SAFETY

Hazards: Adequate surface grading and surface texture are required to prevent ponding of water on the surface that can cause reduced traction due to hydroplaning and icing. Road splash/spray can reduce visibility during periods of higher traffic volume.

Skid Resistance: When high quality aggregates are used, PCCP provide very good initial skid resistance. The use of lower quality aggregates leads to aggregate polishing at the surface that can reduce the skid resistance over time. Surface coatings can obscure the natural aggregate texture and can create slippery surface conditions; however, some coatings include skid resistant materials that provide good to excellent skid resistance.

Road Striping Possible?: Yes.

Other Comments: None.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: Stamped concrete is constructed of PCC, which contains coarse and fine aggregates, portland cement, water, and, sometimes, chemical admixtures. Aggregates may be naturally occurring or quarried, but either requires mechanical processing (crushing, sizing) before they can be used. Fly ash, ground blast furnace slag, and silica fume, which are waste by-products, are sometimes included in the concrete mixture. Reinforced PCCP contains reinforcing bars that are manufactured from steel. The color coating is a manufactured product composed of cement modified acrylic and/or epoxy-based coloring.

Portland cement is manufactured from limestone through a very energy intensive process. In addition to significant energy consumption during the manufacturing process, portland cement manufacturing produces large amounts of carbon dioxide (CO_2); various reports claim that cement manufacturing is responsible for 2% to 7% of CO_2 produced by humans.

Delivery and Haul Requirements: PCC must be hauled from the concrete batch plant. The batch plant must be located near the site because a limited amount of time (i.e. 90 minutes or less) is available after mixing to deliver, place, and compact the PCC.

Potential Short-Term Construction Impacts: Construction processes may impact vegetation adjacent to the roadway. Wash water from concrete equipment can damage vegetation and water quality; settling basins or designated wash out pits should be utilized to collect and contain the wash water. Wet sludge from sawcutting operations also needs to be contained and disposed of properly.

Potential Long-Term Environmental Impacts:

Leachate: None.

Surface Runoff: Stamped concrete is impermeable, which promotes surface runoff. However, surface runoff water quality is not generally impacted by stamped concrete.

Erosion: None.

Water quality: None.

Aquatic species: None.

Plant quality: None.

Air Quality: None.

Other: None.

Ability to Recycle/Reuse: Stamped PCC can be crushed for use as an unbound or stabilized material. Stamped concrete can also be rubblized in-place and covered with an overlay.

Other Environmental Considerations: Light-colored stamped concrete can be used to reduce surface heat reflectivity. For stamped concrete, tire/road noise is typically moderate to high with a higher noise level than conventional PCCP and HACP.

AESTHETICS

Appearance: Stamped concrete can be a highly decorative surfacing. Numerous different patterns (e.g. brick, slate, flagstone, tile, stone, etc.) and colors are available to choose from. Stamped concrete can be used to blend in with the surrounding environment (e.g. slate or rock pattern, colored in earth tones, in a wilderness area) or to contrast the surrounding environment (e.g. pedestrian crosswalk, fire lane, or handicap parking area colored in bright, contrasting colors), depending on the application and designer's intent.

Appearance Degradation Over Time: Over time, some color and pattern wear is possible. Additional applications of color coating can be used to maintain the appearance of the surface. Surfaces can also become discolored by tire marks and oil leakage. Over time it is not uncommon for cracks to develop that will require crack sealing.

COST

Supply Price: N/A

Supply+Install Price: \$70 to \$86/m^2 (\$59 to \$72/yd^2).

EXAMPLE PROJECTS

Bear Lake Parking Lot, Rocky Mountain National Park, CO.

SELECT RESOURCES

American Concrete Institute, (248) 848-3700, www.aci-int.org.
American Society of Concrete Contractors, (314) 962-0210, www.ascconline.org.
Portland Cement Association, (847) 966-6200, www.cement.org.

ROLLER COMPACTED CONCRETE

GENERAL INFORMATION

Generic Name(s): Roller Compacted Concrete (RCC)

Trade Names: N/A

Product Description: Roller compacted concrete (RCC) is constructed of zero-slump (i.e. very stiff) concrete using traditional asphalt paving equipment. RCC does not require steel reinforcing, joints, dowel bars, or forms. RCC possesses most of the benefits of conventional portland cement concrete pavement (PCCP), but has a lower cost and shorter construction time. RCC has mainly been used in low-speed, heavy-duty pavement applications.

