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Glossary of Terms for Segmental Concrete Pavement

AASHTO: American Association of State Highway and Transportation Officials is an association that includes U.S. state and Canadian provincial highway engineers. AASHTO publishes structural design methods for pavement, material standards and test methods, as well as many other documents on roads, highways and transportation.

Abrasion: The mechanical wearing, grinding, scraping or rubbing away (or down) of paver surface by friction or impact, or both.

Absorption: Weight of water incorporated by a concrete paver unit during immersion under prescribed conditions, typically expressed as a percentage relating to the dry weight of the unit.

Admixture: Prepared chemicals added to the concrete during the mixing process to improve production efficiencies and/or hardened properties such as density, absorption, efflorescence control, visual appeal, durability and strength.

Aggregate: Sand, gravel, shell, slag, or crushed stone used in base materials, mixed with cement to make concrete, or with asphalt.

Albedo: The ratio of outbound reflected solar radiation from a pavement surface to inbound radiation.

Angularity: The sharpness of edges and corners of particles. Used to describe sand and aggregates.

Arris: The sharp or salient angle formed by the meeting of two surfaces.

Aspect Ratio: The overall length of a paver divided by its thickness. Example: A 4 in. (100 mm) wide by 8 in. (200 mm) long by 3 1 / 8 in. (80 mm) thick paver has an aspect ratio of 2.5. Compare to Plan Ratio.

ASTM C 936: American Society for Testing and Materials, Standard Specification for Solid Concrete Interlocking Paving Units. This product standard defines dimensions, dimensional tolerances, maximum absorption, minimum compressive strength, maximum abrasion and freeze-thaw durability through various test methods.

Aquifer: A porous, water-bearing geologic formation that yields water for consumption.

Band Cutter: A plier-like tool designed to cut metal or plastic bands around cubes and bundles of paving units without injury.

Base or Base Course: A material of a designed thickness placed under the surface wearing course of paving units and bedding course. It is placed over a sub-base or a subgrade to support the surface course and bedding. A base course can be compacted aggregate, cement or asphalt stabilized aggregate, asphalt or concrete.

Base Rake: A rake with a flat and toothed side to move and level aggregate base (similar in appearance to an asphalt lute). A base rake can be used to evenly spread joint sand on the surface of paving units for faster drying.

Bedding Sand Degradation Tests: Evaluation of the degree of attrition of sand. Tests are conducted with steel balls or other abrading devices agitated with a sand sample in a container. Pre and post-testing sieve analyses are conducted to determine the increase in fines. The tests are used to evaluate the durability of bedding sand under heavy loads or channelized traffic. Tests are often called Micro-Deval tests.

Bedding Sand or Bedding Course: A layer of coarse, washed sand screeded smooth for bedding the pavers. The sand can be natural or manufactured (crushed from larger rocks) and should conform to the grading requirements of ASTM C 33 or CSA A23.1 with limits on the percent passing the No. 200 (0.075 mm) sieve. A screeded sand layer is 1 to 1 1 / 2 in. (25 to 40 mm) thick.

Bentonite Clay: Clay with a high content of the mineral montmorillonite, usually characterized by high swelling on wetting that can be used to help seal paver joints.

Best Management Practice (BMP): A structural device or nonstructural program designed to reduce stormwater runoff and water pollution.

Bishop's Hat: A five-sided paver often used as an edge paver with a 45° herringbone pattern.

Bitumen: A class of asphalts combined with neoprene and used as an adhesive under unit paving.

Bitumen Setting Bed: A sand-asphalt mix used for a bedding layer typically less than 1 in. (25 mm) thick. Paving units are often adhered to the layer with a neoprene-asphalt adhesive.

Blending Pavers: Mixing colored concrete pavers from three or four cubes to insure an even color distribution.

Bulge or Belly: Convex sides of a concrete paver that are often due to excessive water in the concrete mix.

Bundle: Paver clusters stacked vertically, bound with plastic wrap and/or strapping, and tagged for shipment to and installation at the site. Bundles of pavers are also called cubes of pavers. Concrete paver bundles supplied without pallets are strapped together for shipment then delivered and transported around the site with clamps attached to various wheeled equipment. Bundles can also refer to a portion of paving units or band of pavers for transport around the site with wheeled equipment such as a bundle buggy.

Bundle Buggy: A wheeled device (with or without an engine) specifically designed to carry a band or portion of a cube of pavers around a job site.

California Bearing Ratio (CBR): A standardized soils test defined as the ratio of: (1) the force per unit area required to penetrate a soil mass with a 3 in. sq. (19 cm sq.) circular piston (approximately 2 in. (51 mm) diameter) at the rate of 0.05 in. (1.3 mm)/min, to (2) that required for corresponding penetration of a standard material. The ratio is usually determined at 0.1in. (2.5 mm) penetration, although other penetrations are sometimes used. See ASTM D 1883.

Cation: A positively charged atom or group of atoms in soil particles that, through exchange with ions of metals in stormwater runoff, enable those metals to attach themselves to soil particles.

Cement-Aggregate Ratio: The proportional weight of cement to fine and coarse aggregate in concrete. 2

Cement, Portland: Hydraulic cement produced by pulverizing clinker consisting essentially of hydraulic calcium silicates, and usually containing one or more forms of calcium sulfate.

Chamfer: A 45° beveled edge around the top of a paver unit usually 1 / 16 to 1 / 4 in. (2-6 mm) wide. It allows water to drain from the surface, facilitates snow removal, helps prevent edge chipping, and delineates the paving individual units.

Choke Course: A layer of aggregate placed or compacted into the surface of another layer to provide stability and a smoother surface. The particle sizes of the choke course are generally smaller than those of the surface into which it is being pressed.

Clay: Fine-grained soil or the fine-grained portion of soil that can be made to exhibit plasticity (putty-like properties) within a range of water contents, and that exhibits considerable strength when air-dry. The term can designate soil particles finer than 0.002 mm (0.005 mm in some cases).

Cluster: A group of pavers forming a single layer that is grabbed, held, and placed by a paver-laying machine typically on a sand bedding course.

Coarse Aggregate: Aggregate predominantly retained on the U.S. Standard No. 4 (4.75 mm) sieve; or that portion of an aggregate retained on the No. 4 (4.75 mm) sieve.

Compaction: The process of inducing close packing of solid particles such as soil, sand, or aggregate.

Compressive Strength: The measured maximum resistance of a concrete paver to loading expressed as force per unit cross-sectional area such as pounds per square inch or newtons per square millimeter (megapascals).

Concrete Block Pavement: A system of paving consisting of discrete, hand-sized paving units of either rectangular or dentated shapes, manufactured from concrete. Either type of shape is placed in an interlocking pattern, compacted into coarse bedding sand, the joints filled with sand and compacted again to start interlock. The paving units and bedding sand are placed over an unbound or bound aggregate layer. Also called interlocking concrete pavement.

Concrete Grid Pavers: Concrete units (generally small slabs) that have up to 50 percent open area. The units are generally no larger than 16 in. (400 mm) by 24 in. (600 mm). Aggregate or grass can be placed in the openings to promote infiltration of stormwater. Grids are generally used for intermittent parking, access lanes, abating runoff and/or controlling erosion. See ASTM C 1319, Standard Specification for Concrete Grid Paving Units for product standards.

Concrete Pavers: Concrete paving units, rectangular, square or dentated, capable of being placed with one hand into a laying pattern. The surface area is typically 100 in. 2 (0.065 m 2) and the overall length to thickness is 4 or less. Compare to Paving Slab.

Concrete Sand: Washed sand used in the manufacture of ready-mix concrete which conforms to the grading requirements of ASTM C 33 or CSA A23.1. See Bedding Sand.

Course: A row of pavers.

Creep: Slow lateral movement of pavers from horizontal forces such as braking tires. The movement is usually imperceptible except to observations over a long duration.

Crown: The slightly convex shape of a road cross section. It is beneficial to surface drainage and interlock.

Crushed Stone: A product used for pavement bases made from mechanical crushing of rocks, boulders, or large cobblestones at a quarry. All faces of each aggregate have well-defined edges resulting from the crushing operation.

Crusher Run: The total unscreened product of a stone crusher.

CSA-A231.2: Canadian Standards Association product standard for Precast Concrete Pavers (interlocking units) that defines standards for dimensions, minimum compressive strength, and durability under freeze-thaw cycles with deicing salt through various test methods.

Cube(s): Pavers stacked at the factory, strapped or wrapped, with or without a wooden pallet, for shipping and for transfer around the site. The cube has several layers of pavers. The number of layers and pavers on a cube varies with their thickness and shape. See Bundle.

Curve Number (CN): A numerical representation of a given area's hydrological soil group, plant cover, impervious cover, interception, and surface storage. A curve number is used to convert rainfall depth into runoff volume.

Deflection: The temporary movement of a pavement structure due to traffic loads.

Deformation: A change in the shape of the pavement.

Degradation Testing: Testing of sands or aggregate to determine resistance to change in particle size or gradation under loading.

Dense-Graded Aggregate Base: A compacted crushed stone base whose gradation yields very small voids between the particles with no visible spaces between them. Most dense-graded bases have particles ranging in size from 1 1 / 2 in. (38 mm) or 3 / 4 in. (19 mm) down to fines passing the No. 200 (0.075 mm) sieve.

Density: The mass per unit volume.

Dentated Paver: A unit that is not rectangular or square in shape.

Detention Pond or Structure: The temporary storage of stormwater runoff in an area with the objective of decreasing peak discharge rates and providing a settling basis for pollutants.

Drainage Coefficient: Factor used to modify layer coefficient of pavements. It expresses how well the pavement structure can handle the adverse effect of water infiltration. See Layer Coefficient.

Dry Mix Joint Sand Stabilizer: Joint sand treated with chemicals that when placed in contact with water, activates them to bind together the sand particles. This stabilizes the joint sand, reduces its permeability, sand loss and helps prevent weeds.

Edge Paver: A paving unit made with a straight, flush side, or cut straight for placement against an edge restraint.

Edge Restraint: A curb, edging, building or other stationary object that contains the sand and pavers so they do not spread and lose interlock. It can be exposed or hidden from view.

Efflorescence: A white deposit of calcium carbonate on concrete surfaces. It results from the reaction of calcium hydroxide with carbon dioxide from the air. The calcium hydroxide is a byproduct when cement hydrates. It is slightly soluble in water and migrates to the surface through capillary action. The calcium hydroxide remains on the surface, reacts with carbon dioxide, which forms calcium carbonate and water. This conversion, depending on weather conditions, will dissipate over time. Calcium carbonate is the most common type of efflorescence. The presence of efflorescence does not compromise the structural integrity and is not indicative of a flawed product.

Elastic Deformation: A reaction from applied loads where pavement returns to its original position after the load is removed. Compare to permanent deformation under Rutting.

Elephant's Foot: A solid extension formed as part of the bottom of the paver typically the result of a rounding at the bottom of the mold due to excessive wear. Also known as legs.

Embodied Energy: The energy used through the life-cycle of a pavement material or product to extract, refine, process, fabricate, transport, install, commission, utilize, maintain, remove, and ultimately recycle or dispose of pavement materials.

Engraved Pavers: Pavers that have been engraved with letters or images by molding during or after manufacture, shot blasting, wet cutting or that have a cast metal plate set into the surface.

Equivalent Single Axle Loads (ESALs): Summation of equivalent 18,000 pound-force (80 kN) single axle loads used to combine mixed traffic to a design traffic load for the design period; also expressed as Equivalent Axle Loads or EALs.

Erosion: The process of wearing away soil by water, wind, ice and gravity; also the detachment and movement of soil particles by the same forces.

Exfiltration: The downward movement of water through an open-graded, crushed stone base into the soil beneath.

Face Mix or Hard Facing: The application of a thin layer of fine aggregate and cement to the top surface of a concrete paver. The layer is often colored and is used to provide a more intense appearance, greater abrasion resistance, or provide a base for a textured finish.

Failure: The point at which a pavement does not adequately service its intended use. For flexible pavements, rut depth is often a criterion for failure.

False Joints: Grooves on the surface of concrete pavers that appear as full joints between pavers that contribute to the installed joint pattern. False joints can enhance the appearance of the pattern and speed installation compared to placing separate (sub) units. Sometimes called dummy grooves.

Fines: Silt and clay particles in a soil, generally those smaller than the No. 200 or 0.075 sieves.

Fineness Modulus: A factor obtained by adding the total percentages by weight of an aggregate sample retained on each of a specified series of sieves, and dividing the sum by 100; in the United States the standard sieve sizes are No. 100 (0.150 mm), No. 50 (0.300 mm), No. 30 (0.600 mm), No. 16 (1.18 mm), No. 8 (2.36 mm) and No. 4 (4.75mm), and 3 / 8 in. (9.5 mm), 1 1 / 2 in. (37.5 mm), 3 in. (75mm), and 6 in. (150 mm).

Finished Grade: The final elevation of a soil, base, or pavement surface which is often indicated on construction drawings. Also Finish Elevation.

Flash: A thin, brittle layer of cement around the bottom edges or at the top edges of a paver composed of cement, typically due to minor leakage of liquid cement between elements of the mold assembly. Also known as Flange.

Flexible Pavement: A pavement structure which maintains intimate contact with and distributes loads to the subgrade. The base course materials rely on aggregate interlock, particle friction, and cohesion for stability.

Flexural Strength: A property of a paver or slab that indicates its ability to resist failure in bending.

Flowable Fill: A low-strength concrete mix used to fill utility trenches and other excavated pavement openings; also known as unshrinkable fill or controlled low strength material (CLSM). See ASTM D 6103, D 6023, D 6024 and D 4832.

Freeze-Thaw Durability Testing: Tests in which pavers are exposed to cycles of freeze and thaw, partially or totally immersed in water, and with or without salt water.

Frost Action: Freezing and thawing of moisture in pavement materials and the resultant effects on them.

Frost Heave: The raising of a pavement surface due to the accumulation and expansion of ice in the underlying soil or rock.

Geogrids: Geogrids are two dimensional or three dimensional. The two dimensional type are flat and have small, "TV screen" shaped openings. The material is generally placed between the soil and the base to reduce rutting. Three dimensional geogrids are 4 to 8 in. (100 to 200 mm) high and provide stability under loads for cohesionless soils.

Geotextiles: Woven or non-woven fabrics made from plastic fibers used for separation, reinforcement, or drainage between pavement layers.

Gradation: Soil, sand or aggregate base distributed by mass in specified particle-size ranges. Gradation is typically expressed in percent of mass of sample passing a range of sieve sizes. See ASTM C 136.

Grade: (noun) The slope of finished surface of an excavated area, base, or pavement usually expressed in percent; (verb) to finish the surface of same by hand or with mechanized equipment.

Gravel: Rounded or semi-rounded particles of rock that will pass a 3 in. (75 mm) and be retained on a No. 4 (4.75 mm) U.S. standard sieve which naturally occurs in streambeds or riverbanks that have been smoothed by the action of water. A type of soil as defined by the Unified Soil Classification System having particle sizes ranging from the No. 4 (4. 75 mm) sieve size and larger.

Half Stone: A half of a paver.

Hard Edges: A field of pavers that is restrained against a visible edge restraint or curb, thus visually reinforcing the edge of pavement.

Herringbone Pattern: A pattern where joints are no longer than the length of 1 1 / 2 pavers. Herringbone patterns can be 45° or 90° depending on the orientation of the joints with respect to the direction of the traffic.

Hotspot: A land use that generates highly contaminated runoff with concentrations higher than those typical to stormwater.

Human Scale: Using paver sizes, patterns, colors and textures next to large buildings or open areas with the intent of reducing the user perception of being overwhelmed by the large scale of these spaces.

Hydrological Soil Group: The soils classification system developed by the U.S. Soil Conservation Service, now the Natural Resources Conservation Service that categorizes soils into four groups, A through D, based on runoff potential. A soils have high permeability and low runoff whereas D soils have low permeability and high runoff.

Impervious Cover: Surfaces that do not allow rainfall to infiltrate into the soil such as pavements, roofs, sidewalks, driveways, etc.

Infiltration Rate: The rate at which water moves through a soil tested in the field. Measured in inches per hour or meters per second. See ASTM D 3385 and 5093 and compare to Permeability.

Interlock: Frictional forces between paving units that prevent them from rotating, or moving horizontally or vertically in relation to each other; also defined as the inability of a concrete paver to move independently of its neighbors. The friction forces enable load transfer among the paving units. The three kinds of load transfer are vertical interlock, horizontal interlock and rotational interlock. Vertical interlock is achieved by shear transfer of loads to surrounding units through sand in the joints. Horizontal interlock is primarily achieved through the use of laying patterns that disperse forces from braking and accelerating vehicles. The most effective laying patterns for maintaining horizontal interlock are herringbone patterns. Rotational interlock is maintained by the pavers being of sufficient thickness, placed closely together, and being restrained by a stationary edge such as a curb.

Interlocking Concrete Pavement: A system of paving consisting of discrete, hand-sized paving units with either rectangular or dentated shapes manufactured from concrete. Either type of shape is placed in an interlocking pattern, compacted into coarse bedding sand, the joints filled with sand and compacted again to start interlock. The paving units and bedding sand are placed over an unbound or bound aggregate layer. Also called concrete block pavement.

Joint: The space between concrete paving units typically filled with sand.

Joint Filling Sand: Sand used to fill spaces between concrete pavers.

Joint Sand Gap: The vertical distance between the bottom of the chamfer on a paver and the top of the sand in the joint.

Joint Sand Stabilizer: Liquid penetrating or dry mix applied or materials that provide early stabilization of joint sand, reduces its permeability, sand loss and helps prevent weeds. See Dry Mix Joint Sand Stabilizer and Liquid Penetrating Joint Sand Stabilizer.

Joint Sand: Sand swept into the openings between the pavers.

Joint or Joint Spacing: The distance between the sides of the pavers not including the spacers that is typically filled with joint sand.

Karst Geology: Regions of the earth underlain by carbonate rock typically with sinkholes and/or limestone caverns.

K-pattern: A paving pattern with one square unit surrounded by rectangular units. Sometimes called an I-pattern.

Layer Coefficient: From the AASHTO pavement design procedure; a dimensionless number that expresses the material strength per inch (25 mm) of thickness of a pavement layer (surface, base, or sub-base). Example: The layer coefficient of 3 1 / 8 in. (80 mm) thick pavers and 1 in. (25 mm) bedding sand is 0.44 per in. (25 mm), therefore, the Structural Number (SN) = 4 1/8 x 0.44 = 1.82.

Layer or Cluster: A group of pavers manufactured in a laying pattern, generally placed by mechanical equipment.

Laying Face: The exposed, vertical face of a row of pavers on bedding sand; the working edge of the pavement where the laying of pavers occurs.

Laying Pattern: The sequence of placing pavers where the installed units create a repetitive geometry. Laying patterns may be selected for their visual or structural benefits.

Lean Concrete: Concrete of low-cement content used as a structural base material or as flowable fill in utility trenches.

Life-cycle Cost Analysis: A method of calculating all costs anticipated over the life of the pavement including construction costs. Discounted cash-flow methods are generally used, typically with calculation of present worth and annualized cost. Factors that influence the results include the initial costs, assumptions about maintenance and periodic rehabilitation, pavement user and delay costs, salvage value, inflation, discount rate, and the analysis period. A sensitivity analysis is often performed to determine which variables have the most influence on costs.

Lift: A layer of spread or compacted soil fill or aggregate. The rated compacted soil depth achieved by compaction equipment.

Lippage: The difference in vertical distance between the surface of one paving unit and an adjacent unit. An excessive amount of lippage is sometimes called fish scale.

