UNIT SURFACES

UNIT SURFACINGS

BRICK PAVERS

GENERAL INFORMATION

Generic Name(s): Brick Pavers, Paving Brick, Clay Pavers

Trade Names: Numerous products available.

Product Description: Brick pavers are accurately dimensioned blocks constructed of kiln-fired clay, shale, or other similar earthy substance. Brick pavers fit snugly together to form a road surfacing. The brick pavers transfer traffic loads to supporting pavement layers like other flexible pavements and can handle differential settlements without cracking or losing surface integrity. They are similar to rigid pavements because they are resistant to point loads and fuel spills and are not affected by high temperatures. Brick pavers are typically supported on a layer of bedding sand, which is also used to fill the spaces between the pavers. Brick pavers come in a wide range of natural colors, such as brown, red, buff, gray, etc., and can be installed in a range of patterns. Different types of brick are available for use, depending on weather and traffic conditions.

Product Suppliers: Representative list of manufacturers, suppliers, and contractors can be obtained from: Brick Industry Association, 11490 Commerce Park Drive, Reston, VA 20191, (703) 620-0010, www.gobrick.com.

APPLICATION

Typical Use: Road surfacing.

Traffic Range: Very Low to High.

Restrictions:

Traffic: Brick pavers can be designed to support a wide range of traffic loading conditions. Brick pavers are normally limited to low speed traffic applications with speeds less than about 60 km/hr (37 mph).

Climate: None.

Weather: None.

Terrain: Brick pavers can be used for roadway gradients up to 20% for slow moving traffic or pedestrians. However, for general traffic applications, it is recommended that brick pavers be limited to applications with roadway gradients less than 10%. At roadway gradients greater than 10%, joint sand washout can become a problem and braking vehicles will increase pavement creep.

Soil Type: N/A

Other: None.

Other Comments: Brick pavers are commonly used at historical sites and visitor's centers. Brick pavers can also be used as a traffic calming measure.

DESIGN

SLC: 0.35 (for paver and bedding sand combined).

Other Design Values: None.

Base/Subbase Requirements: Brick pavers are placed on top of a 25 to 37 mm (1 to 1.5 in.) thick sand bedding layer. Base/subbase course(s) is (are) located under the sand bedding layer. Subgrade and base materials should be compacted and graded to provide a stable working surface prior to placement of sand bedding layer and pavers. In addition, adequate drainage should be provided by the base to minimize infiltration into and softening of the subgrade.

Other Comments: The base/subbase course(s) is (are) the major structural element for the pavement system. Specific design guidelines are available from the various brick industry organizations. The road surface should be graded to promote surface drainage and prevent ponding on the road surface that can reduce tire traction and wash out sand located between the pavers. Brick pavers can be installed in various patterns; however, a herringbone pattern is most durable and stable and is universally recommended for vehicular traffic loadings.

CONSTRUCTION

Availability of Experienced Personnel: Specialty contractors are widely available in or near large urban areas. In remote areas, contractor availability may be limited and require mobilization of a work crew and equipment from a distant location.

Materials: Brick pavers are manufactured from clay, shale, or other similar earthy substance and come in various shapes, colors, and dimensions. Graded sand is required for the bedding layer.

Equipment: Equipment required for brick paver road construction includes: sand spreading equipment, vibratory plate compactor, hydraulic cutter or saw, and broom. Equipment is widely available in most areas, but availability may be limited in remote areas.

Manufacturing/Mixing Process: Brick pavers are manufactured in plants and shipped to the site for placement. Some paver cutting may be required on site for pavers placed along the roadway edge.

Placement Process: Brick pavers are placed on top of a 25 to 37 mm (1 to 1.5 in.) thick sand bedding layer. The bedding sand should conform to ASTM C 33, be clean, well-graded, and have a maximum particle size of 4.75 mm (#4 sieve.). The pavers can be placed by hand or using special placement equipment. Pavers should be placed with uniform spacing; spacers can be used to ensure that the pavers are placed at the appropriate spacing. Edge restraints are placed along the roadway edge to prevent block movement and raveling at the road surfacing edge. Once placed, a vibratory plate compactor is used to seat the pavers in the bedding sand layer. Once the pavers are seated, sand is spread over the pavers and the vibratory plate compactor is used to vibrate the sand into the paver joints. This process may be repeated as necessary until the joints are filled. Once the joints are filled, excess sand is swept from the paver surface.

Weather Restrictions: Do not install brick pavers during rain or snow or place pavers over frozen base materials or bedding sands.