Product Suppliers: Representative list of manufacturers, suppliers, and contractors can be obtained from: American Concrete Pavement Association, 5420 Old Orchard Road, Suite A-100, Skokie, IL, 60077-1059, (847) 966-2272, www.pavement.com.

APPLICATION

Typical Use: Road surfacing. RCC is also used for industrial storage areas and loading yards.

Traffic Range: Very Low to High.

Restrictions:

Traffic: Roller compacted concrete can be designed to support a wide range of traffic loading conditions; it is frequently used for heavy duty industrial pavements. RCC is normally limited to low speed traffic applications with speeds less than about 60 km/hr (37 mph). RCC can be used for medium to high speed applications if high density paving machines are used or a surface treatment is applied to improve smoothness and skid resistance.

Climate: None.

Weather: None.

Terrain: None.

Soil Type: N/A

Other: None.

Other Comments: None.

DESIGN

SLC: N/A; Rigid pavements, such as RCC, are not designed using AASHTO SLC. Instead, pavement thickness is determined based on the following factors: modulus of subgrade reaction (k), modulus of rupture for the concrete, load transfer between joints, traffic loading, and other factors, such as drainage and reliability. The Portland Cement Association has guides available for RCC pavement design.

Other Design Values: Compressive strength: 28 to 69 MPa (4,000 to 10,000 psi).

Base/Subbase Requirements: Subgrade and base materials should be compacted and graded to provide a stable working surface prior to RCC placement.

Other Comments: Typical design RCC thicknesses on projects have ranged from 150 to 500 mm (6 to 20 in.)

CONSTRUCTION

Availability of Experienced Personnel: Contractors experienced in RCC construction are generally available on a regional level. In many areas, contractor availability may be limited and require mobilization of a work crew and equipment from a distant location.

Materials: RCC construction requires zero-slump (i.e. very stiff) PCC.

Equipment: Equipment required for RCC road construction includes: rear dump trucks for hauling RCC, asphalt concrete paver modified for RCC placement, water truck, smooth drum vibratory roller, and rubber tire roller. Equipment is widely available in most areas, but availability may be limited in remote areas. To reduce haul distances, batch plants have been set up on site.

Manufacturing/Mixing Process: RCC can be mixed at a central mix plant and hauled to the site or a batch plant can be set up on site. RCC requires vigorous mixing due to the low water content in the concrete mixture.

Placement Process: RCC is placed using an asphalt concrete paver. After placement, the RCC is compacted using a smooth drum vibratory roller. Vibratory compaction can be followed by several passes of a rubber tire roller to smooth out any surface voids or fissures. RCC placement and compaction generally must occur within 45 to 90 minutes after the point that water is initially added to the mixture at the plant. Moist curing is used on most projects after RCC placement, normally for a minimum of 7 days. A water truck or irrigation sprinkler system is used to keep the RCC surface moist with a fine mist. A thin asphalt surface treatment can be applied to the RCC surface to prevent moisture loss during curing.

Weather Restrictions: Do not place RCC if it is raining or if temperatures are near or below freezing. The RCC needs to be protected from freezing during the initial curing period (4 to 7 days). Do not place RCC on frozen base/subgrade soils. Special precautions and moist curing conditions are necessary if RCC is placed in high temperature conditions.

Construction Rate: Typical RCC construction rates can be on the order of 770 m^3/day (1,000 yd^3/day).

Lane Closure Requirements: The roadway lane(s) being constructed is closed during construction, so adequate traffic control or temporary traffic diversion is needed. In some instances, the RCC surface has been opened to light traffic as soon as it is constructed. Normal traffic loads can be allowed on the RCC surface after initial curing and once an adequate RCC strength is reached, typically after 7 days. Road surface striping may be performed after the lane is opened.

Other Comments: Compaction and moisture content are critical components in successful RCC construction projects and should be monitored closely. Construction defects are generally difficult to repair. Mix designs and trial mixes should be prepared in advance of construction.

SERVICEABILITY

Reliability and Performance History: RCC was first used for traffic applications for the forest industry in the late 1970s. RCC use expanded to industrial pavement and roadway applications in the 1980s. Although using RCC for road surfacing applications is still relatively new, a fair amount of research, design and construction information, and project experience is available.