Liquid Penetrating Joint Sand Stabilizer: Polymer liquid spread over the surface of pavers and allowed to penetrate the joint sand. After curing, the material stabilizes the joint sand, reduces its permeability, sand loss and helps prevent weeds.

Macro Texture: The deviations of a pavement surface from a true planar surface with dimensions generally 0.5 mm or greater or those that no longer affect tire-pavement interaction.

Markers: The use of concrete pavers with different colors, textures or shapes to mark underground utilities, traffic direction, parking stalls, lanes, pedestrian/vehicular areas, etc.

Mechanical Installation: The use of machines to lift and place layers of pavers on screeded sand in their final laying pattern. It is used to increase the rate of paving.

Mechanistic Design: Elastic analysis of structural response of applied loads through modeling of stresses and strains in a pavement structure.

Micro Texture: The deviations of a pavement surface from a true planar surface with dimensions generally less than 0.5 mm.

Modified Proctor Test: A variation of the Standard Proctor Test used in compaction testing which measures the density-moisture relationship under a higher compaction effort. See ASTM D 1557.

Modulus of Elasticity or Elastic Modulus: The ratio of stress to strain for a material under given loading conditions.

Moisture Content: The percentage by weight of water contained in the pore space of soil, sand or base, with respect to the weight of the solid material.

Mortar: A mixture of cement paste and fine aggregate (sand).

Mortar Sand: Sand used in mortar that typically conforms to ASTM C 144 or CSA A179.

Mosaics: Pavers used as pictorial maps, murals, or geometric patterns as a landmark, to emphasize an area, or suggest movement.

Multi-Colored Paver (Color Blend): A paver with two or more colors. The appearance is usually variegated.

Multi-layer Machine: A machine that manufacturers concrete paving units one layer at a time and places each layer consisting of a number of units on top of each other to form a cube that is allowed to cure prior to packaging for delivery to the site.

National Pollutant Discharge Elimination System (NPDES): A broad regulatory program that seeks to control water pollution by regulating point (sewage discharge) and non-point (runoff discharge) into streams, lakes and bays of the United States. The federal program is implemented at the state and local level via water pollution control plans and a permit system for sewage discharge, as well as runoff from construction sites, urban areas and farmland.

Nuclear Density Testing: The use of a nuclear density gauge to accurately and quickly assess the density and moisture content of soils and dense-graded aggregate in the field. The machine uses a probe inserted into the soil or base that emits very low intensity radiation. See ASTM D 2922.

Observation Well: A perforated pipe inserted vertically into an opengraded base to monitor infiltrate rate of water into the underlying soil.

One/One Hundred Year Storm: A rainfall event that occurs at least once a year and has a 100% chance of occurring within a given year/an event that occurs once in 100 years or has a 1% chance of occurring within a given year.

Open-graded Aggregate Base: A compacted crushed stone (granular) base whose gradation has relatively large spaces between the particles. It can be used as a drainage course in base design, or as a medium for storing stormwater in permeable pavements.

Optimum Moisture Content: The water content at which a soil can be compacted to a maximum dry unit weight by a given compactive effort.

Organic Impurities: Peat, roots, topsoil or decomposing materials in soil, sand or aggregate.

Organic Soil: Spongy, compressible soils usually consisting of peat humus or vegetative matter that have undesirable construction characteristics.

Outlet: The point at which water is discharged from an open-graded base through pipes into a storm sewer or watercourse.

Pavement Performance: The trend of service ability under repetitive loads.

Pavement Rehabilitation: Work undertaken to extend the service life of an existing pavement. This includes placement of additional surfacing material and/or other work necessary to return an existing roadway to a condition of structural or functional adequacy. This could include the complete removal and replacement of the pavement structure.

Pavement Structure: A combination of subbase, base course, and surface course placed on a subgrade to support traffic loads and distribute it to the roadbed.

Paver Extractor: A tool used to grab a paver and remove it from the laying pattern.

Paving Slab (or Flag): A paving unit with a surface area over 100 in. 2 (0.065 m 2) and with maximum length and width dimensions of 36 in. by 36 in. (915 mm x 915 mm). Its overall length to thickness ratio is greater than 4. Paving slabs do not rely on interlock as the principal means of load distribution.

Paver Splitter: A hand operated machine, sometimes hydraulically assisted, for cutting concrete pavers; also called a guillotine splitter.

Peak Discharge Rate: The maximum instantaneous flow from a detention or retention pond, open-graded base, pavement surface, storm sewer, stream or river; usually related to a specific storm event.

Performance: The total number of vehicle or ESAL applications withstood by a pavement before it reaches failure, rehabilitation, or a lower level of serviceability.

Performance Period: The period of time that an initially constructed or rehabilitated pavement structure will last (perform) before reaching its terminal serviceability. This is also referred to as the design period or life, expressed in years. Twenty years is normally used in North America.

Permeability: Measured in the laboratory, the rate of water movement through a soil column under saturated conditions, usually expressed as k in calculations per specific ASTM or AASHTO tests, and typically expressed in inches per hour or meters per second. See ASTM D 2434. Compare to Infiltration.

Permeable Interlocking Concrete Pavement: Concrete pavers with wide joints (l0 mm to 30 mm) or a pattern that creates openings in which rainfall and runoff can infiltrate. The openings are typically filled with aggregate and occasionally with topsoil and grass. The pavers are typically placed on an open-graded aggregate base which filters, stores, infiltrates, and/or drains runoff.

Pervious or Permeable Surfaces/Cover: Surfaces that allow the infiltration of rainfall such as vegetated areas.

Plan Ratio: The overall length of a paver divided by its width. Compare to Aspect Ratio.

Plastic Limit: (1) The water content corresponding to an arbitrary limit between the plastic and the semisolid states of consistency of a soil. (2) Water content at which a soil will just begin to crumble when rolled into a thread approximately 1 / 8 in. (3.2 mm) in diameter.

Plate Compactor: Also known as a plate vibrator, which is used to compact pavers into bedding sand in order to promote interlock among the individual units.

Poisson's Ratio: The ratio of transverse (lateral) strain to the corresponding axial (longitudinal) strain resulting from uniformly distributed axial stress below the proportional limit of the material; the value will average about 0.2 for concrete.

Porosity: The volume of voids in an open-graded base divided by the total volume of the base.

Pozzolanic Materials: Fly ash, pozzolan, silica fume, or blast furnace slag used as substitutes for cement. They are generally used in the concrete mix to increase density and durability of concrete pavers.

Prepared Roadbed: In-place roadbed soils compacted or stabilized according to provisions of applicable specifications.

Present Serviceability Index (PSI): A rating, usually between 0 (completely non-functional) and 5 (new/perfect) that generalizes several measurements of the condition of pavement. It is a convenient method of rating the overall condition and usefulness of a pavement over time and is from AASHTO pavement design methods.

Pre-treatment: BMPs that provide storage and filtering of pollutants before they enter another BMP for additional filtering, settling, and/or processing of stormwater pollutants.

Proctor Compaction Test: A test which measures the relationship of soil density with respect to soil moisture content under a standard compaction effort. This test identifies the maximum density obtainable at optimum moisture content. See ASTM D 698.

Progressive Stiffening: The tendency of pavements to stiffen over time. Interlocking concrete pavement stiffens as it receives increasing traffic loads thereby offering increased structural contribution structure; also referred to as "lock-up."

Pumping: The ejection of saturated bedding and joint sand, through joints or cracks or along edges of pavers when a load is applied.

Reflecting: Using pavers to mirror geometric patterns, shapes, colors or textures in the surrounding site.

Retention Pond: A body of water that collects runoff and stays full permanently. Runoff flowing into the body of water that exceeds its storage capacity is released into a storm sewer or watercourse.

Running Bond Course: A paver course or two where lengths abut against the edge restraint. Also known as a "sailor course."

Running or Stretcher Bond: A laying pattern with continuous joint lines in one direction and four pavers are staggered from one row to the next.

Rutting: Permanent deformation from repetitive traffic loading that exceeds the ability of the pavement structure to maintain its original profile.

Sand: Granular material passing the 3 / 8 in. (5 mm) and retained on the No. 200 (0.075 mm) sieve, made from the natural erosion of rocks, and consisting of subangular or rounded particles. Sands made by crushing of coarse aggregates are called manufactured sands.

Sand Spreaders: Broomed attachments to motorized equipment used to efficiently spread joint sand across the surface of segmental concrete pavements.

Screed Board or Strike Board: A rigid, straight piece of wood or metal used to level bedding sand to proper grade by pulling across guides or rails set on the base course or edge restraints.

Screed Guides or Bars: Grade strips such as pipe that will guide the screed in producing the desired elevation of the bedding sand.

Screenings: A residual product not suitable for bedding sand. It is a by-product from the crushing of rock, boulders, cobble, gravel, blastfurnace slag or concrete. Most of the aggregate passes the No. 4 (4.75 mm) sieve; typically limestone or granite.

Sealer: A material usually applied as a liquid that is used to waterproof, enhance color, and in some cases reduce abrasion of interlocking concrete pavements.

Sediment: Soils transported and deposited by water, wind, ice or gravity.

Segmental Pavement: A pavement whose surface consists of discrete units typically made of concrete, clay, or stone.

Shrinkage: The reduction in volume in soil when moisture content is reduced.

Silt: Soil finer than 0.02 mm and coarser than 0.002 mm (0.5 mm and 0.005 mm in some cases).

Single-layer Machine: A machine that manufactures concrete paving units one layer at a time and places each layer consisting of a number of units on individual boards or pallets to cure prior to packaging into cubes for delivery to the site.

Skid Resistance: A measure of the frictional characteristics of a surface with respect to tires.

Slip Resistance: Resistance against pedestrian slipping; defined as the ratio of a minimum tangential force necessary to initiate sliding of a pedestrian's shoe or related device over a surface. Non-mobility impaired persons require minimum coefficient of friction values ranging from 0.2-0.3. Wheelchair users require friction values ranging from 0.5-0.7. Crutch users and those with artificial limbs require values from 0.7 to 1.0. Clean concrete pavers generally have values exceeding 0.7.

Slump: A measure of consistency and water content of freshly mixed concrete. Slump is the subsidence measured from a specimen immediately after removal of a cone shaped mold. See ASTM C 143. Unlike ready-mixed concrete, pavers are zero slump concrete because of low water content. They are not tested for slump.

Soft Edges: A field of pavers with no visible edge restraint that meets grass or other vegetation, thus giving a soft appearance to the edge.

Soil Separation Fabric: A layer of fabric typically placed between the subgrade and the base to reduce rutting, also called a geotextile.

Soil Stabilization: Chemical or mechanical treatment designed to increase or maintain the stability of a mass of soil or otherwise to improve its engineering properties. Lime, fly ash or cement are typical chemical stabilization materials. Geotextiles and geogrids are typical mechanical materials for soil stabilization.

Soldier Course: A paver course where widths abut against the edge restraint.

Solid Color Paver: A paver with one color created by adding iron oxide, metal oxide, or other mixed metal oxide pigment to the concrete mix.

Spacer Bars, Spacers or Nibs: Small protrusions on each side of the paver (typically 1.5 to 2 mm) that maintain a minimum space so sand can fill into the joints. Spacer bars help prevent edge chipping and spalling. Some spacer bars stop short of the top surface, and are known as "blind spacers." They cannot be seen once the pavers have been installed.

Spall: A fragment, usually in the shape of a flake, detached from the edge or surface of a paver by a blow or sudden force, the action of weather, or pressure from adjacent pavers.

Stabilized Base: An aggregate base with cement, asphalt or other material added to increase its structural capacity. The soil subgrade can be stabilized with cement, lime, fly ash or other materials.

Stack Bond: A laying pattern in which the joints in both directions are continuous.

Standing Screed: Aluminum screed with handles allowing one person to pull it across bedding sand while standing (compared to kneeling while screeding).

Storm Water Pollution Prevention Plans (SWPPP): A principal requirement of stormwater permits issued under NPDES that identifies all potential sources of pollution which may reasonably be expected to affect the quality of storm water discharges from the construction site. A SWPPP also describes practices to be used to reduce pollutants in storm water discharges from the construction site and assures compliance with the terms and conditions of the construction permit. SWPPP requirements vary from state to state. (from Construction Industry Compliance Assistance Center)

Strain: The change in length per unit of length in a given direction.

Stress: The force per unit area.

Structural Number (SN): The basis of the flexible pavement design method developed by the AASHTO. It is a dimensionless number expressing the relative strength of a pavement structure. The SN is calculated from an analysis of traffic, roadbed soil conditions, and environment. The SN equals the sum of layer coefficients, with each coefficient quantifying the material strength and thickness of each pavement layer.

Sub-base: The layer or layers of specified or selected material of designed thickness placed on a subgrade to support a base course. Aggregate sub-bases are typically made of stone pieces larger than that in bases.

Subgrade: The soil upon which the pavement structure and shoulders are constructed.

Sustainable Development: Development (including pavement) that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Tactile Pavers: A paver detectable by sight impaired persons due to change in color or texture from surrounding surfaces. Changes in texture are achieved with detectable warnings.

Tensile Strength: Maximum unit stress which a paver is capable of resisting under axial tensile loading, based on the cross-sectional area of the specimen before loading.

Textured or Architectural Finish: Paver surfaces altered by the manufacturing mold or mechanical means, such as shot blasting, bush hammering, tumbling, grinding, polishing, flame treating, or washing. The purpose of such treatments is often to simulate the appearance of stone.

Time of Concentration: The time required for water to follow from the most remote point of a watershed or catchment to an outlet.

Topsoil: Surface soil, usually containing organic matter.

Urban Heat Island: An urban area that, due to denuded landscape, impermeable surfaces, surfaces with low albedo, massive buildings, heat generating cars and machines, and pollutants, is measurably hotter than surrounding rural areas.

Void Ratio: The volume of voids around the aggregate in an open-graded base divided by the volume of solids.

Water-Cement Ratio: The weight of water divided by the weight of cement in a concrete mixture. Concrete pavers typically have a water-cement ratio of 0.27 to 0.33, lower than ordinary concrete, which contributes to strength and durability.

Wearing course: Pavement surfacing consisting of segmental concrete pavements and joint sand on a sand bedding layer.

Wearing surface: The top surface that contacts traffic.

Weave or Parquet: A laying pattern where two or more pavers are placed side-by-side. Adjacent pavers are placed side-by-side, but turned 90° and alternated 90° throughout the pattern.

Zoning: Using different paver colors, textures, shapes, laying patterns, and surface elevations to delineate pedestrian and vehicular areas or districts.

References
Aggregate Producers Association of Ontario, *Construction Aggregate Consumers' Guide*, Downsview, Ontario, 1990. American Association of State Highway and Transportation Officials, *Guide for the Design of Pavement Structures*, 1993, Washington, D.C. ASTM International, *Annual Book of ASTM Standards*, Vols. 4.02, 4.03, 4.05, 4.08, 4.12, 2000, Conshohocken, Pennsylvania. Canadian Standards Association, "Precast Concrete Pavers," CSAA231.2-95, Rexdale, Ontario. 1995.

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ICPI TECH SPEC NUMBER · 2

Construction of Interlocking Concrete Pavements

Adequate compaction of the soil subgrade and aggregate base materials are essential to the long-term performance of interlocking concrete pavements.

Purpose
This technical bulletin gives construction guidelines to design professionals and contractors of interlocking concrete pavements. The bulletin reviews the steps in constructing an aggregate base, bedding sand and concrete pavers. This pavement structure is commonly used for pedestrian and vehicular applications. Pedestrian areas, driveways, and areas subject to limited vehicular use are paved with units 2 3 / 8 in. (60 mm) thick. Streets and industrial pavements should be paved with units at least 3 1 / 8 in. (80 mm) thick. Aggregate bases stabilized with asphalt or cement are recommended under very heavy loads, and over weak or saturated soil subgrades. These are sometimes used when adequate aggregates are not available or when a stabilized base is more economical than unstabilized aggregate. Concrete pavers made in the U.S. should meet or exceed the requirements established in the American Society for Testing and Materials (ASTM) C 936, Standard Specification for Solid Interlocking Concrete Paving Units. Requirements of this standard include a minimum average compressive strength of 8,000 psi (55 MPa), average absorption no greater than 5%, resistance to at least 50 freeze-thaw cycles with average material loss not exceeding 1%, and conformance to abrasion resistance tests. Concrete pavers made in Canada are required to meet or exceed requirements set forth by the Canadian Standards Association CSA-A231.2 Precast Concrete Pavers. This standard requires a minimum average cube compressive strength of 7,250 psi (50 MPa) or 5,800 psi (40 MPa) at delivery. There should be no greater than 500 g/m 2 of material lost after 50 freeze thaw test cycles while immersed in water with a 3% saline solution. Installation steps include job planning, layout, excavating and compacting the soil subgrade, applying geotextiles (optional), spreading and compacting the sub-base and/or base aggregates, constructing edge restraints, placing and screeding the bedding sand, and placing concrete pavers.

Job Planning
Prior to excavating, check with the local utility companies to ensure that digging does not damage underground pipes or wires. Many localities have one telephone number to call at least two days before excavation for marking utility line locations. Overhead clearances should be checked so that equipment does not interfere with wires. Site access by vehicles and equipment should be established so that the job can be built without delays.

Figure 1. Excavation of the soil subgrade.

Figure 2. Compacting the soil subgrade.

Layout

In preparing for excavation, the area to be removed should be marked with stakes. The stakes should be a slight distance away from the area to be removed so that they are not removed during excavation. The stakes should be marked to establish grades, or have string lines pulled and tied to them. Slopes should be a minimum of 1.5%. In the case of roads, the minimum longitudinal slope should be 1% with a minimum cross slope of 2%. Grade stakes should be checked periodically during the job to be sure that they have not been disturbed.

Excavating, Drainage and Compacting the Soil Subgrade
During and after excavation, the soil should be inspected for organic materials or large rocks. If organic materials, roots, debris, or rocks remain, they should be removed and replaced with clean, compacted backfill material. Free-standing water saturating the soil should be removed. After it is removed, low, wet areas can be stabilized with a layer of crushed stone and/or cement. Typical 4 in. (100 mm) diameter perforated drainage pipes surrounded with minimum 3 in. (75 mm) of No. 57 or similar open-graded stone is wrapped in geotextile. The surface of the stone is even with the top of the compacted soil subgrade. The stone and geotextile pipe assembly is placed along the pavement perimeter to remove excess water in the subgrade soil and base. The perforated pipe should be sloped and directed to outlets at the sides or ends of the pavement. The pipe outlets should be covered with screens to prevent animal ingress. Drainage is recommended in clay soils or other slow draining soils subject to vehicular traffic. Soil subgrade drainage extends pavement performance to the extent that the small additional investment is returned many times in additional pavement service years. Compaction of the soil subgrade is critical to the performance of interlocking concrete pavements. Adequate compaction will minimize settlement. Compaction should be at least 98% of standard Proctor density as specified in ASTM D 698. However, modified Proctor density (ASTM D 1557) is preferred, especially for areas under constant vehicular traffic. This compaction standard may not be achievable in extremely saturated or very fine soils. Stabilization of the soil subgrade may be necessary in these situations. Compaction equipment varies with the type of subgrade soil. Manufacturers of compaction equipment can provide guidance on which machines should be applied to various types of soil. Table 1 gives general guidance on applying the right machines to various soil types. Monitoring soil moisture content is important to reaching the compaction levels described above. Soil moisture and density measurements should be taken to control and verify the degree of compaction. The moisture content and compacted density of the subgrade soil should be checked for compliance to specifications before installing geotextiles.