Construction Rate: Brick paver installation rates vary from 17 to 125 m^2/man-day (20 to 150 yd^2/man-day) for manual placement to 210 to 420 m^2/man-day (250 to 500 yd^2/man-day) for mechanical equipment placement.

Lane Closure Requirements: The roadway lane(s) being constructed is closed during construction, so adequate traffic control is needed. The brick paver surface can be opened to traffic as soon as it is constructed. Road surface striping may be performed after the lane is opened.

Other Comments: None.

SERVICEABILITY

Reliability and Performance History: Brick pavers have been used as a roadway surfacing in the United States since the late 1800s. Brick paver use decreased in the early 1900s as vehicle speeds increased; however, use has increased in recent years. 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 serviceable lives range from 20 to 25 years or more. If the brick paver surface is reconstructed at the end of its serviceable life, the same brick paver units can typically be reused.

Ride Quality: Ride quality is typically fair to good and inferior to most paved surfaces. The smoothness level is a function of workmanship and is usually adequate for low-speed applications. Ride quality deteriorates over the serviceable life.

Main Distress / Failure Modes: Rutting, differential settlement, paver distortion.

Preservation Needs: Periodic removal and replacement of pavers may be required in distorted areas. In addition, additional joint sand may be needed as well. Initial maintenance may be needed after the first year of service. Thereafter, maintenance is typically needed every 8 to 10 years.

SAFETY

Hazards: Brick pavers are occasionally used for mixed pedestrian and vehicular traffic. They provide a rough surface for pedestrians and can constitute a tripping hazard if not properly maintained.

Skid Resistance: Brick pavers provide adequate skid resistance for low speed applications.

Road Striping Possible?: Yes.

Other Comments: Different surface colors, patterns, and/or textures can be used to delineate specific areas, such as crosswalks or "No Parking" zones. Because low ride quality is typically associated with brick pavers, they can be used as a traffic calming tool.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: Brick pavers are manufactured from naturally-occurring clay, shale, or other similar earthy substance. Sands are naturally occurring.

Delivery and Haul Requirements: Brick pavers must be hauled to the site. Depending on local availability, sand may need to be hauled to the site as well.

Potential Short-Term Construction Impacts: If clean aggregate is not used, dust can be a problem during construction and sweeping. Excess sand can be thrown/brushed/washed from the surface into the surrounding environment during construction.

Potential Long-Term Environmental Impacts:

Leachate: None.

Surface Runoff: Brick paver surfacings are permeable with infiltration through the joint sand (approximately 10% infiltration); however, there is still significant surface runoff. The amount of infiltration can decrease, leading to increased surface runoff, over time with clogging of the joint sand.

Erosion: Brick pavers are not susceptible to surface erosion. Some sand loss can occur from the paver joints.

Water quality: Water quality could be affected by sediment loading from sand washed from paver joints.

Aquatic species: None.

Plant quality: None.

Air Quality: None.

Other: None.

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

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

AESTHETICS

Appearance: Brick pavers are available in numerous shapes and natural colors, such as brown, red, buff, gray, etc., and can be placed in various patterns to create a visually pleasing surface. Bricks can be "tumbled" to produce a rougher and more antique appearance.

Appearance Degradation Over Time: Brick pavers will maintain their general appearance over time with small changes. Surface polishing and staining are possible over time. The brick paver coloring is natural, so the color does not fade with use and wear.

COST

Supply Price: \$14 to \$48/m^2 (\$12 to \$40/yd^2).

Supply+Install Price: \$145 to \$185/m^2 (\$120 to \$155/yd^2).

EXAMPLE PROJECTS

Nationwide Boulevard, Columbus, OH.
Main Street, Celebration, FL.

SELECT RESOURCES

Brick Industry Association, (703) 620-0010, www.gobrick.com.
Brick Industry Association (2003). *Flexible Vehicular Brick Paving: Heavy Duty Applications Guide*, Brick Industry Association, 48 pp.

NATURAL STONE PAVERS

GENERAL INFORMATION

Generic Name(s): Natural Stone Pavers, Cobblestones, Sett Paved Surface, Flagstones, Natural Stone Pavements

Trade Names: N/A

Product Description: Natural stone cobbles, or cobblestones, are irregularly sized, smooth, natural stones obtained from river or beach sources. Typical unit cobblestone size ranges from 75 to 200 mm (3 to 8 in.). They are hand placed on a layer of bedding sand and are selected and fitted together to avoid large gaps between adjacent stones. Setts are natural stone pavers that are cut and shaped into regular sizes. Setts are typically rectangular, 100 mm (4 in.) by 200 mm (8 in.) by 150 mm (6 in.) deep. They can be supported on a sand bedding layer or on a layer of lean mix concrete. Flagstones are larger natural stone paving units, typically at least 300 mm (12 in.) by 450 mm (18 in.) and a minimum of 75 mm (3 in.) thick. They are rarely used as a road surfacing, but are occasionally used for sidewalks or decorative courtyards.