Life Expectancy: Life expectancy varies depending on construction materials used, environmental conditions, and traffic volumes. Typical RCC design life is 20 to 30 years.

Ride Quality: Traditionally, RCC ride quality has been fair and inferior to most paved surfaces. RCC generally has a rough surface finish since the low slump makes it difficult to compact uniformly, leading to irregularities and only a fair ride quality. This smoothness level is usually adequate for low-speed applications. Since the 1990s, RCC pavements with excellent ride quality have been constructed using high density asphalt paving machines (i.e. paving machines with modified screeds using dual tamping bars to achieve higher densities, commonly used in Europe). Another option for improving ride quality is to construct a thin asphalt concrete layer or asphalt surface treatment on the RCC surface. Ride quality deteriorates over the serviceable life.

Main Distress / Failure Modes: Cracking, surface erosion.

Preservation Needs: In general, RCC requires relatively little preventative maintenance. Cracking has little impact on RCC performance. For large cracks, periodic crack sealing may be required.

SAFETY

Hazards: Adequate surface grading is required to prevent ponding of water on the surface that can cause reduced traction and hydroplaning.

Skid Resistance: RCC surfaces exhibit poor to marginal skid resistance, limiting their use to low-speed applications. The use of high density paving machines results in a smoother surface with better skid resistance, allowing RCC to be used for some moderate to high speed applications.

Road Striping Possible?: Yes.

Other Comments: None.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: RCC is constructed of PCC, which contains coarse and fine aggregates, portland cement, water, and, sometimes, chemical admixtures. Aggregates may be naturally occurring or quarried, but either requires mechanical processing (crushing, sizing) before they can be used. Fly ash, ground blast furnace slag, and silica fume, which are waste by-products, are sometimes included in the concrete mixture. Portland cement is manufactured from limestone.

Delivery and Haul Requirements: If a batch plant is not set up on site, RCC must be hauled from the mixing plant. The mixing plant must be located near the site because a limited amount of time (i.e. 90 minutes or less) is available after mixing to deliver, place, and compact the RCC.

Potential Short-Term Construction Impacts: Construction processes may impact vegetation adjacent to the roadway. Wash water from concrete equipment can damage vegetation and water quality; settling basins or designated wash out pits should be utilized to collect and contain the wash water.

Potential Long-Term Environmental Impacts:

Leachate: None.

Surface Runoff: RCC is impermeable, which promotes surface runoff. However, surface runoff water quality is not generally impacted by RCC roadways.

Erosion: During the first 2 to 3 years after RCC construction, erosion of fine surface materials occurs due to traffic and weathering. The surface erosion is limited to the top 2 mm (0.08 in.) of the RCC. The surrounding environment can be subjected to this eroded material, but the impact should be negligible.

Water quality: RCC has a minimal impact on water quality. Water quality could be affected by sediment loading from material eroded from the RCC surface.

Aquatic species: None.

Plant quality: None.

Air Quality: RCC does not have a long-term impact on air quality. Some dust generation can occur under heavy traffic, especially if a paste-rich surface is produced.

Other: None.

Ability to Recycle/Reuse: RCC can be crushed for use as an unbound or stabilized material.

Other Environmental Considerations: Light-colored RCC can be used to reduce surface heat reflectivity. For RCC, tire/road noise is typically moderate to high with a higher noise level than HACP. However, it does not have the noise problem created by joints in conventional PCCP.

AESTHETICS

Appearance: RCC has a relatively rough texture and appearance and light gray color. The surface color can be modified using pigments or stains to color the RCC.

Appearance Degradation Over Time: Some surface erosion and raveling can occur over time. However, RCC will maintain its general appearance throughout its serviceable life.

COST

Supply Price: N/A

Supply+Install Price: \$55 to \$70/m^3 (\$46 to \$59/yd^3).

EXAMPLE PROJECTS

Bighorn Avenue, Alliance, NE.
Los Tomates Border Station, Brownsville, TX.

SELECT RESOURCES

Portland Cement Association, (847) 966-6200, www.cement.org.
ACI Committee 325 (1995). *State-of-the-Art Report on Roller-Compacted Concrete Pavements*, ACI 325.10R-95, American Concrete Institute, 32 pp.
Portland Cement Association (1987). *Structural Design of Roller-Compacted Concrete for Industrial Pavements*, Portland Cement Association, 8 pp.
Piggott, R.W. (1999). *Roller Compacted Concrete Pavements: A Study of Long Term Performance*, Portland Cement Association, 62 pp.