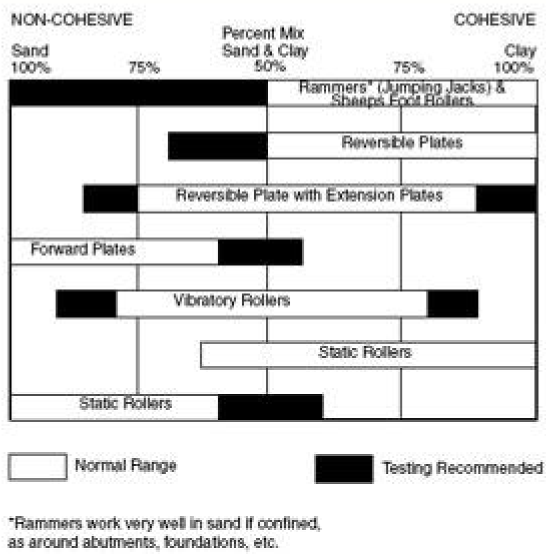

Table 1. Guide to the Application of Compaction Equipment to Various Soils (Courtesy of Vibromax 2000 Co.)

Table 2. Geotextile Physical Property Requirements[1]
< 50% geotextile elongation / > 50% geotextile elongation [2, 3]

Survivability Level	Grab Strength ASTM D 4632 (lbs)	Puncture Restistance ASTM D 4833 (lbs)	Trapezoid Tear Strength ASTM D 4533 (lbs)
High	270/180	100/75	100/75
Medium	180/115	70/40	70/40

Additional Requirements	Test Methods
Apparent Opening Size (AOS) <50% soil passing a No. 200 (75 μm) sieve, AOS <0.6 mm. >50% soil passing a No. 200 (75 μm) sieve, AOS < 0.3 mm.	ASTM D 4751
Permeability k of the fabric >k of the soil (permittivity times the nominal geotextile thickness).	ASTM D 4491
Ultraviolet Degradation At 150 hours exposure, 70% strength retained for all cases.	ASTM D 4355
Geotextile Acceptance	ASTM D 4759

[1] Values shown are minimum roll average values. Strength values are in the weaker principle direction.
[2] Elongation as determined by ASTM D 4632.
[3] The values of geotextile elongation do not imply the allowable consolidation properties of the subgrade soil. These must be deterrmined by separate investigation.

Recommeded Overlaps

Soil Strength (CBR)	Overlap Unsewn (in.)
Less than 1	----
1-2	38
2-3	30
3 & above	24

Applying Geotextiles (Optional)
Geotextile fabric may be used in areas where soil remains saturated part of the year, where there is freeze and thaw, or over clay and moist silty subgrade soils. As a separation layer, they prevent soil from being pressed into the aggregate base under loads, especially when saturated, thereby reducing the likelihood of rutting. When geotextiles are used they preserve the load bearing capacity of the base over a greater length of time than placement without them. Woven or non-woven fabric may be used under the base with a minimum equivalent opening size of No. 3050 sieve. Table 2 lists minimum requirements of geotextiles for base consolidation and soil separation. These are from Task Force 25 AASHTO Guide Specification and Test Procedures for Geotextiles (1990). The minimum down slope overlap should be at least 12 in. (300 mm). When the fabric is placed in the excavated area, it should be turned up along the sides of the opening, covering the sides of the base layer. There should be no wrinkles on the bottom. When the aggregate is dumped on the fabric, the tires from trucks should be kept off the fabric to prevent wrinkling.

Spreading and Compacting the Sub-base and/or Base Aggregates
Specifications typically used by cities, states, or provinces for aggregate base materials under flexible asphalt pavements are adequate for interlocking concrete pavements. If no specifications are available use the recommended grading for the aggregate base shown in Table 3. Spread and compact the base in 4 to 6 in. (l00 to 150 mm) lifts. High force compaction equipment can compact thicker lifts. Consult with compaction equipment manufacturer for guidance. Frozen base material should not be installed, nor should material be placed over a frozen soil subgrade. The thickness of the base is determined by traffic, soil type, subgrade soil drainage and moisture, and climate. Sidewalks, patios and pedestrian areas should have a minimum base thickness (after compaction) of 4 in. (100 mm) over well-drained soils. Residential driveways on well-drained soils should be at least 6 in. (150 mm) thick. In colder climates, continually wet or weak soils will require that bases be at least 2 to 4 in. (50 to100 mm) thicker.

Figure 3. Application of the geotextile under aggregate base.

Table 3. Grading Reqirements for Dense Graded Material

Sieve Size (Square Openings)	Design Range[a] %Passing Bases	Design Range[a] %Passing Subbases	Job Mix Tolerance %Passing Bases	Job Mix Tolerance %Passing Subbases
2" (50 mm)	100	100	–2	–3
1 1/2" (37.5 mm)	95-100	90-100	±5	±5
3/4" (19 mm)	70-89	—	±8	—
3/8" (9.5 mm)	50-70	—	±8	—
No. 4 (4.75 mm)	35-55	30-60	±8	±10
No. 30 (600 µm)	12-55	—	±5	—
No. 200 (75 µm)	0-8[b]	1-12[b]	±3	±5

[a] Job mix formula should be selected with due regard to availability of materials in the area of the project. Job mix tolerances may permit acceptance of test results outside the design range.

[b] Determine by wet sieving. Where frost and free moisture are indicative of site conditions, a lower percentage passing the No. 200 (75 µm) sieve shall be specified.

Note: ASTM D 2940 corresponds closely to this National Stone Association developed specification. While local or state highway specifications may be substituted for the design ranges above, the fraction finer than the No. 200 (75 µm) sieve should be maintained.

Local, state or provincial engineering standards for base thickness can be applied to streets constructed with interlocking concrete pavers. Non freeze-thaw areas with well-drained soils should have at least a 6 in. (150 mm) thick base. Minimum base thicknesses for residential streets are 8 to 10 in. (200 to 250 mm). Greater thicknesses are often used in regions with numerous freeze-thaw cycles, expansive soils, or very cold climates. A qualified civil engineer familiar with local soils and traffic conditions should be consulted to determine the appropriate base thickness for streets and heavy-duty, industrial pavements. Many localities determine base thickness with the 1993 Guide for the Design of Pavement Structures published by the American Association of State Highway and Transportation Officials (AASHTO). The AASHTO procedure calculates the structural number (SN) of the strength coefficients of each base and pavement layer. The SN is determined by assessing the traffic loads, soils, and environmental factors (e.g., drainage, freeze-thaw). The layer coefficient recommended for 3 1 / 8 in. (80 mm) thick pavers on 1 in. (25 mm) bedding sand is 0.44 per inch (25 mm), i.e., the SN = 4 1 / 8 x 0.44 = 1.82. Base thicknesses can be readily determined by using the charts in I CPI Tech Spec 4, Structural Design of Interlocking Concrete Pavement for Roads and Parking Lots or ICPI Lockpave Software. Like compaction of the soil subgrade, adequate compaction of the base is critical to minimizing settlement of interlocking concrete pavements. Special attention should be given to achieving compaction standards adjacent to edge restraints, catch basins and utility structures. When spread and compacted, the aggregate base should be at its optimum moisture. Bases for pedestrian areas and residential driveways should be compacted a minimum 98% of standard Proctor density. For vehicular areas, compaction should be at least 98% of modified Proctor density as determined by ASTM D 1557, or AASHTO T180. While the highest percentage compaction (100%) is preferred, it may not be achievable on weak or saturated soils. Density measurements of the compacted base should be made a nuclear density gauge or other methods approved by the local, state or provincial transportation department. Unless otherwise specified, the compacted thickness of individual lifts and the final base should be + 3 / 4 in. to 1 / 2 in. (+19 mm to 13 mm). Maintaining consistent lift thickness during compaction will help achieve consistent density. Variation in final base surface elevations should not exceed + 3 / 8 in. (+10 mm) when tested with a 10 ft. (3 m) straightedge. The finished surface of a compacted aggregate base should not allow bedding sand to migrate into it. If the surface will allow ingress of bedding sand, a choke course of fine material can be spread and compacted into the surface, or a bitumen tack coat can be applied. The surface of the base course and its perimeter around the edge restraints should be inspected for areas that might allow sand to migrate after installation. Such locations can be joints in curbs, around utility structures or catch basins. These areas should be covered with a geotextile fabric to prevent loss of the bedding sand.

Constructing Edge Restraints
Edge restraints are a key part of interlocking concrete pavements. By providing lateral resistance to loads, they maintain continuity and interlock among the paving units. Aluminum, steel, plastic, or concrete are typical edge restraints. Consult ICPI Tech Spec 3 on edge restraints for recommendations on applications and construction. Edge restraints must be set at the correct level, especially if the tops of the restraints are used for screeding the bedding sand. Their elevations should be checked prior to placing the sand and pavers. Edge restraints are typically installed before the bedding sand and pavers are laid. However, some restraints can be secured into the base as the laying progresses.


Figure 4. Base compaction with a vibratory roller.


Figure 5. Density testing of the aggregate base with a nuclear density gauge.

Placing and Screeding the Bedding Sand

Bedding sand under concrete pavers should conform to ASTM C 33 or CSA A23.1. This material is often called concrete sand. Masonry sand for mortar should never be used for bedding, nor should limestone screenings or stone dust. The bedding sand should have symmetrical particles, generally sharp, washed, with no foreign material. Waste screenings or stone dust should not be used, as they often do not compact uniformly and can inhibit lateral drainage of moisture in the bedding sand. ICPI Tech Spec 17-Bedding Sand Selection for Interlocking Concrete Pavements in Vehicular Applications provides additional guidance on selecting bedding sand. Bedding sand should be spread and screeded to a nominal 1 in. (25 mm) thickness. Frozen or saturated sand should not be installed. If there is an uneven base (due to inconsistent compaction or improper grading), the bedding sand should not be used to compensate for it. Over time, unevenness in the bedding sand will reflect through to the surface. Uneven areas on the base surface must be made level prior to placing the bedding sand. Once the base is complete, screed pipes or rails are placed on it and the bedding sand spread over them. The sand is screeded or smoothed across the pipes with a straight and true strike board. Screed pipes are removed and the resulting void filled with bedding sand. After the sand is screeded it should not be disturbed. Sufficient sand is placed and screeded to stay ahead of the placed pavers. Powered screeding machines that roll on rails and asphalt spreading machines adapted for screeding sand have been successfully used on larger installations to increase productivity.


Figure 6. Screeding the bedding sand.


Figure 7. Placing the concrete pavers.

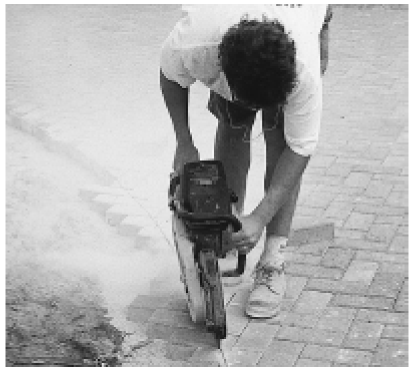

Figure 8. Saw cutting pavers.

Placing the Concrete Pavers

Concrete pavers can be placed in many patterns depending on the shapes. Herringbone patterns (45 or 90 degree) are recommended in all street applications, as these interlocking patterns provide the maximum load bearing support, and resist creep from starting, braking and turning tires. Chalk lines snapped on the bedding sand or string lines pulled across the surface of the pavers are used as a guide to maintain straight joint lines. Buildings, concrete collars, inlets, etc., are generally not straight and should not be used for establishing straight joint lines. Joint widths between the pavers should be consistent and be between 1 / 16 and 3 / 16 in. (2 and 5 mm). Some pavers are made with spacer bars on their sides. These maintain a minimum joint width, allowing the sand to enter between each unit. Pavers with spacers are generally not placed snug against each other since string lines guide consistent joint spacing. Cut pavers should be used to fill gaps along the edge of the pavement. Pavers are cut with a double bladed splitter or a masonry saw. A saw gives a smooth cut. Gaps less than 3 / 8 in. (10 mm) should be filled with sand or filled by shifting courses of pavers. After an area of pavers is placed, it should be compacted with a vibrating plate compactor, which should be capable of exerting a minimum of 5,000 lbs. (22 kN) of centrifugal compaction force and operate at 75-90 hertz. At least two passes should be made across the pavers to seat the pavers in the bedding sand and force it into the joints at the bottom of the pavers. Dry joint sand is swept into the joints and the pavers compacted again until the joints are full. This may require two or three passes of the plate compactor. If the sand is wet, it should be spread to dry on the pavers before being swept and compacted into the joints. Joint sand may be finer than the bedding sand to facilitate filling of the joints. Bedding sand also can be used to fill the joints, but it may require extra effort in sweeping and compacting. Compaction should be within 6 ft (2 m) of an unrestrained edge or laying face. All pavers within 6 ft (2 m) of the laying face should have the joints filled and be compacted at the end of each day. Excess bedding sand is then removed. The remaining uncompacted edge can be covered with a waterproof covering if there is a threat of rain. This will prevent saturation of the bedding sand, minimizing removal and replacement of the bedding sand and pavers. Final surface elevations should not vary more than + 3 / 8 in. (+10 mm) under a 10 ft (3 m) straightedge, unless otherwise specified. Bond or joint lines should not vary ± 1 / 2 in. (15 mm) over 50 ft (15 m) from taut string lines. The top of the pavers should be 1 / 8 to 3 / 8 in. (3 to 10 mm) above adjacent catch basins, utility covers, or drain channels, with the exception of areas required to meet ADA design guideline tolerances. The top of the installed pavers may be 1 / 8 to 1 / 4 in. (3 to 6 mm) above the final elevations to compensate for possible minor settling. A small amount of settling is typical of all flexible pavements. Optional sealers or joint sand stabilizers may be applied. See ICPI Tech Spec 5Cleaning, Sealing and Joint Sand Stabilization of Interlocking Concrete Pavement for further guidance. ICPI Tech Spec 9A Guide Specification for the Construction of Interlocking Concrete Pavement helps translate construction methods and procedures described here into a construction document. Tech Spec 9 provides a template for developing project-specific materials and installation specifications for the bedding and joint sand, plus the concrete pavers. Additional guide specifications and detail drawings for various applications are available at www.icpi.org as well as ICPI Tech Specs. Other ICPI Tech Specs and technical manuals should be referenced for information on design, detailing, construction and maintenance.

Figure 9. Compacting the pavers and bedding sand.

Figure 10. Spreading and sweeping joint sand.

Figure 11. Vibrating sand into the joints.

Figure 12. Excess sand swept from the finished surface will make the pavement ready for traffic.

References

National Stone Association, Flexible Pavement Design Guide for Roads and Streets. Fourth Edition, Washington, D.C., January 1985.
National Stone Association, Stone Base Construction Handbook, Second Edition, Washington, D.C., September 1988.

Figures 1-3,6,7,9-10,12 are courtesy of the Waterways Experiment Station, U.S. Army Corp of Engineers. Figure 5 is courtesy of the Portland Cement Association.

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ICPI TECH SPEC NUMBER · 3

Edge Restraints For Interlocking Concrete Pavements

Introduction

Edge restraints are an essential component of interlocking concrete pavements. Restraints hold the pavers tightly together, enabling consistent interlock of the units across the entire pavement. They prevent spreading of the pavers from horizontal forces from traffic. Edge restraints are designed to remain stationary while receiving impacts during installation, from vehicles and from freeze-thaw cycles. The following is a discussion of methods of restraining concrete pavers placed on bedding sand and installed on a base. This is the prevailing method of construction. Edge restraints are needed for concrete pavers joined to a rigid base with mortar, bitumen/neoprene, or polymer adhesive.

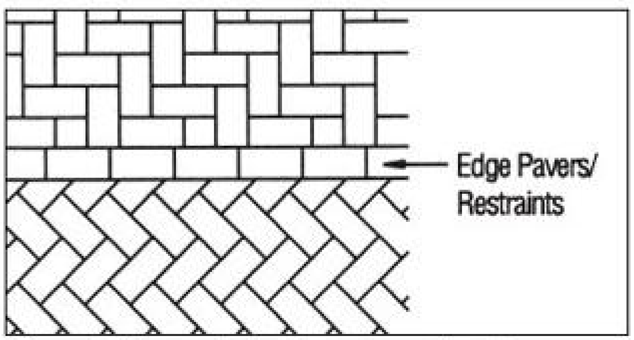

Figure 1. Change in laying pattern direction.

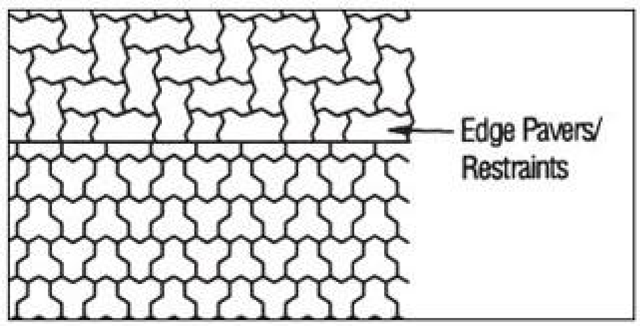

Figure 2. Change in paver shape.

Figure 3. Ramp pavers changing angle.

Design Considerations

Restraints are required along the perimeter of interlocking concrete pavements, or where there is a change in the pavement material. For example, when a laying pattern changes direction, there may be a need for an edge paver to act as a restraint (Figure 1). When a paver shape changes within an area of paver, the edge paver at the end of each pattern can serve as a restraint (Figure 2). If there is a change in slope, a straight edge should be formed at the top, with the pavers and the pattern resumed down the slope (Figure 3). Vertical walls of buildings can also provide a suitable restraint. Some edge restraints require spiking to an aggregate base. The rule of thumb is that the base extend beyond the restraint at least the same dimension as the thickness of the base material. For example, if the base is 6 in. (150 mm) thick, then it should extend at least 6 in. (150 mm) beyond the spikes in the restraints. This contributes stability to the restraint, especially in soils subject to heaving. Soil backfill is never a suitable edge restraint, and edge restraints should never be installed on top of the bedding sand. If there is a possibility of sand loss from beneath the pavers or between the joints of the edge restraints, geotextile (filter cloth) is recommended to prevent its migration. A 12 in. (0.3 m) wide strip can be applied along the base and turned up along the sides of the restraints. Filter cloth generally is not required across the entire surface of an aggregate base, nor should it be placed on top of the bedding sand.

	Precast Concrete Cut Stone	Steel Aluminum Troweled Concrete	Plastic	Poured Concrete and Walls
Sidewalks-no vehicular traffic	•	•	•	•
Plazas—no vehicular traffic	•	•	•	•
Residential driveways	•	•	•	•
Crosswalks in asphalt or concrete streets	•	•	•	•
Commercial/Industrial driveways	•		•	•
Parking lots	•		•	•
Streets—all types	•			•
Utility covers	•			•
Gas stations	•			•
Industrial flooring				•
Trucking terminals				•

Table 1. Application guide for edge restraints

Types of Edge Restraints
Table 1 shows the types of edge restraints and their application. There are two general types of edge restraints. Those made elsewhere and installed at the site include precast concrete, plastic, cut stone, aluminum and steel. Restraints formed on-site are made of poured-in-place concrete.

Manufactured Edge Restraints
Full depth precast concrete or cut stone edging generally extends the depth of the base material. They can be set on compacted aggregate or concrete backfill (Figure 4).

Partial depth precast concrete edge restraints may be used for residential and light duty commercial applications. (Figure 5). These precast units are anchored on a compacted aggregate base with steel spikes. The spikes are typically 3 / 8 in. (10 mm) diameter. Depending on the design, the top of the concrete edge can be hidden or exposed.

Plastic edging installs quickly and will not rust or rot. Plastic edging should be specifically designed for use with pavers. It can be used with light duty residential, commercial or on some heavy duty, industrial applications, depending on the design. It should be firmly anchored into the compacted aggregate base course with spikes (See Figure 7). The spikes should penetrate well into the aggregate base. Spikes do not need to penetrate the bottom of the base. Consult the manufacturer's literature for the recommended spacing of the spikes. Edging for planting beds and flower gardens is not an acceptable restraint for interlocking concrete pavements.