Product Suppliers: Natural stone pavers are produced by a small number of specialty rock product suppliers and are typically only produced by special order.

APPLICATION

Typical Use: Road surfacing.

Traffic Range: Very Low to Low.

Restrictions:

Traffic: Typically not used for heavy traffic loading applications. Natural stone pavers are normally limited to low speed traffic applications with speeds less than about 24 km/hr (15 mph).

Climate: None.

Weather: None.

Terrain: Stone pavers can be used on roadway gradients up to 20% for slow moving traffic or pedestrians. However, for general traffic applications, it is recommended that stone pavers be limited to applications with roadway gradients less than 10%. At roadway gradients greater than 10%, joint sand washout can become a problem and braking vehicles can dislodge paver units. Joint sand can be stabilized to prevent washout.

Soil Type: N/A

Other: None.

Other Comments: Natural stone paver road surfacings are typically only justified for historic sites. The general appearance of natural stone paver surfacings can be reproduced at a lower cost by the use of decorative concrete pavers, brick pavers, or by imprinted HACP or stamped PCCP.

DESIGN

SLC: 0.35 (for paver and bedding sand combined).

Other Design Values: None.

Base/Subbase Requirements: Natural stone pavers are placed on top of a 25 to 50 mm (1 to 2 in.) thick, compacted sand bedding layer. A thicker bedding layer may be needed for random sized cobblestones. Lean mix concrete can also be used for a bedding layer, but sand will still be needed to fill joints between paving units. Base/subbase course(s) is (are) located under the bedding layer. Subgrade and base materials should be compacted and graded to provide a stable working surface prior to placement of bedding layer and pavers. In addition, adequate drainage should be provided for the bedding and base layers to minimize infiltration into and softening of the subgrade.

Other Comments: The base/subbase course(s) is (are) the major structural element for the pavement system. Specific design guidelines are available from the various concrete paver supplier organizations, which are generally applicable for use with natural paver stones. The road surface should be graded to promote surface runoff and prevent ponding on the road surface that can reduce tire traction and wash out the sand between the pavers.

CONSTRUCTION

Availability of Experienced Personnel: Specialty contractor availability is limited in most areas. Installing natural stone pavers is tedious and highly labor-intensive work and requires experienced personnel. Natural stone cobbles require greater skill to lay than stone setts.

Materials: Natural stone cobbles, are irregularly sized, smooth, natural stones obtained from river, beach or pit sources. Typical unit cobblestone size ranges from 75 to 200 mm (3 to 8 in.). Setts are natural stone pavers that are shaped into regular sizes. Setts are typically rectangular, 100 mm (4 in.) by 200 mm (8 in.) by 150 mm (6 in.) deep. Flagstones are larger natural stone paving units, typically at least 300 mm (12 in.) by 450 mm (18 in.) and a minimum of 75 mm (3 in.) thick. Graded sand is required for the bedding layer.

Equipment: Equipment required for unit paver road construction includes: sand spreading equipment, vibratory plate compactor, hydraulic cutter or saw, and a broom. Equipment is widely available in most areas, but availability may be limited in remote areas.

Manufacturing/Mixing Process: Natural stone cobbles can be obtained from some aggregate producers. Setts or flagstones are typically shaped by specialty suppliers into a particular size or thickness prior to shipment to the site. Some stone cutting may be required on site for pavers placed along the roadway edge.

Placement Process: Natural stone pavers are placed on top of a 25 to 50 mm (1 to 2 in.) thick sand bedding layer. Lean mix concrete can also be used for a bedding layer for pavers of uniform thickness, but sand will still be needed to fill joints between paving units. The pavers are placed by hand and arranged to avoid large gaps between pavers. For regular shaped paver units, a uniform spacing should be achieved. Once placed, a vibratory plate compactor is used to seat the pavers in the bedding sand layer. Once the pavers are seated, sand is spread over the pavers and the vibratory plate compactor is used to vibrate the sand into the voids between pavers. This process may be repeated as necessary until the voids are filled. Once the voids are filled, excess sand is swept from the paver surface.

Weather Restrictions: Do not install natural stone pavers during rain or snow or place pavers over frozen base materials.

Construction Rate: The construction rate for natural stone pavers is very slow. Natural stone paver installation rates can average 20 m^2/day (24 yd^2/day) for a three-person crew.