WHITETOPPING

GENERAL INFORMATION

Generic Name(s): Portland Cement Concrete Whitetopping, Whitetopping, Ultrathin Whitetopping (UTW)

Trade Names: N/A

Product Description: Whitetopping is a pavement rehabilitation technique that involves construction of a portland cement concrete (PCC) overlay or inlay on top of hot asphalt concrete pavement (HACP). Three different types of whitetopping are commonly used in construction: conventional whitetopping, thin whitetopping, and ultrathin whitetopping (UTW). Conventional whitetopping is a PCC overlay or inlay, typically at least 200 mm (8 in.) thick, placed over an existing asphalt concrete surface. Conventional whitetopping does not rely on bonding with the HACP layer and no special treatment of the HACP layer is required. Thin and ultrathin whitetopping rely on bond development between the PCC overlay or inlay and the existing HACP; by creating a bond between the two layers, the existing HACP layer provides significant structural support and allows for the whitetopping overlay thickness to be reduced. Thin whitetopping typically has a thickness of 100 to 200 mm (4 to 8 in.). UTW typically has a thickness of 50 to 100 mm (2 to 4 in.). For thin and ultrathin whitetopping, joint spacing is reduced compared to conventional whitetopping.

Product Suppliers: Representative list of manufacturers, suppliers, and contractors can be obtained from: American Concrete Pavement Association (ACPA), 5420 Old Orchard Road, Suite A-100, Skokie, IL, 60077-1059, (847) 966-2272, www.pavement.com.

APPLICATION

Typical Use: Road surfacing, typically for road rehabilitation projects.

Traffic Range: Very Low to High.

Restrictions:

Traffic: None.

Climate: None.

Weather: None.

Terrain: None.

Soil Type: N/A

Other: Whitetopping is not recommended for applications where the existing asphalt concrete is badly deteriorated or when substantial portions of the asphalt concrete have to be removed during rehabilitation. Whitetopping should also be avoided when the asphalt concrete has material problems, such as asphalt stripping.

Other Comments: UTW is used primarily where rutting is a recurring problem in existing asphalt concrete surfaces or to add carrying capacity to existing asphalt sections.

DESIGN

SLC: N/A; Rigid pavements, such as conventional PCC whitetopping, are not designed using AASHTO SLC. Instead, the whitetopping thickness is determined based on the following factors: modulus of subgrade reaction (k_s) and the thickness of the granular and asphalt layers. Easy to use design charts and tables are available from the American Concrete Pavement Association ("Whitetopping – State of the Practice", Engineering Bulletin EB210.02)

Since UTW is a relatively new surfacing, design procedures are still being developed that adequately incorporate the bonding effect between the whitetopping overlay and the asphalt concrete.

Other Design Values: None.

Base/Subbase Requirements: It is recommended that whitetopping be placed over an asphalt concrete layer with a thickness of at least 75 mm (3 in.) after milling.

Other Comments: A properly designed joint pattern is necessary to prevent random slab cracking. Typical joint spacing for UTW is between 0.6 and 1.5 m (2 and 5 ft). As a rule of thumb, the recommended maximum joint spacing is 12 to 15 times the overlay thickness. By reducing the joint spacing, slab bending is reduced. As a result, stresses in the whitetopping overlay are mainly compressive instead of flexural in nature.

CONSTRUCTION

Availability of Experienced Personnel: Whitetopping is becoming a commonly used surfacing and experienced contractors are, in general, widely available. Availability may be limited for projects in remote areas.

Materials: PCC is a mixture of aggregate, cementitious material, water, and additives used to help with production and paving and to improve durability. Concrete with a 28-day compressive strength of 30 MPa (4,000 psi) is normally used. Welded wire mesh or bar mats can be used for internal strengthening of the whitetopping and dowels can be included for transferring wheel loads between slabs. Several types of fiber reinforcement may be used, especially for UTW.

Equipment: Equipment required for PCC whitetopping construction includes: concrete mixing trucks for hauling PCC, construction forms for roadway edges and construction joints, concrete paver, water truck, vibratory equipment, and finishing equipment (e.g. burlap drag, tining comb). Continuous slip form concrete pavers are used on high productivity or very large projects. Equipment is widely available in most areas, but availability may be limited in remote areas.