Aluminum and steel edging should be selected to provide a smooth vertical surface against the pavers. L-shaped edging provides additional stability. Stakes or spikes fastened to the edging should be below the pavers or on the outside of the restraints. Steel should be painted or galvanized so that rust does not stain the pavers. Consult manufacturer's literature for recommended spacing of the spikes. Spikes to secure steel and aluminum edging should extend well into the base course (Figure 6). Like plastic edging, spikes used for aluminum or steel edging should never be placed into the soil. Aluminum and steel edgings are manufactured in different thicknesses. The thickest edging is recommended when pavers are subjected to vehicular traffic. Timber is not recommended for an edger restraint because it warps and eventually rots. Elevations should be set accurately for restraints that rest on the base. For example, 2 3 / 8 in. (60 mm) thick pavers with 1 in. (25 mm) of bedding sand would have a base elevation set 3 in. (75 mm) below that of the finish elevation of the pavers. This allows 1 / 4 in. (7 mm) settlement from compaction and 1 / 8 in. (3 mm) for minor settling over time.

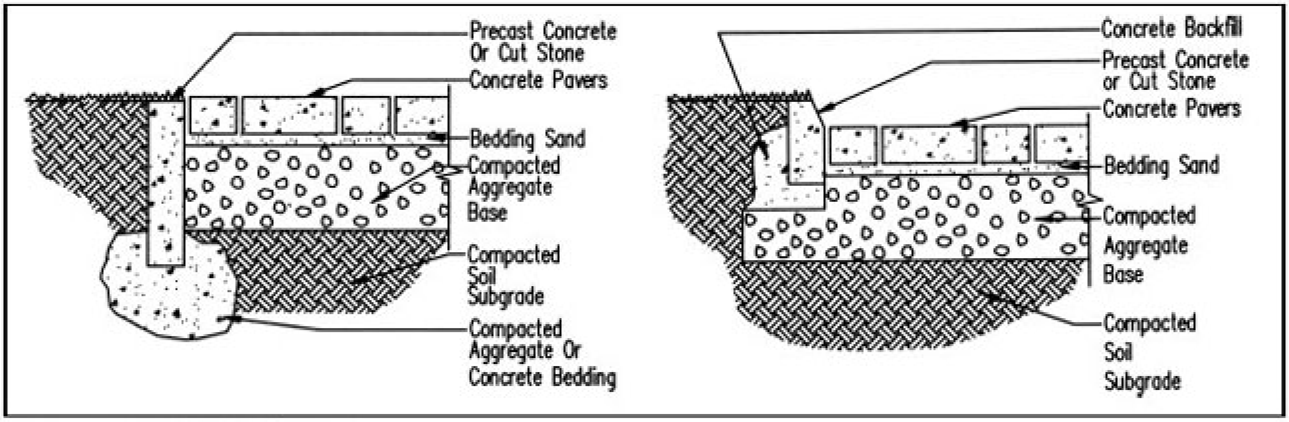

Figure 4. Precast concrete/cut stone.

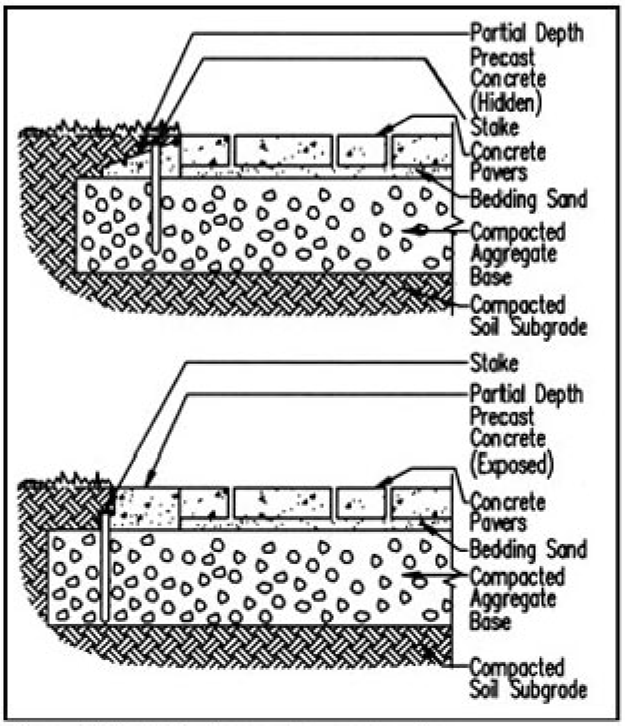

Figure 5. Partial depth precast concrete edge.

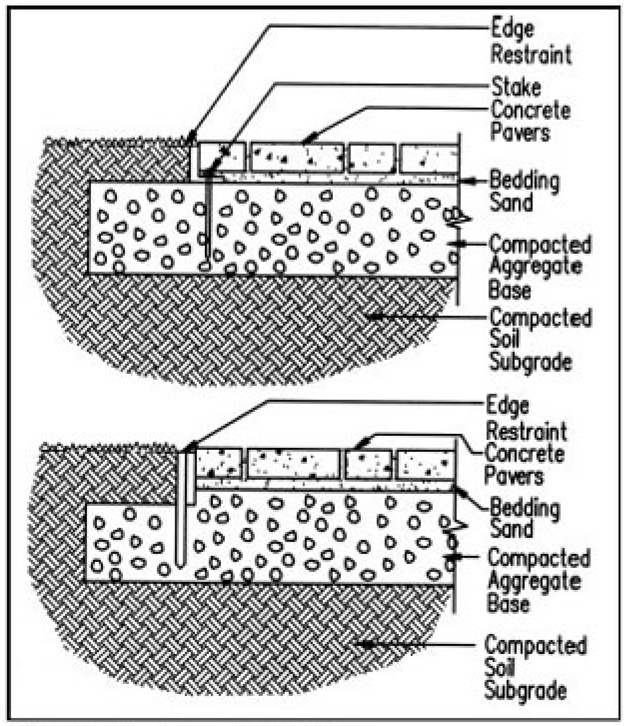

Figure 6. Aluminum and steel edging.

Restraints Formed On-site

Poured-in-place concrete curbs or combination curb and gutters required by municipalities make suitable restraints for pavers. Exposed concrete edges should have a 1 / 8 in. (3 mm) radius edge to reduce the likelihood of chipping. As with precast, the side of the curbs should extend well below the sand bedding course (Figure 8). Complete compaction of the soil subgrade and base next to these curbs is essential to preventing settlement of the pavers. Troweled concrete from a bag mix or batched onsite can be applied without forms against edge pavers and on the compacted base. When mixed on-site the aggregate (sand and crushed stone)-cement ratio should be at least 5 to 1. If the top of the concrete edge is recessed and slopes away from the pavers, grass can grow next to them (Figure 9). The depth below the surface of the pavers must be sufficient to prevent the concrete from becoming a heat sink that dries the grass and topsoil. This edge restraint is suitable for pavers subjected to pedestrian traffic and for residential driveways. Troweled edges should be at least 6 in. (150 mm) wide and of sufficient thickness to cover at least two-thirds of the side of the edge pavers, bedding sand layer, and a minimum of 2 in. (50 mm) into the base. Steel reinforcing can be placed in the concrete to increase service life. Compacting units against troweled concrete should be done after the concrete has set. Care should be taken to ensure that the plate compactor does not crack the concrete edge or loosen pavers imbedded in it. If the concrete is left to cure for a few days prior to compacting the pavers, the edges should be covered with plastic sheeting to prevent water from settling the uncompacted bedding sand. If water is allowed to enter bedding sand of any installation, it will be difficult to compact the pavers into it. The pavers will need to be removed, the saturated bedding sand removed, unsaturated sand installed, and the pavers replaced and compacted. Troweled concrete edges are not recommended in freezing climates as they may crack and be an ongoing maintenance problem. A concrete curb or edge that is "submerged" or hidden can be used to restrain concrete pavers. See Figure 10. The top surface of the concrete edge has pavers mortared to it. Acrylic fortified mortar is recommended and pavers exposed to freeze-thaw and deicing salts should be applied with high-strength epoxy materials. The minimum cross section dimensions of the curb should be 8 in. x 8 in. (200 mm x 200 mm). These dimensions apply to residential driveways and low volume streets. Larger sized curbs will be required in higher traffic areas or for support over weak soil. The concrete edge may require a layer of compacted aggregate base as a foundation. The width of concrete will need to be equal to the width of whole pavers mortared to it. This detail should not be used in heavy traffic areas such as major urban streets with regular truck or bus traffic.

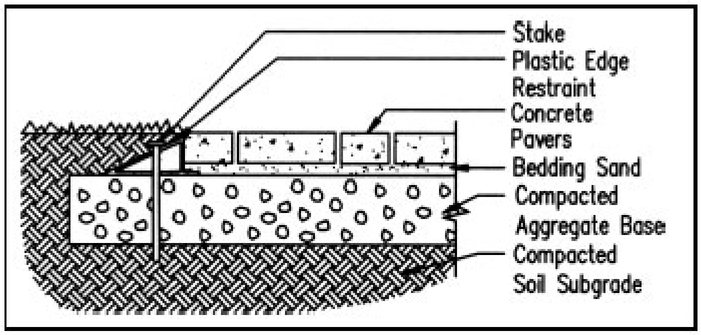

Figure 7. Plastic edge restraint.

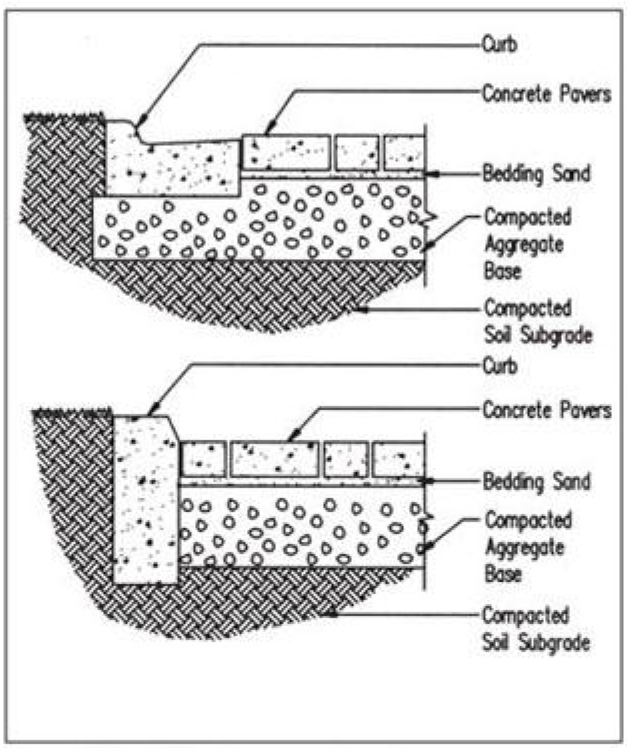

Figure 8. Poured-in-place concrete curbs.

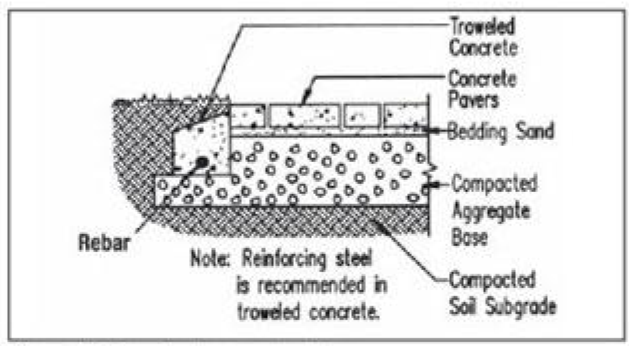

Figure 9. Troweled concrete edges.

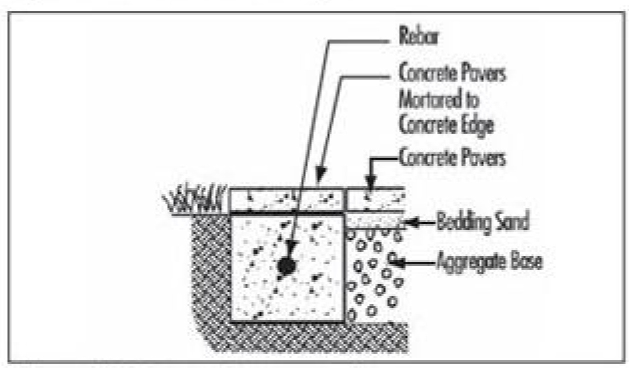

Figure 10. Submerged concrete edge.

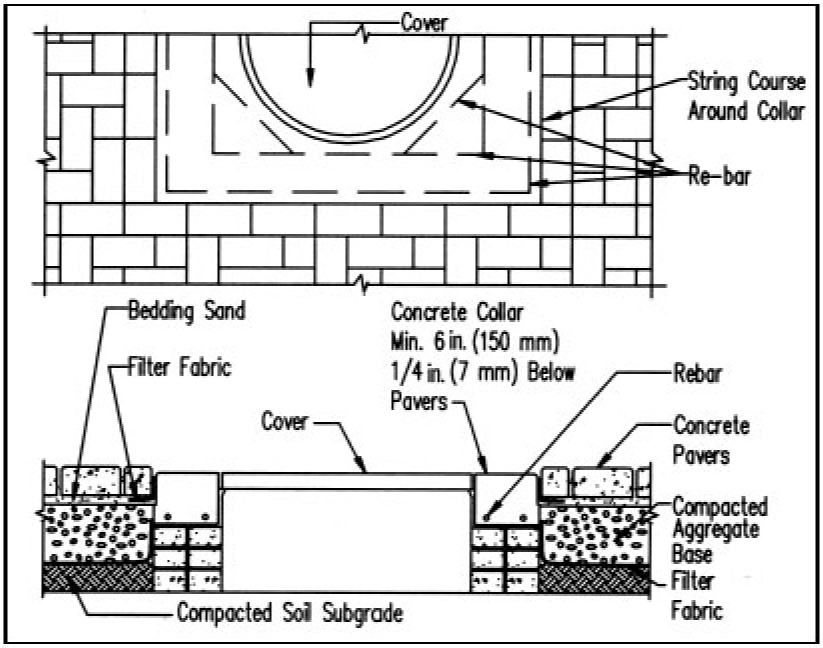

Figure 11. Utility cover.

Other Design Considerations
Paver sidewalks against curbs-Joints throughout poured-in-place or precast concrete curbs should allow excess water to drain through joints in them without loss of bedding sand. If there are no joints, weep holes placed at regular intervals will prevent the sand from migrating. A 1 in. (25 mm) diameter hole every 15 ft. (5m) is a recommended spacing. The bottom of the holes should be at the same elevation as the top of the base. They should be covered with filter cloth to prevent loss of bedding sand. Joints in curbs often have expansion material in them. This material tends to shrink and decompose. Filter cloth placed over these joints will prevent the sand from migrating. Expansion joint materials are not required between the pavers and the curb.

Utility covers in streets and walks (e.g., sewers, water and gas valves, telephone, electrical,) should have concrete collars around them. Consistent compaction of aggregate base against cast iron collars is difficult, so a concrete collar placed around them after base compaction reduces the potential for settlement. Concrete collars should be 1 / 4 in. (6 mm) below the pavers to prevent catching snowplow blades (Figure 11). Drain and catch basin inlets should have a concrete collar around them if they are not encased in concrete. When overlaying existing asphalt or concrete streets with pavers and bedding sand, utility covers are raised and new concrete collars poured around them. When raised, the covers and frames should be inspected for cracks that might allow migration of sand. Cracks should be repaired. Filter cloth should be applied on the base around the concrete collar, turned up against the collar to prevent sand loss.

Catch basins-During the early life of interlocking concrete pavement, there may be a need to drain excess water from the bedding sand. Drain holes may be drilled or cast into the sides of catch basins to facilitate this. The bottom of the holes are at the same elevation as the bottom of the base. Space holes at least 12 in. (0.3 m) apart, and make 1 in. (25 mm) in diameter. The holes should be covered with filter cloth to prevent loss of bedding sand. This drainage detail can prevent pumping and loss of bedding sand around the catch basin.

Crosswalks-Pavers in a crosswalk or abutting another pavement can be placed against a concrete beam (Figure 12), or a beam and slab base combination for pavements subject to heavy vehicular traffic (Figure 13). The beam prevents horizontal creep of the pavers due to braking and turning tires. Stresses from wheel loads are concentrated at the edge of the pavers and base. They do not interlock and transfer loads to the concrete beam, pavement surfaces or base. Premature rutting can occur at the junction of these materials and can be avoided by using a cement-treated or concrete base. These types of bases are recommended in heavy traffic areas such as thoroughfares. For applications with over 1.5 million 18-kip (80 kN) equivalent axle load (Caltrans Traffic Index > 9.4) design life, the bedding sand should be evaluated for resistance to degradation. Contact the ICPI for test methods and criteria for evaluating bedding sand hardness and degradation. When cement-treated or concrete bases are used under a crosswalk or plaza, drain holes should be drilled or cast at the lowest elevation(s) (Figure 13). These should be a minimum diameter of 2 in. (50 mm), filled with open-graded aggregate and covered with filter cloth. This drain detail can be applied in areas where the water table is over 3 ft (0.9 m) deep. Otherwise, the drain should be enclosed in a pipe and directed to a sewer or other appropriate outlet. Drain holes may not be an option due to the expense of directing them to distant storm sewers or catch basins. In addition, local bedding sand may not have sufficient durability after degradation testing or other tests to assess its durability. It may not be able to withstand degradation from repeated, channelized wheel loads without rutting. In such cases, the designer may consider using a sand-bitumen setting bed on a concrete base. This bedding layer is typically 3 / 4 to 1 in. (20 to 25 mm) thick consisting of asphalt and bedding sand. Once the hot material is screeded and compacted on a concrete base, it cools and a thin coat of a neoprene-asphalt adhesive is applied to the bedding. The pavers are placed firmly into the adhesive and rolled with a small hand roller to bed them into it. The joints are filled with sand. The joint sand is often stabilized with cement or a joint sand stabilizer. See ICPI Tech Spec 5-Cleaning, Sealing and Joint Sand Stabilization of Interlocking Concrete Pavements for more information. Figure 14 shows a crosswalk section through an existing saw-cut asphalt pavement. This application is appropriate for residential streets with minimal truck traffic. The existing asphalt should be in good condition with no cracks, raveling, or delamination. The thickness of the cut asphalt should extend below the bottom of the bedding sand in order to prevent its loss. The typical asphalt thickness would be 4 in. (100 mm). Placing cement-treated base or lean concrete base under the edge of the pavers and asphalt will reduce the risk of rutting at this interface. The base should be at least 4 in. (100 mm) thick and extend under the asphalt and paver edges approximately 12 in. (300 in.). A small strip of filter fabric placed along the base and the cut asphalt can help prevent bedding sand from migrating under the asphalt.

Gutters and drainage channels made with pavers should be embedded in fortified mortar, a bitumen-neoprene bed, or polymer adhesive. The mortar mix should resist degradation from freeze-thaw and salt. Care must be taken in applying the mortar as it can stain the pavers. Sand is not recommended in joints subject to channelized water flow. The sand will eventually wash out of the paver joints and weaken the pavement. Cement can be dry mixed with joint sand (3% to 4% by weight) to reduce washout in areas subject to channelized drainage or from water draining from roof eaves without gutters. Care must be taken to not let the cement stain the pavers when sweeping the sand and cement into the joints. A more effective method is use of joint sand stabilization materials. Stabilizers are recommended to reduce risk of wash out on steep slopes. See ICPI Tech Spec 5-Cleaning, Sealing and Joint Sand Stabilization of Interlocking Concrete Pavement for more information.