Lane Closure Requirements: The roadway being constructed is closed during construction. Because of the slow rate of construction, temporary traffic diversions are needed during construction. The natural stone paver surface can be opened to traffic as soon as a sufficiently long section is constructed. Road surface striping is technically feasible, but given the slow traffic speeds and typically short paved road sections, may not be necessary.

Other Comments: Fitting stone pavers around utility access covers and other street furniture is problematic and usually source locations for higher maintenance.

SERVICEABILITY

Reliability and Performance History: Natural stone pavers have been used as a roadway surfacing for centuries. However, natural stone pavers are rarely used in the United States at this time due to the high cost and labor-intensive nature of construction. A significant amount of research, design and construction information, and project experience is available for unit pavers and brick pavers, which are similar to natural stone pavers in many aspects.

Life Expectancy: Life expectancy varies depending on construction materials used, environmental conditions, and traffic volumes. If properly installed using durable natural stone, typical life expectancy is more than 100 years.

Ride Quality: Ride quality is typically very poor and inferior to most paved surfaces. Nonetheless, the ride quality is usually accepted for low-speed applications. Ride quality deteriorates over the serviceable life.

Main Distress / Failure Modes: Differential settlement, depressions, paver distortion.

Preservation Needs: Periodic removal and replacement of pavers may be required in distorted areas. In addition, additional joint sand may be needed as well. Initial maintenance may be needed after the first year of service. Thereafter, maintenance is typically needed every 8 to 10 years.

SAFETY

Hazards: Unit pavers are occasionally used for mixed pedestrian and vehicular traffic. They provide a rough surface for pedestrians and can constitute a tripping hazard if not properly maintained.

Skid Resistance: The natural stone surfaces become polished with wear and can be a skid hazard in wet weather. However, the hazard is mitigated by slow driving speeds.

Road Striping Possible?: Yes.

Other Comments: Different surface colors or patterns can be used to delineate specific areas. Natural stone pavers can be used in conjunction with brick pavers, for example. Because very low ride quality is typically associated with natural stone pavers, they can be used as a traffic calming tool.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: Cobble stones and sand are naturally occurring.

Delivery and Haul Requirements: Natural stone pavers must be hauled to the site. Depending on local availability, sand may need to be hauled to the site as well.

Potential Short-Term Construction Impacts: If clean sand is not used, dust can be a problem during construction and sweeping. Excess sand that is brushed or washed from the surface can impact the surrounding environment during construction.

Potential Long-Term Environmental Impacts:

Leachate: None.

Surface Runoff: Natural stone paver surfacings are permeable with infiltration through the joint sand (10-30% infiltration); however, there is still significant surface runoff. The amount of infiltration can decrease, leading to increased surface runoff, over time with clogging of the joint sand.

Erosion: Natural stone pavers are not susceptible to surface erosion. Some sand loss can occur from the paver joints.

Water quality: Natural stone pavers have a minimal impact on water quality, assuming clean, inert sand is used. Water quality could be affected by sediment loading from sand washed from paver joints.

Aquatic species: None.

Plant quality: None.

Air Quality: None.

Other: None.

Ability to Recycle/Reuse: Natural stone pavers can be salvaged and reused or crushed for use as an unbound or stabilized material.

Other Environmental Considerations: Light-colored natural stone pavers can be used to reduce surface heat reflectivity. For natural stone pavers, tire/road noise is typically high with a higher noise level than HACP.

AESTHETICS
Appearance: Natural stone pavers can be produced in numerous shapes and colors, depending on the parent rock type and source. They can be placed in various patterns to create a visually pleasing surface. **Appearance Degradation Over Time:** Natural stone pavers will maintain their general appearance over time with small changes.
COST
Supply Price: \$85 to \$100/m^2 (\$70 to \$100/yd^2.) **Supply+Install Price**: \$300 to \$360/m^2 (\$250 to \$300/yd^2).
EXAMPLE PROJECTS
Downtown Streets, Nantucket, MA.
SELECT RESOURCES
www.pavingexpert.com.

UNIT PAVERS

GENERAL INFORMATION

Generic Name(s): Concrete Paving Blocks, Concrete Unit Pavers, Paving Stones, Interlocking Concrete Pavement, Segmental Pavers

Trade Names: Numerous products available.

Product Description: Unit pavers are accurately dimensioned, dense concrete products that fit snugly together to form a road surfacing. They transfer traffic loads similarly to flexible pavements and can handle differential settlements without cracking or losing surface integrity. They are similar to rigid pavements because they are resistant to point loads and fuel spills and are not affected by high temperatures. Unit pavers are typically supported on a layer of bedding sand, which is also used to fill the spaces between the pavers. Unit pavers are available in numerous shapes and colors.