Manufacturing/Mixing Process: PCC can be mixed at a central mix plant and hauled to the site or a mobile concrete batching plant can be set up on site.

Placement Process: Prior to PCC placement, cold milling of the existing asphalt concrete surface is required for thin and ultrathin whitetopping. The milled surface should be thoroughly cleaned of loose material prior to PCC placement to ensure a good bond between the overlay and the milled surface. Whitetopping placement is similar to conventional PCCP. The concrete mix is discharged from mixing trucks and placed using vibrating screeds or hand troweled. On large projects, continuous slip form concrete pavers can be used. The concrete is consolidated with vibrators to increase density and reduce voids. Load transfer across joints is provided by aggregate interlock, or by the installation of dowel bars, for heavier traffic loading. In general, whitetopping is built using plain, unreinforced concrete. However, the use of fiber reinforcement can allow longer joint spacing to be utilized. The surface can be textured to improve skid resistance. The concrete should be cured in place for 4 to 7 days, depending on exposure conditions. To facilitate curing, curing compounds can be applied, or wet burlap can be used, or insulated sheets in low ambient temperatures. The joints can be formed by sawing, tooling, or by using inserts. Sawing within 4 to 12 hours of concrete placement is the most common method for joint construction.

Weather Restrictions: Do not place PCC if it is raining or if temperatures are near or below freezing. The whitetopping needs to be protected from freezing during the initial curing period (4 to 7 days). Special precautions are necessary if PCC is placed when temperatures are above about 35 ºC (94 ºF) or during high winds (rapid evaporation).

Construction Rate: Typical whitetopping construction rates can be up to 1,500 m^3/day (1,800 yd^3/day). Due to the large number of sawed joints, particularly for UTW, care should be taken not to place any more pavement than can reasonably be sawed in a day.

Lane Closure Requirements: The roadway lane being constructed is closed during construction and curing, so adequate traffic control is needed. Normal traffic loads can be allowed on the whitetopping surface after initial curing and once an adequate PCC strength is reached, typically after about 3 days. High strength PCC can be used to achieve design concrete strengths faster, so the road surfacing can be opened to traffic sooner, as soon as eight hours after placement. Road surface striping may be performed after the lane is opened.

Other Comments: Water/cement ratios are critical components in successful whitetopping construction projects and should be monitored closely. Construction defects are generally difficult to repair. Mix designs and trial mixes should be prepared in advance of construction.

SERVICEABILITY

Reliability and Performance History: Conventional whitetopping is a common roadway surfacing and was first used in 1918. Thin whitetopping and ultrathin whitetopping are relatively new surfacings; they were first used in the early 1990s. However, thin and ultrathin whitetopping have been used on numerous projects since their development. An extensive amount of research, design and construction information, and project experience is available.

Life Expectancy: Life expectancy varies depending on construction materials used, original asphalt pavement support, environmental conditions, and traffic volumes. Typical conventional whitetopping serviceable lives are 20 to 30 years. Typical UTW serviceable lives are estimated at 5 to 15 years.

Ride Quality: Whitetopping provides very good ride quality after construction. Ride quality deteriorates over the serviceable life, partially due to cracking and faulting at the whitetopping joints.

Main Distress / Failure Modes: Cracking, faulting, popouts, spalling.

Preservation Needs: In general, whitetopping requires relatively little preventative maintenance. Joints may require periodic joint resealing. Depending on the type of sealant used, resealing may be required every 5 to 10 years. Many agencies do not seal whitetopping joints. Surface grinding may be required to maintain good frictional characteristics.

SAFETY

Hazards: Adequate surface grading and surface texture are required to prevent ponding of water on the surface that can cause reduced traction due to hydroplaning and icing. Road splash/spray can reduce visibility during periods of higher traffic volume.

Skid Resistance: When high quality aggregates are used, whitetopping provides very good initial skid resistance. The use of lower quality aggregates leads to aggregate polishing at the surface that can reduce the skid resistance over time. Surface grinding or texturing can be used to increase the skid resistance of the whitetopping surface.

Road Striping Possible?: Yes.