Elevations-When edge restraints are installed before placing the bedding sand and pavers, the restraints are sometimes used to control thickness when screeding the bedding sand. Elevations for screeding should be set from the restraints after their elevations have been verified. Attention should be given to the elevation of the pavers next to the restraints. Sand-set pavers may require a finish elevation of 1 / 4 in. (6 mm) above the top of the restraint. This allows for minor settlement of the pavers and surface drainage. Bitumen-set, mortared or adhesive-set pavers should be at least 1 / 8 in. (3 mm) above adjacent curbs or other edge restraints.

Construction tips-Some restraints allow the pavers and bedding sand to be installed prior to placing the edge materials. The field of pavers is extended past the planned edge location. The pavers are marked with a chalk line, or by using the edge material itself as large ruler for marking (Figure 15). The marked pavers are then cut with a powered saw or mechanical splitter. The unused ends and excess bedding sand are removed up to the cut pavers, and the edge restraints installed. This technique is particularly useful for creating curved edges. When the gap between the pavers and the restraint exceeds 3 / 8 in. (10 mm), the space should be filled with cut pavers. Cut pavers exposed to tires should be no smaller than one-third of the whole paver. The paving pattern may require shifting to accommodate cut pavers. Stability of cut edge pavers exposed to tire traffic is increased when a running course (string or sailor) of whole pavers is placed between the edge restraint or concrete collar and the cut edge pavers. Pavers are cut to fit against this edge course (see Figures 11 and 12). Other shapes include edge pavers that make a straight, flush edge. This detail can reduce incidental chipping of the cut pavers. In some situations, site fixtures can be installed after the pavers are placed and vibrated and the joints filled with sand. Openings can be saw cut, the edge restraints placed, and the tree grates, bollards, or other fixtures installed.

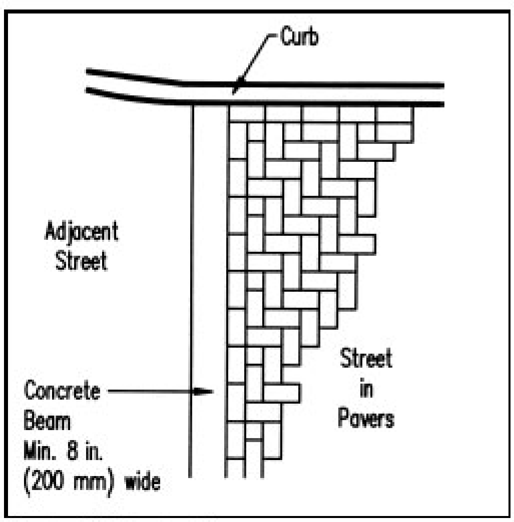

Figure 12. Concrete beam.

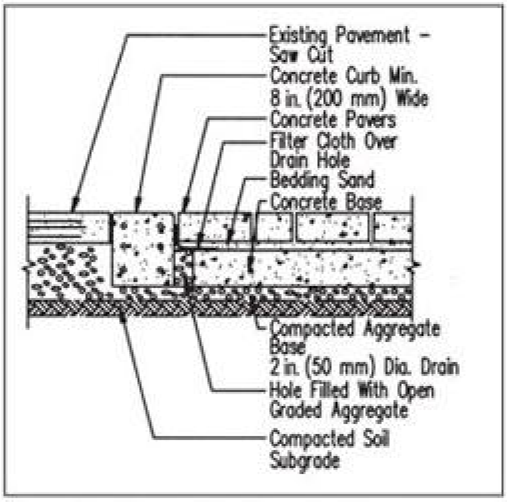

Figure 13. Crosswalk with concrete base.

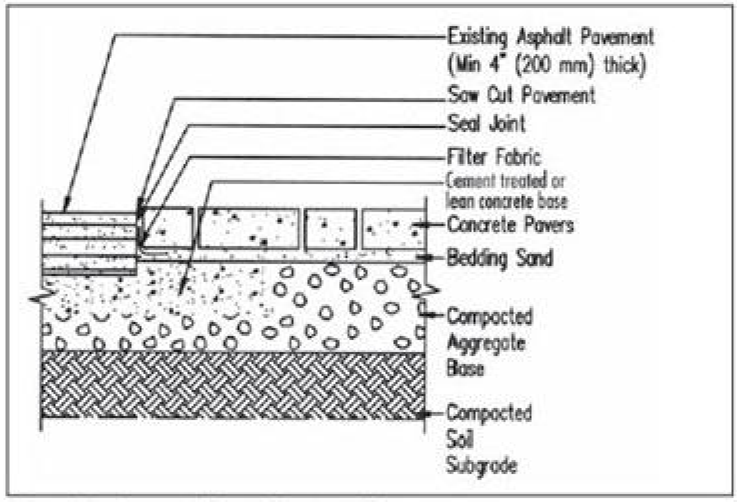

Figure 14. Crosswalk in existing asphalt pavement.

Figure 15. Saw cutting marked pavers on bedding sand. The cut pavers are carefully removed and edging is placed against the pavers and spiked in place.

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Structural Design of Interlocking Concrete Pavement for Roads and Parking Lots

When considering design and construction, three types of interlock must be achieved: vertical, rotational and horizontal interlock.

History
The concept of interlocking concrete pavement dates back to the roads of the Roman Empire. They were constructed with tightly-fitted stone paving units set on a compacted aggregate base. The modern version, concrete pavers, is manufactured with close tolerances to help ensure interlock. Concrete pavers were developed in the Netherlands in the late 1940's as a replacement for clay brick streets. A strong, millennia-old tradition of segmental paving in Europe enabled interlocking concrete pavement to spread quickly. It is now established as a conventional means of paving there, with some three billion ft 2 (300 million m 2) installed annually. Concrete pavers came to North America in the 1970's. They have been used successfully in numerous residential, commercial, municipal, port and airport applications.

Figure 1. The Roman Appian Way: early interlocking pavement.

Advantages
The paving system offers the advantages of concrete materials and flexible asphalt pavement. As high-strength concrete, the units have high resistance to freeze-thaw cycles and deicing salts, high abrasion and skid resistance, no damage from petroleum products or indentations from high temperatures. Once installed, there is no waiting time for curing. The pavement is immediately ready for traffic. Stress cracking and degradation of the surface is minimized because the numerous joints, or intentional "cracks," act as the means for load transfer. Like flexible asphalt pavement, an aggregate base accommodates minor settlement without surface cracking. An aggregate base facilitates fast construction, as well as access to underground utilities. Mechanical installation of concrete pavers can further shorten construction time. Pavement reinstatement is enhanced by reusable paving units, thereby reducing waste materials.

The Principle of Interlock
Interlock is the inability of a paver to move independently from its neighbors. It is critical to the structural performance of interlocking concrete pavement. When considering design and construction, three types of interlock must be achieved: vertical, rotational, and horizontal interlock. These are illustrated in Figure 2. Vertical interlock is achieved by the shear transfer of loads to surrounding units through sand in the joints. Rotational interlock is maintained by the pavers being of sufficient thickness, placed closely together, and restrained by a curb from lateral forces of vehicle tires. Rotational interlock can be further enhanced if there is a slight crown to the pavement cross section. Besides facilitating drainage, the crown enables the units to tighten slightly, progressively stiffening through loads and minor settlement across the entire pavement, thereby increasing structural capacity. When progressive stiffening has stabilized, the pavement experiences what is known as "lockup." Horizontal interlock is primarily achieved through the use of laying

patterns that disperse forces from braking, turning, and accelerating vehicles. The most effective laying patterns for maintaining interlock are herringbone patterns. Testing has shown that these patterns offer greater structural capacity and resistance to lateral movement than other laying patterns (1, 2, 3). Therefore, herringbone patterns are recommended in areas subject to vehicular traffic. See Figure 3. Stable edge restraints such as curbs are essential. They maintain horizontal interlock while the units are subject to repeated lateral loads from vehicle tires. ICPI Tech Spec 3, Edge Restraints for Interlocking Concrete Pavements offers guidance on the selection and detailing of edge restraints for a range of applications.

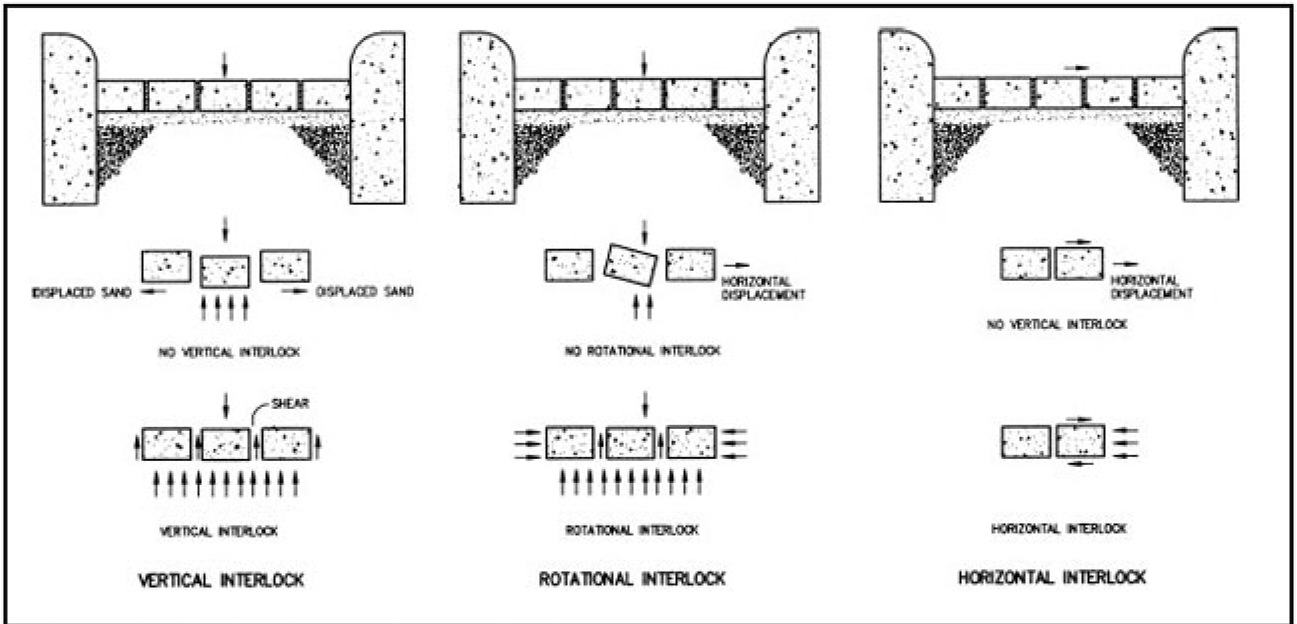
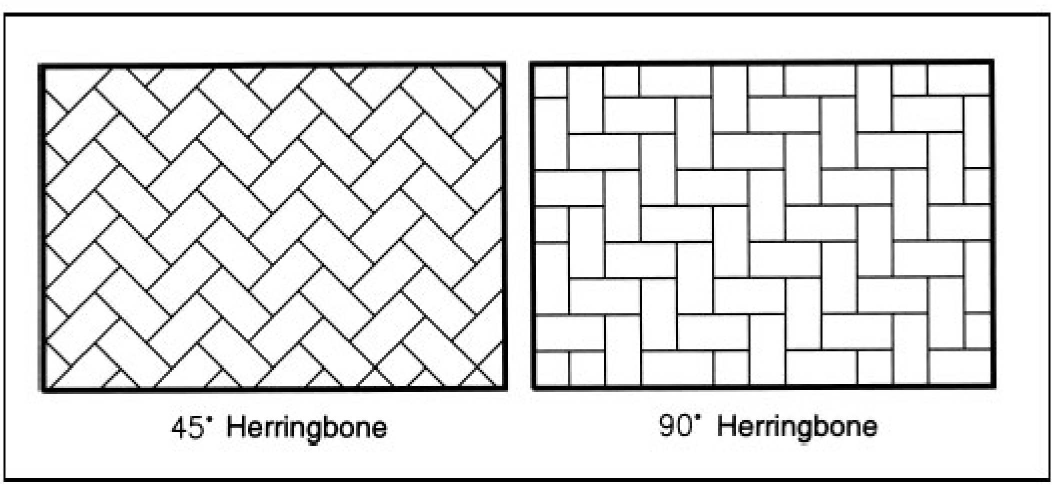


Figure 2. Types of interlock: vertical, rotational, horizontal.

Typical Pavement Design and Construction
Figure 4 illustrates typical schematic cross sections for interlocking concrete pavement. Both the base and subbase are compacted aggregate. Many pavements for city and residential uses do not require an aggregate subbase except for very heavy use, or over a weak soil subgrade. In these situations it may be more economical to use asphalt or cement-stabilized base layers. They are often placed over a subbase layer of unbound compacted aggregate. Construction is covered in ICPI Tech Spec 2, Construction of Interlocking Concrete Pavement. The steps for preparing the soil subgrade and base materials are similar to those required for flexible asphalt pavements. After the base surface is built to specified elevations and surface tolerances, bedding sand is screeded in an even layer, typically 11 1 / 2 in. (2540 mm) thick. The units are placed, manually or mechanically, on the smooth bedding sand, constrained by stationary edge restraints. The pavers are vibrated with a high frequency plate vibrator. This action forces sand into the bottom of the joints of the pavers and begins compaction of the bedding sand. Sand is then spread and swept into the joints, and the pavers are compacted again until the joints are filled. Complete compaction of the sand and slight settlement of the pavers tightens them. During compaction, the pavement is transformed from a loose collection of pavers to an interlocking system capable of spreading vertical loads horizontally. This occurs through shear forces in the joints.

Figure 3. Laying patterns for vehicular traffic.



Structural Design Procedure
The load distribution and failure modes of flexible asphalt and interlocking concrete pavement are very similar: permanent deformation from repetitive loads. Since failure modes are similar, a simplified procedure of the method is adapted from Reference 4 and the American Association of State Highway and Transportation Officials (AASHTO) 1986 and 1993 *Guide for Design of*

Pavement Structures (5). The following structural design procedure is for roads and parking lots. Base design for crosswalks should consider using stabilized aggregate or cast-in-place concrete. Stiffer bases will compensate for stress concentration on the subgrade and base where the pavers meet adjoining pavement materials. Design for heavy duty pavements such as port and airport pavements is covered in ICPI manuals entitled, ***Port and Industrial Pavement Design for Concrete Pavers***, and ***Airfield Pavement Design with Concrete Pavers***.

Design Considerations
The evaluation of four factors and their interactive effects will determine the final pavement thickness and material. These include environment, traffic, subgrade soil strength, and pavement materials. The design engineer selects values representing attributes of these factors. The values can be very approximate correlations and qualitative assumptions. Each factor, however, can be measured accurately with detailed engineering studies and extensive laboratory testing. As more detailed information is obtained about each factor, the reliability of the design will increase. The effort and cost in obtaining information about each should be consistent with the importance of the pavement. A major thoroughfare should receive more analysis of the soil subgrade and traffic mix than a residential street. Furthermore, the degree of analysis and engineering should increase as the subgrade strength decreases and as the anticipated traffic level increases. In other words, pavements for high volume traffic over weak soils should have the highest degree of analysis of each factor as is practical.

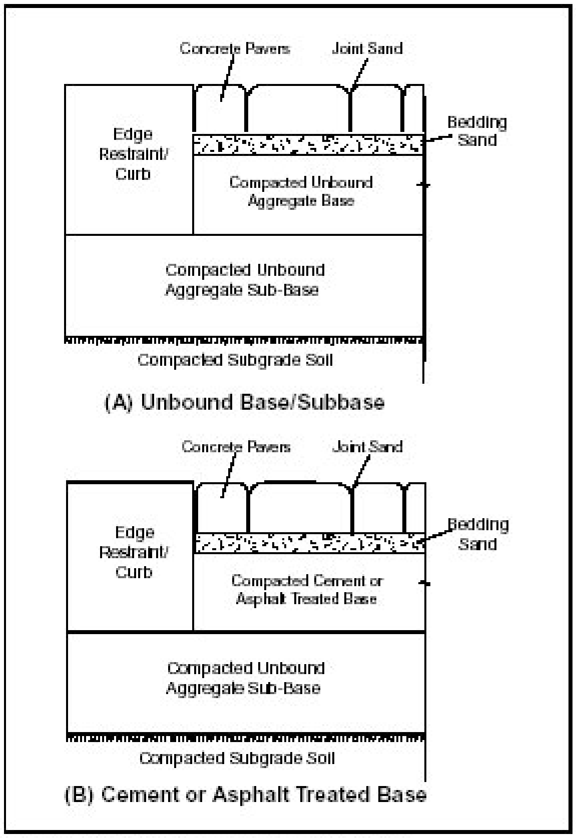


Figure 4. Typical schematic cross sections.

Environment-Moisture and temperature significantly affect pavement. As moisture in the soil or base increases, the load bearing capacity of the soil or the strength of the base decreases. Moisture causes differential heaving and swelling of certain soils, as well. Temperature can affect the load bearing capacity of pavements, particularly asphalt stabilized layers. The combined effect of freezing temperatures and moisture can lead to two detrimental effects. First, expansion of the water during freezing can cause the pavement to heave. Second, the strength of the pavement materials can be reduced by thawing. These detrimental effects can be reduced or eliminated one of three ways. Moisture can be kept from entering the pavement base and soil. Moisture can be removed before it has a chance to weaken the pavement. Pavement materials can be used to resist moisture and movement from swelling or frost. Limited construction budgets often do not allow complete protection against the effects of moisture and freeze-thaw. Consequently, their effects should be mitigated to the highest extent allowed by the available budget and materials. In this design procedure, the effects of moisture and frost are part of characterizing of the strength of subgrade soil and pavement materials. Subjective descriptions of drainage quality and moisture conditions influence design strength values for subgrade soils and unbound granular materials. In addition, if freeze-thaw exists, then soil subgrade strength is reduced according to the degree of its frost susceptibility.

Traffic-When pavement is trafficked, it receives wear or damage. The amount of damage depends on the weight of the vehicles and the number of expected passes over a given period of time. The period of time, or design life, is usually 20 years. Predicted traffic over the life of the pavement is an estimate of various vehicle loads, axle and wheel configurations, and the number of loads. The actual amount of traffic loads can often exceed the predicted loads. Therefore, engineering judgement is required in estimating expected sources of traffic and loads well into the future. Damage to pavement results from a multitude of axle loads from cars, vans, light trucks, buses and tractor-trailers. In order to more easily predict the damage, all of the various axle loads are expressed as damage from an equivalent standard axle load. In other words, the combined damaging effects of various axle loads are equated to the damaging effect of 18-kip (80 kN) equivalent single axle load (ESALs or EALs) repetitions. Damage factors for other axle loads are shown in Table 1. For example, the table shows that a single axle load of 38-kip (169 kN) would cause the same pavement damage as approximately 30 passes of an 18-kip (80 kN) single axle. For pavements carrying many different kinds of vehicles, greater study is needed to obtain the expected distribution of axle loads within the design period. If no detailed traffic information is available, Table 2 can be used for general guidance by listing typical EALs as a function of road class. EALs in Table 2 can be converted to TI or Traffic Index used by Caltrans in California to characterize axle loads. The following formula converts 18-kip (80kN) equivalent single axle loads (ESALs) to a TI: TI = 9.0 x (ESAL/10 6) 0.119 **.** Table 7 correlates ESALs used in Figures 5, 6 and 7 to TIs. In some situations, the designer cannot know the expected traffic in five, ten or fifteen years into the future. Therefore, the reliability (degree of conservatism) of the engineer's predictions can be modified as follows: Adjusted EALs = F R x EALs (estimated or from Table 2) where F R is the reliability factor. Recommended reliability factors by road class are also given in Table 2, along with the corresponding adjusted EALs and TIs for use in the design. In some residential development projects, interlocking concrete pavement streets are constructed first and then housing is built. Axle loads from construction-related truck traffic should be factored into the base thickness design. The loads can be substantial compared to the lighter loads from automobiles after construction is complete.