Product Suppliers: Representative list of manufacturers, suppliers, and contractors can be obtained from: Interlocking Concrete Pavement Institute, 1444 I Street NW, Suite 700, Washington, D.C. 20005-6542, (202) 712-9036, www.icpi.org

APPLICATION

Typical Use: Road surfacing.

Traffic Range: Very Low to High.

Restrictions:

Traffic: Unit pavers can be designed to support a wide range of traffic loading conditions; they are frequently used for heavy duty industrial pavements. Unit pavers are normally limited to low speed traffic applications with speeds less than about 80 km/hr (50 mph). Minimum 80 mm (3.125 in.) thick pavers are recommended for all road applications.

Climate: None.

Weather: None.

Terrain: Unit pavers can be used roadway gradients up to 20% for slow moving traffic or pedestrians. However, for general traffic applications, it is recommended that unit pavers be limited to applications with roadway gradients less than 10%. At roadway gradients greater than 10%, joint sand washout can become a problem unless stabilized and braking vehicles may increase pavement creep. Joint sand can be stabilized to prevent washout.

Soil Type: N/A

Other: None.

Other Comments: None.

DESIGN

SLC: 0.44 (for 80 mm (3.125 in.) thick paver and 25 mm (1 in.) of bedding sand combined).

Other Design Values: None.

Base/Subbase Requirements: Unit pavers are placed on top of a 25 mm (1 in.) thick sand bedding layer. Base/subbase course(s) is (are) located under the bedding layer. Subgrade and aggregate base materials should be compacted to a minimum of 98% modified Proctor density and graded to provide a stable working surface prior to placement of the sand bedding layer and pavers. In addition, adequate drainage should be provided by the base to minimize infiltration into and softening of the subgrade.

Other Comments: The base/subbase course(s) is (are) the major structural element for the pavement system. Specific design guidelines are available from the various concrete paver supplier organizations. The road surface should be graded to promote surface runoff and prevent ponding on the road surface, typically a minimum 1.5% with similar cross slopes. This will maintain tire traction and help prevent wash out sand located between the pavers. Unit pavers can be installed in various patterns; however, a herringbone pattern is recommended for vehicular traffic.

CONSTRUCTION

Availability of Experienced Personnel: Specialty contractors are widely available in or near large urban areas. In remote areas, contractor availability may be limited and require mobilization of a work crew and equipment from a distant location.

Materials: Unit pavers are manufactured from portland cement concrete (PCC) and come in various shapes, colors, and dimensions. A graded sand conforming to the gradation of ASTM C 33 for concrete sand with no greater than 1% passing the 0.075 mm (No. 200) sieve is required for the bedding layer. Joint sand gradations typically conform to ASTM C 144.

Equipment: Equipment required for unit paver road construction includes: sand spreading equipment, vibratory plate compactor, hydraulic cutter or saw, and a broom. Equipment is widely available in most areas, but availability may be limited in remote areas. Special paver laying machines can be used to place multiple pavers at one time, but equipment availability may be limited outside of large urban areas. Paver laying equipment is economical when large, uniform areas of pavers must be placed.

Manufacturing/Mixing Process: Unit pavers are manufactured in plants and shipped to the site for placement. If paver laying machines are to be used for paver placement, the pavers must be stacked in the final laying pattern at the manufacturing plant prior to shipment. Some paver cutting may be required on site for pavers placed along the roadway edge.

Placement Process: Unit pavers are placed on top of a 25 mm (1 in.) thick sand bedding layer. The bedding sand should be clean, well-graded, and have a maximum particle size of 9.5 mm (0.375 in.). The pavers can be placed by hand or using special placement equipment. Pavers should be placed with uniform joint spacing; spacers can be used to ensure that the pavers are placed at the appropriate spacing. Edge restraints are placed along the roadway edge to prevent block movement and raveling at the road surfacing edge. Once placed, a vibratory plate compactor is used to seat the pavers in the bedding sand layer. Once the pavers are seated, sand is spread over the pavers and the vibratory plate compactor is used to vibrate the sand into the paver joints. This process may be repeated as necessary until the joints are filled. Once the joints are filled, excess sand is swept from the paver surface.

Weather Restrictions: Do not install unit pavers during rain or snow or place pavers over frozen base or bedding sand materials.

Construction Rate: Unit paver installation rates vary from 30 to 40 m^2/man-day (36 to 48 yd^2/man-day) for manual placement to 400 to 600 m^2/man-day (476 to 714 yd^2/man-day) for mechanical equipment placement. This includes screeding sand, placing and compacting the pavers, filling the joints with sand, a second compaction and removal of excess sand.