Other Comments: Because PCCP provides a high-quality road surfacing, there is a tendency for higher road usage and speeding. Surface texturing is often used to increase the skid resistance of whitetopping and decrease the level of vehicle skidding and hydroplaning. The type, spacing, width, and depth of the texturing affects skid resistance and tire/road noise. Numerous surface texturing options are available, including drag textures (broom, artificial turf, burlap), tine textures (transverse, longitudinal), exposed aggregate textures, and hardened concrete textures (diamond ground, diamond groove, abrated). For local roads where hydroplaning is not a primary concern, burlap or broom textures are commonly used. For high speed applications, such as highways, transverse tine texturing is the most commonly used texturing. Transverse tining provides a good, durable, skid resistant surface, reduces road splash/spray, reduces headlight glare from wet surfaces, reduces hydroplaning potential, and facilitates surface drainage.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: Whitetopping is constructed of PCC, which contains coarse and fine aggregates, portland cement, water, and, sometimes, chemical admixtures. Aggregates may be naturally occurring or quarried, but either requires mechanical processing (crushing, sizing) before they can be used. Fly ash, ground blast furnace slag, and silica fume, which are waste by-products, are sometimes included in the concrete mixture. Reinforced whitetopping may contain reinforcing bars that are manufactured from steel or synthetic fibers that are derived from various plastics.

Portland cement is manufactured from limestone through a very energy intensive process. In addition to significant energy consumption during the manufacturing process, portland cement manufacturing produces large amounts of carbon dioxide (CO_2); various reports claim that cement manufacturing is responsible for 2% to 7% of CO_2 produced by humans.

Delivery and Haul Requirements: PCC must be hauled from the mixing plant. The mixing plant must be located near the site because a limited amount of time (i.e. 90 minutes or less) is available after mixing to deliver, place, and consolidate the PCC.

Potential Short-Term Construction Impacts: Construction processes may impact vegetation adjacent to the roadway. Wash water from concrete equipment can damage vegetation and water quality; settling basins or designated wash out pits should be utilized to collect and contain the wash water. Wet sludge from sawcutting operations also needs to be contained and disposed of properly.

Potential Long-Term Environmental Impacts:

Leachate: None.

Surface Runoff: Whitetopping is impermeable, which promotes surface runoff. However, surface runoff water quality is not generally impacted by whitetopping.

Erosion: Whitetopping is a bound material and is not susceptible to surface erosion.

Water quality: None.

Aquatic species: None.

Plant quality: None.

Air Quality: None.

Other: None.

Ability to Recycle/Reuse: Whitetopping can be crushed for use as an unbound or stabilized material. Because thin and ultrathin whitetopping are relatively recent technologies, the full range of recycling options are not known.

Other Environmental Considerations: Light-colored whitetopping can reduce surface heat reflectivity. For whitetopping, tire/road noise is typically similar to conventional PCCP; noise is moderate to high with a higher noise level than HACP. Surface texturing can reduce tire/road noise.

AESTHETICS

Appearance: Whitetopping typically has a smooth surface texture and light gray color. The close spacing of sawn joints, as close as 0.6 m (2 ft.), in the ultrathin whitetopping,c produces a distinctly different surface appearance from conventional PCCP. The appearance can be influenced by aggregate type and source, so visual aesthetics can be improved by using select aggregates, when available. Surface appearance can also be modified by using pigments or stains to color the concrete or finishing techniques to change the surface texture.

Appearance Degradation Over Time: Whitetopping will maintain its general appearance throughout its service life.

COST

Supply Price: N/A

Supply+Install Price: $15.60 to $19.10/$m^2$ ($13.00 to $16.00/$yd^2$) for UTW, 50 mm (2 in.) thick. $24.00 to $32.30/$m^2$ ($20.00 to $27.00/$yd^2$) for thin whitetopping, 127 to 178 mm (5 to 7 in.) thick. $36.00/$m^2$ ($30.00/$yd^2$) for conventional whitetopping, 200 mm (8 in.) thick.

EXAMPLE PROJECTS

Interstate I-20, near Bolton, MS.
U.S. Highway 169 and Webster Street, North Mankato, MN.

SELECT RESOURCES

American Concrete Pavement Association, (847) 966-2272, www.pavement.com.
Smith, K.D., Yu, H.T., and Peshkin, D.G. (2002). *Portland Cement Concrete Overlays: State of the Technology Synthesis*, FHWA-IF-02-045, Federal Highway Administration, Washington, D.C., 190 pp.