TABLE 1
Axle Load Damage Factors

Single Axle Kips (kN)	Single Axle Damage Factor	Tandem Axle Kips (kN)	Tandem Axle Damage Factor
2 (9)	0.0002	10 (44)	0.01
6 (27)	0.01	14 (62)	0.03
10 (44)	0.08	18 (80)	0.08
14 (62)	0.34	22 (98)	0.17
18 (80)	1.00	26 (115)	0.34
22 (98)	2.44	30 (133)	0.63
26 (115)	5.21	34 (157)	1.07
30 (133)	10.03	38 (169)	1.75
34 (157)	17.87	42 (186)	2.75
38 (169)	29.95	46 (204)	4.11

TABLE 2
Typical Design EALs

Road Class	EALs* (millions)	Reliability Factor	Design EALs* (millions)
Arterial or Major Streets			
Urban	7.5	3.775	28.4
Rural	3.6	2.929	10.6
Major Collectors			
Urban	2.8	2.929	8.3
Rural	1.5	2.390	3.5
Minor Collectors			
Urban	1.3	2.390	3.0
Rural	0.55	2.390	1.3
Commercial/Multi-Family Locals			
Urban	0.43	2.010	0.84
Rural	0.28	2.010	0.54

**Assume a 20 year design life.*

Soil Subgrade Support The strength of the soil subgrade has the greatest effect on determining the total thickness of the interlocking concrete pavement. When feasible, resilient modulus (M r), R-value, or soaked California Bearing Ratio (CBR) laboratory tests should be conducted on the typical subgrade soil to evaluate its strength. These tests should be conducted at the most probable field conditions of density and moisture that will be anticipated during the design life of the pavement. M r tests are described in AASHTO T-307 (7); R-value in ASTM D 2844 (6) or AASHTO T-190 (7); and CBR in ASTM D 1883 (6) or AASHTO T-193 (7). CBR and R-values are correlated in Reference 9. In the absence of laboratory tests, typical resilient modulus (M r) values have been assigned to each soil type defined in the United Soil Classification System (USCS), per ASTM D 2487 (6), or AASHTO soil classification systems (see Tables 3 and 4). Three modulus values are provided for each USCS or AASHTO soil type, depending on the anticipated environmental and drainage conditions at the site. Table 3 includes formulas that explain the approximate relationship between Mr and CBR, plus Mr and R-value from Reference 9. Guidelines for selecting the appropriate M r value are summarized in Table 5. Each soil type in Tables 3 and 4 has also been assigned a reduced M r value (far right column) for use only when frost action is a design consideration. Compaction of the subgrade soil during construction should be at least 98% of AASHTO T-99 or ASTM D 698 for cohesive (clay) soils and at least 98% of AASHTO T-180 or ASTM D 1557 for cohesionless (sandy and gravelly) soils. The higher compaction standards described in T-180 or D 1557 are preferred. The effective depth of compaction for all cases should be at least the top 12 inches (300 mm). Soils having an M r of 4,500 psi (31 MPa) or less (CBR 3% or less/R-value 8 or less) should be evaluated for either replacement with a material with higher bearing strength, installation of an aggregate subbase capping layer, improvement by stabilization, or use of geotextiles.

Pavement Materials-The type, strength and thickness of all available paving materials should be established. Crushed aggregate bases, or stabilized bases used in highway construction are generally suitable for interlocking concrete pavement. Most states, provinces and municipalities have material and construction standards for these bases. If none are available, then the standards for aggregate bases found in ASTM D 2940 (6) may be used. Minimum recommended strength requirements for unbound aggregate bases should be CBR = 80% and CBR = 30% for subbases. For unbound aggregate base material, the Plasticity Index should be no greater than 6; the Liquid Limit limited to 25; and compaction should be at least 98% of AASHTO T-180 density. For unbound granular subbase material, the material should have a Plasticity Index less than 10, a Liquid Limit less than 25, and compaction requirements should be at least 98% of AASHTO T-180 density. In-place density should be checked in the field as this is critical to the performance of the pavement. If an asphalt-treated base is used, the material should conform to dense graded, well compacted, asphalt concrete specifications, i.e., Marshall stability of at least 1800 pounds (8000 N). For example, a state Superpave intermediate binder course mix required for interstate or primary roads may be adequate. Cement-treated base material should have a 7-day unconfined compressive strength of at least 650 psi (4.5 MPa). Recommended minimum base thicknesses are 4 in. (100 mm) for all unbound aggregate layers, 3 in. (75 mm) for asphalt-treated bases, and 4 in. (100 mm) for cement-treated bases. A minimum thickness of aggregate base (CBR=80) should be 4 in. (100 mm) for traffic levels below 500,000 EALs and 6 in. (150 mm) for EALs over 500,000. Bedding sand thickness should be consistent throughout the pavement and not exceed 1.5 in. (40 mm) after compaction. A thicker sand layer will not provide stability. Very thin sand layers (less than 3 / 4 in. [20 mm] after compaction) may not produce the locking up action obtained by sand migration upward into the joints during the initial compaction in construction. The bedding layer should conform to the gradation in ASTM C 33 (6), as shown in Table 6. Do not use screenings or stone dust. The sand should be as hard as practically available.

TABLE 3

Subgrade Resilient Modulus (M_r) as a Function of USCS Soil Type

10^3 psi = 6.94 MPa

USCS Soil Group	Resilient Modulus (10^3 psi) Drainage Option 1	Drainage Option 2	Drainage Option 3	Reduced Modulus* (10^3 psi)
GW, GP, SW, SP	20.0	20.0	20.0	N/A
GW-GM, GW-GC, GP-GM, GP-GC	20.0	20.0	20.0	12.0
GM, GM-GC, GC	20.0	20.0	20.0	4.5
SW-SM, SW-SC, SP-SM	20.0	20.0	20.0	9.0
SP-SC	17.5	20.0	20.0	9.0
SM, SM-SC	20.0	20.0	20.0	4.5
SC	15.0	20.0	20.0	4.5
ML, ML-CL, CL	7.5	15.0	20.0	4.5
MH	6.0	9.0	12.0	4.5
CH	4.5	6.0	7.5	4.5

NOTE: Refer to Table 5 for selection of appropriate option.

**Use only when frost action is a design consideration.*

M_r = Resilient Modulus, psi

M_r = 1500 (CBR)   Note: CBR ≤ 20%

M_r = 1000 + 555R

TABLE 4

Subgrade Resilient Modulus (M_r) as a Function of AASHTO Soil Type

10^3 psi=6.94 MPa

AASHTO Soil Group	Resilient Modulus (10^3 psi) Option 1	Option 2	Option 3	Reduced Modulus* (10^3 psi)
A-1-a	20.0	20.0	20.0	N/A
A-1-b	20.0	20.0	20.0	12.0
A-2-4,A-2-5,A-2-7	20.0	20.0	20.0	4.5
A-2-6	7.5	15.0	20.0	4.5
A-3	15.0	20.0	20.0	9.0
A-4	7.5	15.0	20.0	4.5
A-5	4.5	6.0	9.0	4.5
A-6	4.5	10.5	20.0	4.5
A-7-5	4.5	6.0	7.5	4.5
A-7-6	7.5	15.0	20.0	4.5

**Use only when frost action is a design consideration.*

Joint sand provides vertical interlock and shear transfer of loads. It can be slightly finer than the bedding sand. Gradation for this material can have a maximum 100% passing the No. 16 sieve (1.18 mm) and no more than 10% passing the No. 200 sieve (0.075 mm). Bedding sand may be used for joint sand. Additional effort in filling the joints during compaction may be required due to its coarser gradation. See ICPI Tech Spec 9, Guide Specification for the Construction of Interlocking Concrete Pavement for additional information on gradation of bedding and joint sand. Concrete pavers should conform to the ASTM C 936 (6) in the U.S. or CSA A231.2 (8) in Canada. A minimum paver thickness of 3.15 inches (80 mm) is recommended for all pavements subject to vehicular traffic, excluding residential driveways. As previously mentioned, the units should be placed in a herringbone pattern. No less than one-third of a cut paver should be exposed to tire traffic. Research in the United States and overseas has shown that the combined paver and sand layers stiffen as they are exposed to greater numbers of traffic loads. The progressive stiffening, or "lock up," generally occurs early in the life of the pavement, before 10,000 EALs. Once this number of loads has been applied, M r = 450,000 psi (3100 MPa) for the 3.125 in. (80 mm) thick paver and 1 in. (25 mm) of bedding sand. Pavement stiffening and stabilizing can be accelerated by static proof-rolling with an 810 ton (810 T) rubber tired roller. The above modulus is similar to that of an equivalent thickness of asphalt. The 3.125 in. (80 mm) thick pavers and 1 in. (25 mm) thick bedding sand have an AASHTO layer coefficient at least equal to the same thickness of asphalt, i.e., 0.44 per inch (25 mm). Unlike asphalt, the modulus of concrete pavers will not substantially decrease as temperature increases, nor will they become brittle in cold climates. They can withstand loads without distress and deterioration in temperature extremes.

TABLE 5
Environment and Drainage Options for Subgrade Characterization

Quality of Drainage	Percent of Time Pavement is Exposed to Moisture Levels Approaching Saturation			
	<1%	1 to 5%	5 to 25%	>25%
Excellent	3	3	3	2
Good	3	3	2	2
Fair	3	2	2	1
Poor	2	2	1	1
Very Poor	2	1	1	1

TABLE 6
ASTM C 33
Gradation for Bedding Sand

Sieve Size	Percent Passing
3/8 inches (9.5 mm)	100
No. 4 (4.75 mm)	95-100
No. 8 (2.36 mm)	80-100
No. 16 (1.18 mm)	50-85
No. 30 (0.600 mm)	25-60
No. 50 (0.300 mm)	10-30
No. 100 (0.150 mm)	2-10
No. 200 (0.075 mm)	0-1

TABLE 7

ESALs	TI
$5x10^4$	6
$1x10^5$	6.8
$3x10^5$	7.2
$5x10^5$	8.3
$7x10^5$	8.6
$1x10^6$	9
$3x10^6$	10.3
$5x10^6$	10.9
$7x10^6$	11.3
$1x10^7$	11.8
$2x10^7$	12.8
$3x10^7$	13.5

Structural Design Curves
Figures 5, 6, and 7 are the base thickness design curves for unbound aggregate, asphalt-treated and cement-treated materials. The thicknesses on the charts are a function of the subgrade strength (M r , Rvalue or CBR) and design traffic repetitions (EALs). Use the following steps to determine a pavement thickness:

1. Compute design EALs or convert computed TIs to EALs. Use known traffic values or use the recommended default values given in Table 2. EALs are typically estimated over a 20-year life. Annual growth of EALs over the life of the pavement should be considered.

2. Characterize subgrade strength from laboratory test data. If there is no laboratory or field test data, use Tables 3 and 4 to estimate M r , CBR or R-value.

3. Determine the required base thickness. Use M r , R-value or CBR for subgrade strength and design EALs or TIs listed in Table 7 input into Figures 5, 6 or 7, depending on the base material required. A portion or all of the estimated base thickness exceeding the minimum thickness requirements can be substituted by a lower quality, unbound aggregate subbase layer. This is accomplished through the use of layer equivalency values: 1 in. (25 mm) of aggregate base is equivalent to 1.75 in. (45 mm) of unbound aggregate subbase material; 1 in. (25 mm) of asphalt-treated base is equivalent to 3.4 in. (85 mm) of unbound aggregate subbase material; and 1 in. (25 mm) of cement-treated base is equivalent to 2.5 in. (65 mm) of unbound aggregate subbase.

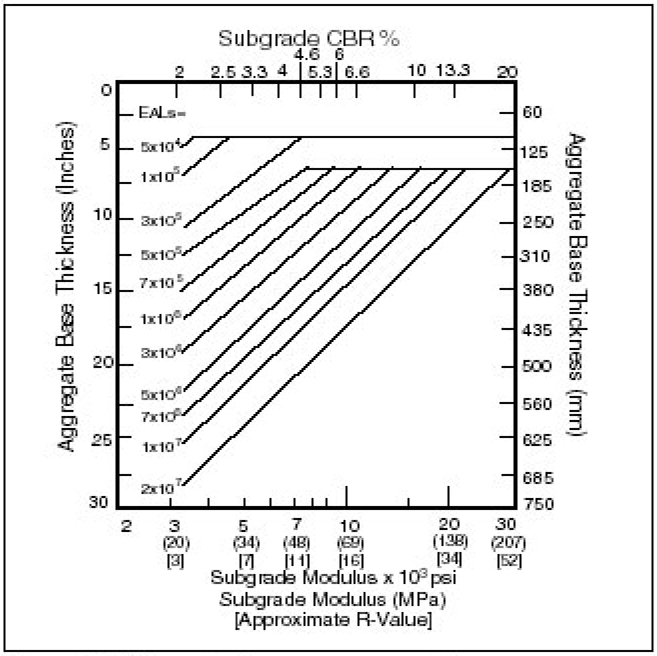


Figure 5. Thickness design curves–aggregate base.

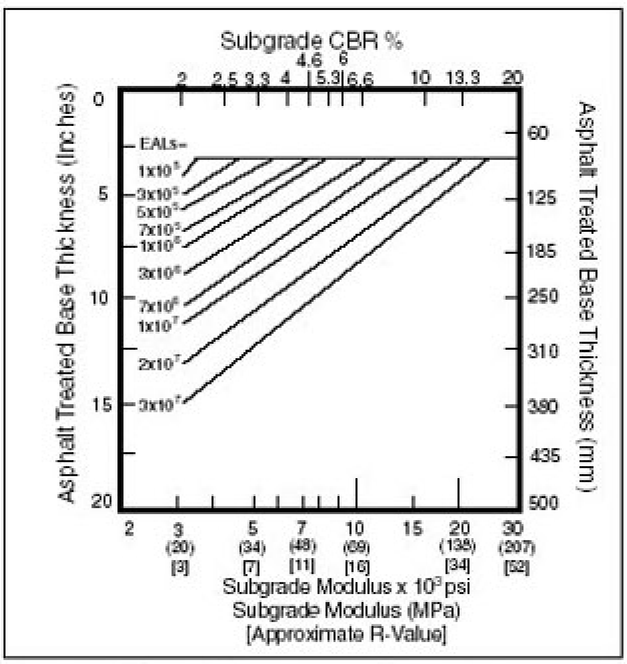


Figure 6. Thickness design curves–asphalt treated base.

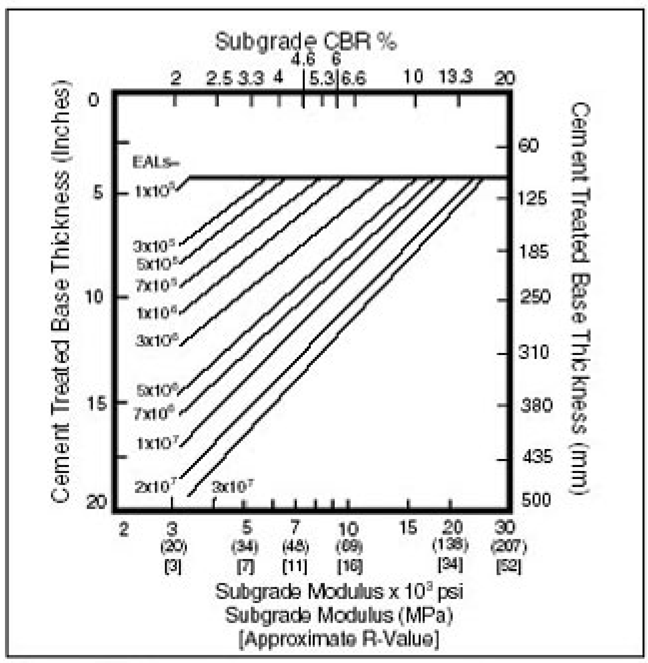


Figure 7. Thickness design curves–cement treated base.

Example

Design Data-A two-lane urban, residential street is to be designed using concrete pavers. Laboratory tests on the subgrade soil indicate that the pavement is to be constructed on a sandy silt; i.e., ML soil type according to the USCS classification system. No field CBR or resilient modulus data are available. From available climatic data, and subgrade soil type, it is anticipated that the pavement will be exposed to moisture levels approaching saturation more than 25% of the time. Drainage quality will be fair, and frost is a design consideration. Detailed EAL traffic data are not available. Using the above information, designs are to be developed for the following base and subbase paving materials: unbound aggregate base, asphalt-treated base, and unbound aggregate subbase. All designs are to include a base layer but not necessarily the aggregate subbase layer.

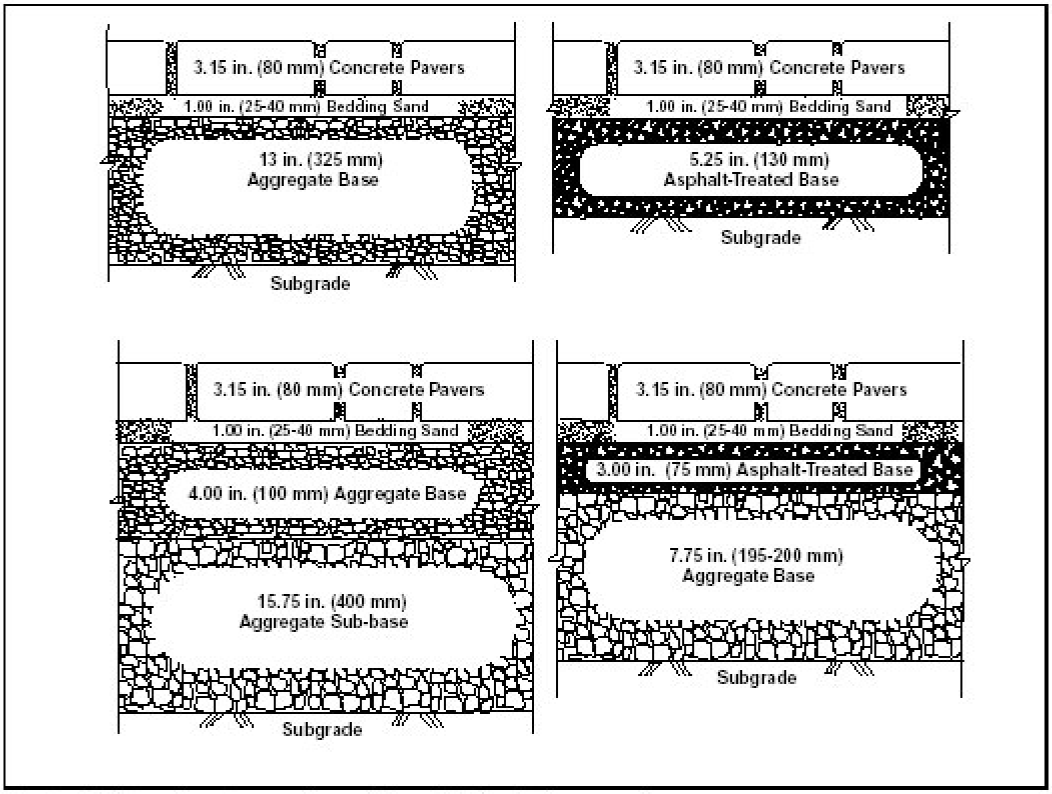


Figure 8. Alternative cross section solutions for the design example.

Solution and Results

1. Estimate design EAL repetitions. Since detailed traffic information was not available, the value recommended in Table 2 was used: 840,000 design EALs or TI = 8.8.