Lane Closure Requirements: The roadway lane(s) being constructed is closed during construction, so adequate traffic control is needed. The unit paver surface can be opened to traffic as soon as it is constructed. Road surface striping may be performed after the lane is opened.

Other Comments: None.

SERVICEABILITY

Reliability and Performance History: Similar to unit pavers, stone and brick paver roadways have been used for centuries. Manufactured concrete unit pavers have been used as a roadway surfacing since the 1960s; unit paver use grew rapidly in the 1980s. A significant 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 serviceable lives range from 20 to 40 years.

Ride Quality: Ride quality is typically fair to good but not as smooth as paved surfaces. The smoothness level is a function of workmanship and is usually adequate for low-speed applications. Ride quality deteriorates over the serviceable life.

Main Distress / Failure Modes: Rutting, differential settlement, paver distortion.

Preservation Needs: Periodic removal and replacement of pavers may be required in distorted areas. In addition, additional joint sand may be needed as well. Initial maintenance may be needed after the first year of service. Thereafter, maintenance is typically needed every 8 to 10 years.

SAFETY

Hazards: Rutting can lead to water accumulation on the pavement surface, causing a driving hazard. Unit pavers are occasionally used for mixed pedestrian and vehicular traffic. Regular inspection of the surface is required to identify and correct tripping hazards.

Skid Resistance: Provided high quality aggregates are used in paver construction, unit pavers provide adequate skid resistance for low speed applications.

Road Striping Possible?: Yes.

Other Comments: Different surface colors or patterns can be used to delineate specific areas, such as crosswalks or "No Parking" zones. Because low ride quality is typically associated with unit pavers, they can be used as a traffic calming tool.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: Unit pavers are constructed of portland cement and aggregates. Recycled materials such as fly ash are used to replace a portion of the cement content.

Delivery and Haul Requirements: Unit pavers must be hauled to the site. Depending on local availability, sand may need to be hauled to the site as well.

Potential Short-Term Construction Impacts: If clean aggregate is not used, dust can be a problem during construction and sweeping. Excess sand can be thrown/brushed/washed from the surface into the surrounding environment during construction.

Potential Long-Term Environmental Impacts:

Leachate: None.

Surface Runoff: Unit paver surfacings are permeable with infiltration through the joint sand (10-30% infiltration); however, there is still significant surface runoff. The amount of infiltration can decrease, leading to increased surface runoff, over time with clogging of the joint sand with sediment and detritus. Joint sand stabilization materials applied during construction significantly reduce water infiltration.

Erosion: Unit pavers are not susceptible to surface erosion. Some sand loss can occur from the paver joints.

Water quality: Unit pavers have a minimal impact on water quality. Water quality could be affected by sediment loading from sand washed from paver joints.

Aquatic species: None.

Plant quality: None.

Air Quality: None.

Other: None.

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

Other Environmental Considerations: Light-colored unit pavers can be used to reduce surface heat reflectivity. For unit pavers, tire/road noise is typically moderate to high. Noise levels can be controlled by selection of shape, pattern, and chamfer size.

AESTHETICS

Appearance: Unit pavers are available in numerous shapes and colors and can be placed in various patterns to create a visually pleasing surface.

Appearance Degradation Over Time: Unit pavers will maintain their general appearance over time with small changes. Surface polishing, color fading, and staining are possible over time.

COST

Supply Price: \$12 to \$15/m^2 (\$14 to \$18/yd^2) for paving units.

Supply+Install Price: \$36 to \$48/m^2 (\$30 to \$40/yd^2) for paving units, bedding and joint sand.

EXAMPLE PROJECTS

11^{th} Avenue Streetscape, Altoona, PA.
Iowa Avenue Streetscape, Iowa City, IA.

SELECT RESOURCES

Interlocking Concrete Pavement Institute, (202) 712-9036, www.icpi.org
Rollings, R.S., and Rollings, M.P. (1992). *Applications for Concrete Paving Block in the United States Market*, Uni-Group USA., 114 pp.
Smith, D.R. (2000). *Permeable Interlocking Concrete Pavements*, Interlocking Concrete Pavement Institute, 44 pp.

POROUS UNIT PAVERS

GENERAL INFORMATION

Generic Name(s): Porous Unit Pavers, Permeable Interlocking Concrete Pavement, Porous Pavement, Permeable Segmental Pavers

Trade Names: Numerous products available.