2. Characterize subgrade soil strength. Since only its USCS soil classification is known, Table 3 was used to establish the design strength value. For a USCS ML soil and the given moisture and drainage conditions, the estimated subgrade modulus value is M r = 7,500 psi (52 MPa), CBR = 5% or R-value = 23. Since frost action is a consideration, the reduced design strength value is M r = 4,500 psi (31 MPa), CBR = 3% or R-value = 8.

3. Determine base thickness requirements. Input of the design traffic (840,000 EALs) and subgrade strength (M r = 4,500 psi [31 MPa]) values into Figures 5 and 6 yields base thickness requirements of 13 in. (330 mm) for unbound aggregate, or 5.25 in. (133 mm) for an asphalt treated base. These values can be used to develop subbase thicknesses. Since all designs must include a base layer, only that thickness exceeding the minimum allowable value, 4 in. (100 mm) for aggregate bases and 3 in. (75 mm) for asphalt-treated bases, was converted into subbase quality material. With the aggregate base option, 9 in. (230 mm) or 13 4 in. of material can be converted into aggregate subbase quality material, resulting in 15.75 inches (400 mm) or 9 x 1.75 inches. Likewise, for the asphalt-treated base option, 2.25 in. (57 mm) or 5.25 3.0 in. of material can be converted into aggregate subbase quality material, resulting in 7.75 in. (197 mm) or 2.25 x 3.40 in. The final cross section design alternatives are shown in Figure 8 with 3.15 in. (80 mm) thick concrete pavers and a 1.0 in. (25 mm) thick bedding sand layer over several bases. These are a sample of the possible material type and thickness combinations which satisfy the design requirements. Cost analyses of these and other pavement cross section alternatives should be conducted in order to select the optimal design.

Computerized Solutions

Interlocking concrete pavement can be designed with ICPI Lockpave software, a computer program for calculating pavement base thicknesses for parking lot, street, industrial, and port applications. User designated inputs include traffic loads, soils, drainage, environmental conditions, and a variety of ways for characterizing the strength of pavement materials. Parking lot and street pavement thickness can be calculated using the 1993 AASHTO pavement design procedure (an empirical design method) or a mechanistic, layered elastic analysis that computes projected stresses and strains in the pavement structure modified by empirical factors. The AASHTO 2002 Guide for Design of Pavement Structures includes procedures for mechanistic analysis of pavement layers. Outputs include pavement thickness using different combinations of unstabilized and stabilized bases/subbases. Base thicknesses can be calculated for new construction and for rehabilitated asphalt streets using an overlay of concrete pavers. After a pavement structure has been designed, the user can project life-cycle costs by defining initial and lifetime (maintenance and rehabilitation) cost estimates. Design options with initial and maintenance costs plus discount rates can be examined for selection of an optimal design from a budget standpoint. Sensitivity analysis can be conducted on key cost variables on various base designs. For further information on ICPI Lockpave, contact ICPI members, ICPI offices, or visit the web site http://www.icpi.org.

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Cleaning, Sealing and Joint Sand Stabilization of Interlocking Concrete Pavement

When properly installed, interlocking concrete pavements have very low maintenance and provide an attractive surface for decades. Under foot and vehicular traffic, they can become exposed to dirt, stains and wear. This is common to all pavements. This technical bulletin addresses various steps to ensure the durability of interlocking concrete pavements and to help restore their original appearance. These steps include removing stains and cleaning, plus joint stabilization or sealing if required. Stains on specific areas should be removed first. A cleaner should be used next to remove any efflorescence and dirt from the entire pavement. A newly cleaned pavement can be an opportune time to apply joint sand stabilizers or seal it. In order to achieve maximum results, use stain removers, cleaners, joint sand stabilizers, and sealers specifically for concrete pavers. These may be purchased from a manufacturer, contractor, dealer or associate member of the Interlocking Concrete Pavement Institute.

Figure 1. Many sealers enhance the appearance of concrete pavers and protect against staining.

REMOVING STAINS

Commercial stain removers available specifically for concrete pavers provide a high degree of certainty in removing stains. Many kinds of stains can be removed while minimizing the risk of discoloring or damaging the pavers. The container label often provides a list of stains that can be removed. If there are questions, the supplier should be contacted for help with determining the effectiveness of the chemical in removing specific stains. Identify the stains prior to applying the cleaner. A test application should be evaluated in a small, inconspicuous stained area for cleaning effectiveness. Some stains may require repeated applications of the remover to achieve effective cleaning. This is often the case for deep set oil stains. With all stain removers, cleaners, joint sand stabilizers, and sealers, the label directions and warnings should be read and carefully followed for all precautions. Start removal of stains at the bottom of the pavement and work up the slope in manageable sections. By working up the slope, cleaning fluids will drain down the pavement. This technique assists in uniform removal while allowing the used cleaner to be rinsed away consistently. The surface remains dry ahead of the cleaner-soaked wet areas, allowing better visibility of the stains to be removed. Take care in selecting and applying cleaning products, as acidic ones may harm vegetation and grass. These cleaners should not run onto vegetation. When using strong acidic stain removers or cleaners that might drain onto vegetation, saturate the vegetation with water prior to using acidic cleaners. This will minimize absorption of cleaner rinse water and reduce risk of damage to vegetation.

Removal of Common Stains

There are proprietary cleaning products specifically designed for concrete pavers. Many have been developed through extensive laboratory and field testing to ensure cleaning effectiveness. These chemicals should be used whenever possible. Using manufactured cleaning chemicals for specific stains relieves the user from the uncertainty of attaining the proper mixture of chemicals. If no proprietary stain removal products are available, a comprehensive source of information on stain removal is found in *Removing Stains* *from Concrete* by William H. Kuenning. It describes chemicals, detergents or poultice (scrubbing) materials recommended for removing particular stains, and the steps to be followed in removal. This publication recognizes that some of the treatments involve hazardous chemicals and it advises specific precautions. Removal of several common stains from *Removing Stains from Concrete* are listed below (1). Most involve typical household chemicals. The information given is the best available at the time of writing. The ICPI disclaims any and all responsibility for the application of the information. The user is advised to use cleaners specifically made to remove stains that commonly occur on concrete pavers. They will likely be more effective.

Asphalt and emulsified asphalt-Chill with ice (if warm outside), scrape away and scrub the surface with scouring or abrasive powder. Rinse thoroughly with water.
Cutback asphalt and roofing tar-Use a poultice made with talc or diatomaceous earth. Mix with kerosene, scrub, let dry and brush off. Repeat as needed.
Blood, candy, ketchup, mustard, grease drippings from food-For stubborn stains, apply liquid detergent full strength and allow it to penetrate for 20 to 30 minutes. Scrub and rinse with hot water. Removal is easier if these stains are treated immediately.
Caulking-Scrape off excess and scrub with a poultice of denatured alcohol. Rinse with hot water and detergent. Acrylic latex caulk-follow guidelines for removal of latex paint.
Chewing gum-Same as caulking, or scrub with naphtha.
Clay soil-Scrape off dry material, scrub and rinse with hot water and strong detergent.
Creosote-Apply a poultice with paint thinner and talc. Scrub and allow to dry. Scrape off, scrub with scouring powder and rinse with water.
Leaf, wood rot, or tobacco stains-apply household bleach and scrub with a stiff bristled brush.
Mortar-Let harden and carefully remove hardened spots with a trowel, putty knife or chisel.
Smoke-Scrub with a poultice of talc with bleach diluted 1:5 with water. Rinse with water.
Oil or grease that has penetrated-Mop up any excess oil with rags. Cover the area with oil absorbent (kitty litter). Talc, fuller's earth, diatomaceous earth can be used. Leave it on the stain for a day then sweep up.
Paint-Fresh paint should be mopped up immediately with rags or paper towels by blotting. Do not wipe as this will spread the paint and extend the job of removal. If the paint is latex and water based, soak and then scrub the area with hot water, scouring powder and a stiff brush until no more improvement is seen. Let the remaining paint dry and remove as described below.
Dried paint-Scrape any excess oil based paint, varnish or water based latex paint off the surface. Apply a commercial paint remover and let it sit for 20 to 30 minutes. Loosen with gentle scrubbing. Do not rub the loosened paint into the surface of the paver. Instead, blot up the loosened paint and thinner. Repeat as necessary.
Tire skid marks-Scrub black area with water, detergent and scouring powder. In the case of small stained areas, removal and replacement with new pavers may be an option.

OVERALL CLEANING
Overall cleaning of the pavement can start after stains are removed. In preparation for cleaning, low tree branches, shrubs and vegetation adjacent to the pavement should be tied back or covered to protect from over spray of cleaning solutions or sealers. The area should be inspected for any cracked or broken units. These should be replaced. Badly stained units can be replaced, but it is usually easier to clean stains and less costly than replacing the pavers. When pavers have stains too difficult to remove, replace them with the same type of units. Refer to ICPI *Tech Spec 6, Reinstatement of Interlocking Concrete Pavements*, for a full description on replacing pavers. If pavers must be replaced, there may be a difference in color from the surrounding pavers. This variation should eventually disappear. If color variation is unacceptable, controlled use of proprietary cleaners designed to improve the color of concrete pavers can minimize variation. Removal of accumulated dirt and efflorescence is the objective of cleaning. It is essential in preparing the pavers for sealing as well. Many cleaners effective in removing dirt and efflorescence are a mix of detergent and acid. Cleaners with strong acids will change the color of the pavers slightly. The degree of change can be controlled by the type of acid in the cleaner, its concentration and the length of time on the pavers. Proprietary cleaners will give specific instructions on their application. These directions should be followed. In order to achieve proper results, cleaners should be tried on a small area to test results and any color changes. The concentration and time on the pavement can be adjusted accordingly. Protective clothing and goggles should always be worn when using acidic solutions. Anticipate where the cleaning fluids will drain, i.e., across the pavement and not onto grass or vegetation. Sediment or cleaners allowed to pond in low spots may stain the pavers. If unsure of the runoff direction, test drainage with ordinary water first to identify any trouble spots. Be sure to rinse these areas thoroughly. Turn off all automatic sprinkler systems during cleaning, sealing and drying.

Professional Cleaning Methods
For most jobs, cleaning should be handled by a professional company experienced in the use of cleaners and spray equipment. Professionals typically use a pressure washer and an applicator to apply efflorescence cleaner (when needed). The various methods for applying joint sand stabilizers and sealers are covered later. A high pressure sprayer applies cleaner and water between 600 and 2,000 psi (4.1 and 13.8 MPa), and at a rate between 6 and 12 gallons/minute (22 and 45 liters/minute). See Figure 2. The rate of flow is adjusted to ensure sufficient rinsing. The pressure loosens dirt and pushes water from the surface without the need for scrub brushes. The nozzle type and its distance from the paver surface influences the effectiveness of the cleaning as well. A nozzle that creates a wide spray enables a large area to be covered efficiently and prevents sand from being washed from the joints. A low angle of attack from a wide nozzle spray will also reduce the risk of dislodging joint sand. Cleaners to remove efflorescence are applied with a low pressure pump spray 30 to 100 psi (0.2 to 0.7 MPa). A shower type spray nozzle will help ensure even distribution of the cleaner. Cleaning chemicals are applied, allowed to sit an appropriate time, then rinsed away with a high pressure sprayer. The final rinse should be water only. A large amount of water is more important to rinsing than high pressure. For small areas, an adequate cleaning job can be achieved without this equipment. Such areas include residential patios, walks, or small driveways. Cleaners can be applied by hand, the pavers scrubbed to remove dirt and efflorescence, then thoroughly rinsed with water from a garden hose. Scrub brushes with steel bristles are not recommended. They will loosen from the brush, rust, and leave stains. Brass or plastic bristles are acceptable. This method of cleaning is for do-it-yourselfers who wish to refurbish a small area of pavers. The additional time required to clean and seal pavers without the help of a professional should be weighed against investing in a competent company to do the job. Professionals have the equipment and experience with the various chemicals. They can achieve the highest level of results in the least amount of time.

Figure 2. Pressurized cleaning equipment used by professional cleaning and sealing companies can bring out the best appearance from pavers.

Efflorescence and Its Removal
Efflorescence is a whitish powder-like deposit which can appear on concrete products. When cement hydrates (hardens after adding water), a significant amount of calcium hydroxide is formed. The calcium hydroxide is soluble in water and migrates by capillary action to the surface of the concrete. A reaction occurs between the calcium hydroxide and carbon dioxide (from the air) to form calcium carbonate, then called efflorescence. Efflorescence does not affect the structural performance or durability of concrete pavers. The reaction that takes place is the formation of water soluble calcium bicarbonate from calcium carbonate, carbon dioxide and water. It may appear immediately or within months following installation. Efflorescence may reach its peak in as short as 60 days after installation. It may remain for months and some of it may wear away. If installation takes place during dry period of the year, the next cycle of wet weather may sometimes be necessary for efflorescence to materialize. If there is a need to remove deposits before they wear away, best results can be obtained by using a proprietary efflorescence remover. The acid in proprietary cleaning chemicals is buffered and blended with other chemicals to provide effective cleaning without damage to the paver surface. Always refer to the paver supplier or chemical company supplying the chemicals for recommendations on proper dilution and application of chemicals for removal of efflorescence. They are generally applied in sections beginning at the top of slope of the pavement. If the area is large, a sprayer is an efficient means to apply the cleaner. The chemicals are scrubbed on the surface, then rinsed away. Results can be verified after letting the area dry for at least 24 hours. In most instances one application is sufficient. However, in severe instances of efflorescence, a second application may be necessary. Contact the manufacturer of the cleaning product to determine if a second application will not discolor the pavers or expose some aggregates. Note: Protective clothing, chemical resistant rubber boots and gloves, and eye goggles should be worn when applying acid or alkalies.

JOINT SAND STABILIZERS AND SEALERS
Stabilizer and sealers are two distinct products sometimes with overlapping functions. Joint sand stabilizers help secure sand in the joint after it has been installed. Their primary function reduces the risk of removal of joint sand from flowing water, wind, aggressive cleaning, tire action and intrusion of organic matter, seeds and ants. Joint sand stabilizers come in liquid and dry applied forms. Some liquid stabilizers are made of the same materials as sealers, but with a higher solids content with additional wetting agents. When applied to the paver surface and joints, stabilizers can make the surface easier to clean and prevent staining in a manner similar to sealers. Depending on the chemical contents, liquid stabilizers may or may not change the appearance of the paver surface. All surface sealers are applied as liquids. Their primary function is providing additional protection to concrete paver surfaces. Such chemicals can be similar to products used to seal cast-in-place concrete slabs. Sealers are applied to the entire surface of an installation to add further protection from stains, oils, dirt, or water. Occasionally, sealers are applied to pavers during manufacturing. Whether applied in a factory or on a site, most sealers change the appearance of the paver surface by darkening it and enhancing the surface color. Since liquid sealers penetrate the joint sand to some extent during application, they secondarily provide some stabilization.

Figure 3. This liquid joint sand stabilizer is applied with a low-pressure sprayer and squeegeed across the surface after allowing some time for soaking into the joints. This helps maintain slip and skid resistance of the paver surface.

Figure 4. Liquid joint sand stabilizers can deepen the surface color slightly and they provide some surface sealing as well. Tumbled pavers shown here have wider joints than other shapes. These type of pavers can require stabilization of the joint sand.

Figure 5. Joint sand can be pre-mixed and delivered to the site (typically in bags), or mixed with stabilizer at the site, then swept into the joints, compacted for consolidation in them to create interlock, and wetted to activate the stabilizer.

Joint Sand Stabilizers

Liquid and dry applied stabilizers provide initial protection against joint sand loss. They accelerate joint sealing that can normally occur from a combination of atmospheric dust deposits, dirt and sediment that finds its way to the pavement, and contributions from passing tires. Stain removal, efflorescence removal, and overall surface cleaning should precede application of liquid stabilizers in new construction. None of these preparatory treatments are needed prior to the application of a dry applied stabilizer. It is applied first with the joint sand to complete the paver surface and begin interlock. Stain and efflorescence removal, cleaning and sealing can be done subsequently. Joint sand stabilization materials are fairly new, so no industry-wide guidelines yet exist on the expected lifetime or reapplication rates. Some stabilized joints in pavements show years of longevity. There is evidence that projects in freeze-thaw climates have performed well for more than six years. Joint sand stabilization is generally optional and not required for many interlocking concrete pavements. Sand in joints will likely stabilize over time without additional treatment as a result of silts or other fines working their way into spaces between the sand particles. The rate of stabilization depends on the amount and sources of traffic, plus sources of fines that work their way into the joints from traffic over time. There are some applications where early stabilization of the joints is important to maintaining functional performance of the paver surface. For example, stabilization is recommended on high slope applications over 7% and on applications where the slope is less than 1.5%. Applications on high slopes will help prevent washout of joint sand. Stabilizers in very low slope or flat areas can help reduce infiltration of standing water. Stabilization benefits pavements subject to aggressive, regular cleaning. Examples might include amusement parks and restaurant exteriors. Pavements that see regular, heavy rainfall can benefit from stabilization of the joint sand. Surfaces that experience concentrated water flow such as gutters receiving sheet flow from large areas or at the drip lines under the eaves of buildings will better resist erosion of joint sand if stabilized. Stabilizers have been effective in securing joint sand in places subject to high winds such as in desert climates. They can prevent joint sand displacement from high-speed tire traffic. Like sealers, joint and stabilization materials reduce the potential for weeds and ants in the joints. In residential applications stabilization at downspouts and under eaves helps keep joint sand in place. Tumbled pavers (cobble stone-like units) and circular patterns have wider joints than other paver shapes. Tumbled pavers may require stabilized joint sand between them if they have slightly irregular sides and wide joints. Studies on the permeability of the surface of interlocking concrete pavements have indicated ranges between 10% and 20% perviousness (2). The rate of permeability depends on several factors. They include the fineness of the joint sand (percent of material passing the No. 200 or 0.075 mm sieve), the joint widths, slope, consolidation of the sand plus the age of the installation. Newly placed pavers have higher permeability (as much as 25%) than installations trafficked for several years. Sealers and joint sand stabilizers can contribute to long-term performance by reducing infiltration of water to the bedding sand and base.

Figure 6. Whether using liquid or dry joint stabilization materials, the surface of the pavers should be cleaned with a blower or broom after the joint sand is compacted into the joints.

Figure 7. Dry-applied joint sand with a stabilizer is wetted in order to activate it and stiffen the sand. Once the joints dry, they are stabilized.

Liquid Penetrating Stabilizers
These are water or solvent-based with the primary resin or bonding agent being an acrylic, epoxy, modified acrylic, or other polymers as solids (by volume) typically 18% to 28%. Solvent or water carries the solids into the joint sand. They will evaporate and leave the solids behind as the binding agent. Modifiers such as epoxy resins may also add to the ability of the product to create a solid matrix in the joint sand. When initially applied, liquid stabilization materials should be allowed to penetrate at least 3 / 4 inch (20 mm) into the joint sand. A mock-up is beneficial in determining application rates for specific products, joint sands, and for specific job site conditions. Joint sand gradation can affect the depth of penetration of the liquid stabilizer. The amount of fines or material passing the No. 200 (0.075 mm sieve) can influence the depth of penetration. A joint sand gradation with less than 5% passing the No. 200 (0.075 mm) sieve can allow better penetration of liquid stabilizers. A job site mock-up should be tried to determine the penetration rate. The mock-up also will determine the appropriate application rate. Prior to applying liquid materials, the surface should be clean and dry and any efflorescence removed from the pavers. Either a broom or leaf blower can efficiently remove excess sand. Some successful methods of application involve applying liquid joint stabilizers with low pressure, high volume spray, followed immediately by a squeegee to move the material into the joints. See Figure 3. Other methods use rollers, watering cans, or hand pumped, garden-type sprayers. Some equipment has multiple spray nozzles and mechanized rollers and/or squeegees. All application methods must provide uniform dispersion and effective penetration. Liquid stabilizers bind the sand in the joint and secondarily provide sealing of the concrete paver surface. All liquid based stabilizers create some change in the appearance of the pavers. This ranges from a slight color enhancement, a modest sheen, to a high gloss. Like sealers, cured liquid joint stabilizers that remains on the surface of the pavers enhances their color, inhibits fading, and protects against staining. It also makes the paver surface easier to clean and maintain (Figure 4). However, joint sand stabilization will last significantly longer than the enhancement of the surface appearance.