Product Description: Porous unit pavers have an interlocking geometry that results in regular void spacing through the completed pavement system. While the voids are filled with sand, they allow good stormwater infiltration while maintaining a driveable surface. The infiltrated water can be collected in a drainage layer and outlet to a storm collection system or can be stored in a specially designed reservoir layer within the pavement structure that allows the water to infiltrate downwards into the subgrade. In some designs, a sand-topsoil mix can be used in the paver openings to support grass. The unit pavers are accurately dimensioned dense concrete products that fit together to form a road surfacing. They transfer traffic loads similarly to flexible pavements and can handle differential settlements without cracking or losing surface integrity. Porous pavers are also similar to rigid pavements because they are resistant to point loads and are not affected by high temperatures. Pavers are available in numerous shapes and colors.

Porous unit pavers can also be constructed of high strength plastic. Plastic pavers typically have more void space than concrete unit pavers and are commonly filled with gravel, sand, or sand-topsoil mix.

Product Suppliers: Representative list of manufacturers, suppliers, and contractors can be obtained from: Interlocking Concrete Pavement Institute, 1444 I Street NW, Suite 700, Washington, D.C. 20005-2210, (202) 712-9036, www.icpi.org

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 unit paver products are available.

APPLICATION

Typical Use: Road surfacing.

Traffic Range: Very Low to Low.

Restrictions:

Traffic: Porous unit pavers are normally limited to low speed traffic applications with speeds less than about 30 km/hr (20 mph).

Climate: None.

Weather: None.

Terrain: Porous pavers are not recommended for roadway gradients steeper than 5%; roadway gradients as flat as possible are desired.

Soil Type: Porous pavers are 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 base 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 pavers have mainly been used for low volume parking lots and roads and recreational areas. They are also used for fire or emergency access lanes and for occasional use parking. For low use areas, many pavers can support grass growth and will maintain the appearance of a natural surface.

DESIGN

SLC: 0.44 (for paver and bedding sand combined)

Other Design Values: None.

Base/Subbase Requirements: Unit pavers are placed on top of a 25 to 50 mm (1 to 2 in.) thick sand bedding course, which is the same material used to fill the spaces between the pavers. The bedding sand is usually 100% passing 9.5 mm (0.375 in). Base/subbase course(s) is (are) located under the bedding sand layer. The base/subbase course(s) is (are) the major structural element for the pavement system. Specific design guidelines are available from the various concrete paver supplier organizations. Unless high permeability subgrade soils are present, a permeable base layer needs to be provided below the bedding layer to detain infiltrated stormwater and allow it to infiltrate into the subgrade. The infiltrated stormwater is filtered to some degree as it passes through the drainage layer.

The depth of the permeable base layer 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 paver and base course, and the subgrade has potential for frost heaving, additional material should be added to the base course to below the frost zone. The 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.

Other Comments: 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: Specialty contractors are widely available in or near large urban areas. In remote areas, contractor availability may be limited and require mobilization of a work crew and equipment from a distant location.

Materials: Unit pavers are manufactured from portland cement concrete (PCC) and come in various shapes, colors, and dimensions. Graded sand is required for the bedding layer. Permeable base materials are required for structural support and stormwater storage. Unit pavers manufactured of high strength plastic are also available.

Equipment: Equipment required for unit paver road construction includes: sand spreading equipment, vibratory plate compactor, hydraulic cutter or saw, and a broom. Equipment is widely available in most areas, but availability may be limited in remote areas. Special block laying machines can be used to place multiple pavers at one time, but equipment availability may be limited outside of large urban areas. Block laying equipment is economical when large, uniform areas of pavers must be placed.

Manufacturing/Mixing Process: Unit pavers are manufactured in plants and shipped to the site for placement. If block laying machines are to be used for paver placement, the pavers must be stacked in the appropriate pattern at the manufacturing plant prior to shipment. Some paver cutting may be required on site for pavers placed along the roadway edge.

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 base/subbase layer. Then, the base layer and 25 to 50 mm (1 to 2 in.) thick sand bedding course are placed and compacted. Porous unit pavers are placed on top of a sand bedding course. The bedding sand should be clean, well-graded, and have a maximum particle size of 9.5 mm (3/8 in.). The pavers can be placed by hand or using special placement equipment. Pavers should be placed with uniform spacing; spacers can be used to ensure that the pavers are placed at the appropriate spacing. Edge restraints are placed along the roadway edge to prevent block movement and raveling at the road surfacing edge. Once placed, a vibratory plate compactor is used to seat the pavers in the bedding sand layer. Once the pavers are seated, sand is spread over the pavers and the vibratory plate compactor is used to vibrate the sand into the paver joints. This process may be repeated as necessary until the joints are filled. Once the joints are filled, excess sand is swept from the paver surface.

Weather Restrictions: Do not install unit pavers during rain or snow or place pavers over frozen base materials.

Construction Rate: Unit paver installation rates vary from 17 to 125 m^2/man-day (20 to 150 yd^2/man-day) for manual placement to 210 to 420 m^2/man-day (250 to 500 yd^2/man-day) for mechanical equipment placement.

Lane Closure Requirements: The roadway lane(s) being constructed is closed during construction, so adequate traffic control is needed. The unit paver surface can be opened to traffic as soon as it is constructed. Road surface striping may be performed after the lane is opened.

Other Comments: None.

SERVICEABILITY

Reliability and Performance History: Manufactured concrete unit pavers have been used as a roadway surfacing since the 1960s; unit paver use grew rapidly in the 1980s. A significant 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 serviceable lives range from 20 to 25 years for porous concrete pavers.

Ride Quality: Ride quality is typically fair to good and inferior to most paved surfaces. The smoothness level is a function of workmanship and void space and is usually adequate for low-speed applications. Ride quality deteriorates over the serviceable life.

Main Distress / Failure Modes: Differential settlement, paver distortion, loss of sand and gravel from voids.

Preservation Needs: Periodic removal and replacement of pavers may be required in distorted areas. Additional joint sand may be needed as well to fill the paver voids. Initial maintenance may be needed after the first year of service. Thereafter, maintenance is typically needed every 8 to 10 years, except for the addition of sand in the voids every 1 or 2 years.

SAFETY

Hazards: Porous pavers are occasionally used for mixed pedestrian and vehicular traffic. They provide a rough surface for pedestrians and can constitute a tripping hazard if not properly maintained.

Skid Resistance: Porous unit pavers provide good skid resistance for low speed applications.

Road Striping Possible?: No.

Other Comments: Different surface colors or patterns can be used to delineate specific areas, such as crosswalks or "No Parking" zones. Because low ride quality is typically associated with unit pavers, they can be used as a traffic calming tool.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: Porous concrete pavers are constructed of PCC. Plastic pavers are constructed of high strength, high density polyethylene (HDPE). Sands are naturally occurring.

Delivery and Haul Requirements: Unit pavers must be hauled to the site. Depending on local availability, sand may need to be hauled to the site as well.

Potential Short-Term Construction Impacts: If clean aggregate is not used, dust can be a problem during construction and sweeping. Excess sand can be thrown/brushed/washed from the surface into the surrounding environment during construction.

Potential Long-Term Environmental Impacts:

Leachate: None.

Surface Runoff: Porous unit paver surfacings are permeable with significant infiltration through the paver voids; however, there may still be a small amount of surface runoff. The amount of infiltration can decrease, leading to increased surface runoff, over time with clogging of the void sand and vegetation growth.

Erosion: The material in the porous paver voids is susceptible to surface erosion. However, porous paver infiltration rates should be high enough to prevent significant surface runoff (leading to erosion), except during heavy storms.

Water quality: None. However, if the surface water infiltrating the pavement surface contains contaminates that are not easily trapped or reduced, the contaminants will flow through the pavement structure and be introduced into the surrounding soil and potentially into the groundwater.

Aquatic species: None. However, porous pavers can be a vehicle for contaminates to be introduced into nearby bodies of water by infiltrating into the surrounding soils and groundwater. Therefore, porous pavers are not recommended for areas near groundwater dinking supplies or other sensitive bodies of water.

Plant quality: None.

Air Quality: None.

Other: None.

Ability to Recycle/Reuse: Porous unit pavers can be reused if they are not damaged.

Other Environmental Considerations: Light-colored unit pavers can be used to reduce surface heat reflectivity.

AESTHETICS

Appearance: Unit pavers are available in numerous shapes and colors and can be placed in various patterns to create a visually pleasing surface. For low use applications, some pavers can support grass growth, which can result in the surfacing looking like a grass field from a distance.

Appearance Degradation Over Time: Unit pavers will maintain their general appearance over time with small changes. Surface polishing, color fading, and staining are possible over time.

COST

Supply Price: \$18 to \$21/m^2 (\$15 to \$18/yd^2).

Supply+Install Price: \$36 to \$48/m^2 (\$30 to \$40/yd^2).

EXAMPLE PROJECTS

Parking Area, Reliant Stadium, Houston, TX.

SELECT RESOURCES

Interlocking Concrete Pavement Institute, (202) 712-9036, www.icpi.org
Smith, D.R. (2000). *Permeable Interlocking Concrete Pavements*, Interlocking Concrete Pavement Institute, 44 pp.