Dry Joint Sand Stabilizers
These are dry additives mixed with joint sand. The additives are organic, inorganic, or polymer compounds that stiffen and stabilize the joints when activated by water applied to the joint sand. Additives come either pre-mixed with bagged joint sand, or are sold separately as an additive mixed with the joint sand on the job site per the supplier's instructions. The additive is often mechanically mixed for consistency. Dry stabilizers are appropriate for residential settings, parking lots, bike lanes, plazas, and other areas with low velocity wheel loads or areas without concentrated water flow. They are convenient for application by homeowners. Some dry stabilizers have been successfully used in high traffic streets. The pavers are initially compacted into the bedding sand. Joint sand is applied to the surface with a stabilizer additive mixed in it. See Figure 5. It is then compacted into the joints with a plate compactor like all interlocking concrete pavement installations. After compaction and removal of all sand from the paver surface, the joints are wetted. When dry, the material in the sand stabilizes the full depth of the joint and it helps maintain interlock among the pavers. For either pre-mixed or job site mixed additives, a job site mock-up is beneficial for determining the depth of stabilization. The mock-up will determine the rate and application method of water to ensure full activation of the stabilizer. A mock-up will confirm a consistent method for uniform distribution of the additive in the sand for job site mixed additives in particular. Prior to application, blowing or sweeping the surface clean is recommended. See Figure 6. Since water activates these products, no moisture should be present on the surface or in the joints until they are ready to be placed in the joints. Once the pavers and joint sand are compacted, the joints are full of sand, and all excess sand is removed from the surface, water is added to activate the bonding agent. The water is applied as a light, wide spray, and allowed to collect and soak into the joints (Figure 7). A narrow spray should not be used because it can dislodge sand from the joints. It is imperative to immediately remove any excess moist joint sand that inadvertently gets on the surface of the pavers. Otherwise, once it is moistened and allowed to cure on the surface, the sand will need to be removed with hot water. Some stabilizers may require removal with a wire brush or a pressure washer. Dry products will not leave a surface sheen like liquid stabilization products. This can be beneficial for a contractor or owner who needs to stabilize isolated areas through selected application of the product.

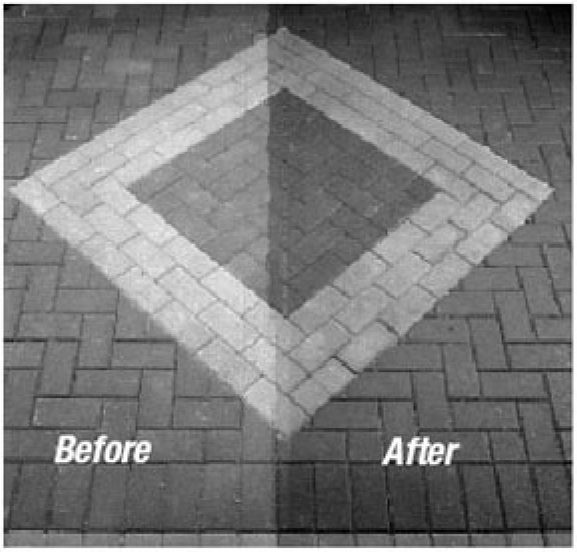

Figure 8. Before and after application of an acrylic sealer shows how it deepens the appearance of concrete pavers.

Figure 9. Sealers resist stains which makes them ideal for high use areas where they might occur.

Installation, Functional and Structural Considerations
Liquid and dry applied joint stabilizers are not a substitute for recommended installation practices. Prior to their application, all liquid stabilization products require that the joint sand be compacted and consolidated in the joints until full. Some dry stabilizers require mixing with joint sand then sweeping, filling, and compacting the sand and pavers until the joints are full. Other stabilizers are premixed in bags and are ready for filling the joints. Stabilizers resist many of environmental factors that lead to functional deterioration of the paver surface. However, stabilizers do not add to the structural (load bearing) capacity of the pavement. Therefore, structural calculations for base thickness design should not consider a joint sand stabilizer.

SEALERS
Uses
Sealers reduce the intrusion of water, stains, oils and dirt into the paver surfaces. Like stabilizers, application of a sealer follows stain removal, efflorescence removal and overall surface cleaning. Sealers are used for visual and functional reasons. They offer visual improvement by intensifying the paver colors. Some will add a glossy sheen or "wet" look to the pavement (see Figure 8). Other sealers offer some color enhancement and produce a low sheen, or a flat finish. Sealers offer many functional advantages. They can protect pavers from stain penetration. They are useful around trash receptacles, fast food restaurants, driveways, other areas subject to stains, and where oil drippings are not wanted (see Figure 9). Like stabilizers, sealers are also useful in stopping unwanted insects and weeds. Sealers can stabilize joint sand between pavers cleaned by vacuum sweeping equipment. They can help maintain the sand in the joints under high velocity water flows. Where solvents may be spilled onto pavers, elastomeric urethanes and certain water based sealers have been successfully used to prevent their penetration. Likewise, special urethane sealers have been used to seal and stabilize joint sand subject to propeller wash, jet engine fuels and exhaust in commercial and military airports (2).

Types of Sealers for Concrete Pavers
Table 1 lists the various types of sealer for concrete pavers. The table suggests applications and compares important properties (3). The sealer manufacturer or supplier should be consulted prior to using any sealer to verify that their product will perform in the environment planned for its use. Sealers not recommended for use with pavers are alkyds, esters, and polyvinyl acetates. Epoxies and silicones are generally not used on concrete pavers.

Solvent and Water Based Sealers
Like stabilizers, sealers can be either solvent or water based. Solvent based sealers consist of solids dissolved in a liquid. Solvent based products carry the dissolved solids as deep as the solvent will penetrate into the concrete paver. After the solvent evaporates, the sealer remains. Water based sealers are emulsions, or very small particles of the sealer dispersed in water. Water based sealers penetrate concrete as far as the size of the particles will permit. After the water evaporates, typically at a slower rate than solvents, the remaining particles bond with the concrete and to each other. These particles cannot penetrate as deeply as those carried by solvents. Water based sealer curing time will vary with the temperature, wind conditions and humidity.

Silanes/Siloxanes
Silanes and siloxanes are durable and penetrate concrete well. Silanes are the simpler form that, when exposed to moisture, begin to link up to other silanes. Siloxanes do the same linking together. Both chemicals become a polymer, curing as a film in the capillaries of the concrete. A hydrophobic barrier to moisture is created, preventing moisture from entering but allowing the concrete to "breathe" or release water vapor. Because silanes and siloxanes reduce moisture from entering the concrete, they can deter efflorescence from appearing on the surface of concrete pavers. They initially enhance colors and produce a flat, no-gloss finish on the paver surface. This makes silanes and siloxanes very suitable on exterior areas for resisting efflorescence when a glossy surface is not desired. Silanes and siloxanes do not resist penetration of petroleum stains unless they have additives specifically for that purpose. When required, proprietary mixtures with additives can increase petroleum stain resistance. Other additives can ensure greater consistency in the color of pavers and avoid a blotchy appearance. Silanes have smaller molecules, so they penetrate farther into the concrete than larger

siloxane molecules. However, they are more volatile (tend to evaporate) until they bond to the concrete paver. Silane sealers generally require a higher percent of solids to counteract their rate of evaporation. Therefore, silanes tend to be more expensive than siloxanes. Silanes and siloxanes are typically used as water repellents for concrete bridge decks, parking garages, and masonry walls. Their primary use for reinforced concrete structures is to prevent the ingress of chloride ions from de-icing salts(4). This intrusion causes reinforcing steel corrosion in the concrete, and a weakened structure. Their ability to decrease intrusion of chloride materials provides additional protection of pavers subject to deicing salts or salt air, such as walks, streets, parking lots, plaza roof and parking decks. They are also useful around pool decks to minimize degradation from chlorine. Most silane and siloxane sealers are solvent based. Certain manufacturers offer water based products as well. These products may have a very short shelf life after the silane or siloxane has been diluted with water. The user should check with the manufacturer on the useful life of the product.

Acrylics
Acrylic sealers can be solvent or water based. They enhance paver colors well and create a gloss on the surface. Acrylic sealers provide good stain resistance. Their durability depends on traffic, the quality of the acrylic and the percentage of solids content. They provide longer protection from surface wear than silanes or siloxanes. Acrylic sealants are widely used in residential and commercial paver applications. They generally last for a few years in these applications before re-coating is required. Acrylics specifically developed for concrete pavers do not yellow over time. When they become soiled or worn, pavers with acrylics can be easily cleaned and resealed without the use of extremely hazardous materials. Acrylics should not be used on high abrasion areas such as industrial pavements or floors. Water based acrylics perform well for interior applications. They may be allowed by municipalities that regulate the release of volatile organic contents (VOCs) in the atmosphere.

Urethanes
As either solvent or water based, polyurethanes produce a high gloss and enhance the color of pavers. Aromatic urethanes should contain an ultra-violet (UV) inhibitor to reduce yellowing over time. The product label should state that the sealer is UV stable. Urethanes themselves are more resistant to chemicals than acrylics. While aliphatic urethanes can be used for coating the surface of pavers, elastomeric (aromatic or aliphatic) urethanes should be used where the primary need is to stabilize joint sand. For airfield and gas station applications, the urethane should have a minimum elongation of 100% per ASTM D 2370, Standard Test Method for Tensile Properties of Organic Coatings. Urethanes resist degradation from petroleum based products and de-icing chemicals. This makes them suitable for heavy industrial areas, as well as airfield and gas station pavements. Urethanes cannot be rejuvenated simply by re-coating. If urethane sealers must be removed, methylene chloride or sand blasting is often necessary. Methylene chloride is a hazardous chemical, and is not acceptable for flushing into storm drains. It should not be allowed to soak into the soil. Therefore, urethane removal is best handled by professionals.

***Table 1**—Properties of Sealers for Concrete Pavers—Confirm application and properties with supplier.*

	Patios, walks, pool decks	Residential/ Comercial drives	Gas Stations Airports	Areas subject to chlorine & heavy de-icing salts	Finish	Enhances color	Joint sand stabilizer	UV resistant	Can be re-coated	Ease of removal	Price
Silane	Yes	Yes		Yes	Flat	*		Yes	Yes	Mod.	++
Siloxane	Yes	Yes		Yes	Flat	*		Yes	Yes	Diff.	++
Acrylic	Yes	Yes			Gloss	Yes	Yes	Varies	Yes	Diff.	+
Urethane	Yes	Yes	Yes	Yes	Gloss	Yes	Yes	Varies	No	V. Diff.	++
Water-based Epoxy	Yes	Yes	Yes	Yes	Semi-Gloss	Yes	Yes	Yes	Yes	Mod.	++

*Initially, then diminishes. Diff.=Difficult V. Diff.=Very Difficult +=Moderate Price ++=Higher price

Water Based Epoxy Sealers
Water based epoxy sealers combine other types of sealers with epoxy. They cure by chemical reaction as well as by evaporation. They have very fine solids allowing them to penetrate deep into concrete while still leaving a slight sheen to enhance the color of the pavers. They generally do not change the skid resistance of the surface. When applied, water based epoxy sealers create an open surface matrix that allows the paver surface to breathe thereby reducing the risk of trapping efflorescence under the sealer should it rise to the surface. They resist most chemicals and degradation from UV radiation. These characteristics make these types of sealers suitable for high use areas such as theme parks and shopping malls. The elasticity and adhesion of these sealers make them appropriate for heavily trafficked street projects and areas subject to aggressive cleaning practices.

Figure 10. Urethane is applied with squeegees to stabilize joint sand between pavers on aircraft pavement.

SEALING PROCEDURES
All dirt, oil stains and efflorescence must be removed prior to sealing. The cleaned surface must be completely dry prior to applying most sealers. Allow at least 24 hours without moisture or surface dampness before application. The pavers may draw efflorescence to the surface, or the sealer or liquid stabilizer may whiten under any one of these conditions:

· The surface and joints are not dry
· The pavers have not had an adequate period of exposure to moisture
· There is a source of efflorescence under the pavers (i.e., in the sand, base, or soil) moving through the joint sand and/or pavers
· The sealer is not breathable, i.e., does not allow moisture to move through to the surface of the paver and evaporate.

If the base under the pavers drains poorly, the sealer is applied to saturated sand in the joints, or is applied too thick, the sealer can become cloudy and diminish the appearance of the pavers. In this situation, the sealer must be removed or re-dissolved. Consult your sealer supplier for advice on treating this situation. Cover and protect all surfaces and vegetation around the area to be sealed. For exterior (low-pressure) sprayed applications, the wind should be calm so that it does not cause an uneven application, or blow the sealer onto other surfaces. For many sealers, especially those with high VOC's, wear protective clothing and mask recommended by the sealer manufacturer to protect the lungs and eyes. Sealers can be applied with a hand roller if the area is small (under 1000 ft 2 or 100 m 2). For larger areas, more efficient application methods include a powered roller, or a low pressure sprayer. Sealers are often applied with a foam roller to dry pavers having clean surfaces and chamfers. However, the use of a squeegee to spread the sealer will avoid pulling joint sand out of the joints. See Figure 10. Sealer should be spread and allowed to stand in the chamfers, soaking into the joints. Penetration into the joint sand should be at least 3 / 4 inch (20 mm). The excess sealer on the surface is pushed to an unsealed area with a rubber squeegee. The action of a squeegee wipes most of the sealer from the surface of the pavers while leaving some remaining in the chamfers to eventually soak into the joints. Generally only one coat is required. For other applications, follow the sealer manufacturer's recommendation for application and for the protective gear to be worn during the job. With some sealers that recommend two coats, the first coat is usually applied to saturation. A light second coat, if needed, can be applied for a glossy finish. Be careful not to over apply the sealers such that the surface becomes slippery when cured. For water based sealers requiring two coats, always apply the second coat while the first coat is still very tacky. Prevent all traffic from entering the area until the sealer is completely dry, typically 24 hours. If spraying sealer on the pavers, care should be taken to prevent the spray nozzle from clogging and causing large droplets to be unevenly distributed on them. This is most important for water based sealers. This can cause a poor appearance and performance. Sealers normally require reapplication after a period of wear and weather. The period of reapplication will depend on the use, climate, and quality of the sealer.

Safety Considerations
Adequate slip (foot) and skid (tire) resistance of concrete pavers should be maintained with properly applied joint sand stabilizer or surface sealers. See ICPI *Tech Spec 13 Slip and Skid Resistance of Interlocking Concrete Pavements* for test methods and guidelines. See www.icpi.org to obtain this and all ICPI Tech Spec technical bulletins. The manufacturers of stabilization and sealers should be consulted concerning slip and skid resistance performance characteristics under wet and dry conditions. Some commercial or industrial pavement use painted pavement markings. Consult with the stabilizer and sealer manufacturers for compatibility of their materials with pavement markings. Where there are pavement markings, applications using high gloss materials should be avoided as they can increase the difficulty of reading pavement markings under certain light conditions. Federal, state/provincial, and some municipal governments regulate building materials with high volatile organic contents (VOCs). The restrictions usually apply to solvent based sealers. The VOC level of a sealer refers to the pounds per gallon (or grams per liter) of solvent which evaporates from the sealer, excluding the water. VOCs have been regulated since they can contribute to smog. Most water based sealers comply with VOC restrictions and some solvent based products may comply as well. The user should check with the sealer supplier to verify VOC compliance in those areas that have restrictions. Many solvent based products are combustible and emit hazardous fumes. Therefore, flame and sparks should be prevented in the area to be sealed. Never use solvent based sealers in poorly ventilated or confined areas. Persons applying joint sand stabilizers and sealers should wear breathing and eye protection as recommended by the manufacturer, as well as protective equipment mandated by local, state/provincial, or federal safety agencies. Follow all label precautions and warnings concerning handling, storage, application, disposal of unused materials, and those required by all government agencies. The U.S. Federal Government and Canadian Government require that all shipments of hazardous materials by common carrier must be

accompanied by a Material Safety Data Sheet (MSDS). All chemical manufacturers must supply sheets to shippers, distributors and dealers of cleaners, joint sand stabilizers, and sealers if the materials are hazardous. The MSDS must accompany all shipments and be available to the purchaser on request. The MSDS lists the active ingredients, compatibility and incompatibility with other materials, safety precautions and an emergency telephone number if there is a problem in shipping, handling or use. The user should refer to the MSDS for this information.

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Reinstatement of Interlocking Concrete Pavements

INTRODUCTION

Concrete pavers can act as a zipper in the pavement. When the need arises to make underground repairs, interlocking concrete pavements can be removed and replaced using the same material. Unlike asphalt or poured-in-place concrete, segmental pavement can be opened and closed without using jack hammers on the surface and with less construction equipment. This results in no ugly patches and no reduction in pavement service life. In addition, no curing means fast repairs with reduced user delays and related costs. The process of reusing the same paving units is called reinstatement. This Tech Spec covers how to reinstate or "unzip and zip" interlocking concrete pavement. The following step-by-step procedure applies to any interlocking concrete pavement, including pedestrian areas, parking lots, driveways, streets, industrial, port and airport pavements.

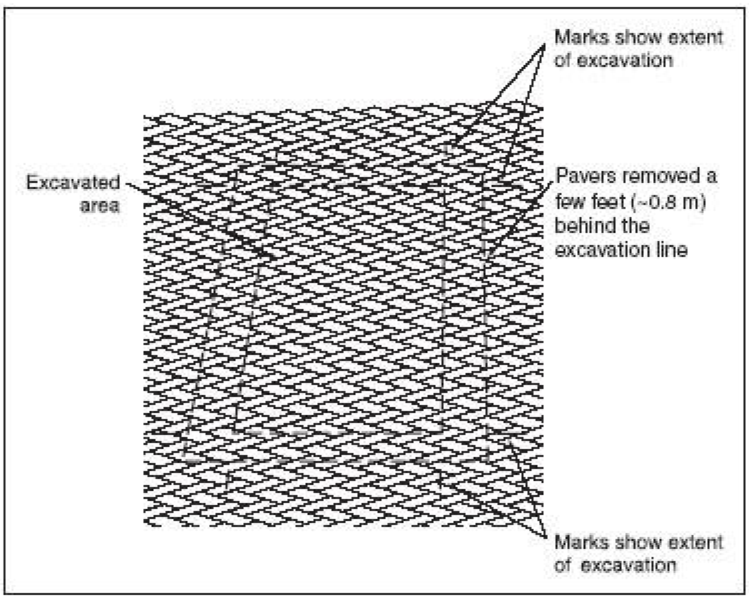

Figure 1. Pavement markings show the extent of paver removal and trench area.

Step 1--Locate Underground Utilities in the Area to be Excavated

The location and depth of existing utilities should be established prior to excavating. Many localities have one telephone number to call for obtaining marked utility locations. Set cones, traffic signs, or barricades around the area to be excavated according to local, state or provincial standards. Determine and mark the area of pavers to be removed. Remove pavers a few feet (~0.8 m) wider on each side of the trench opening. This shoulder around the opening should consist of undisturbed bedding sand. It will be used as a guide for reinstating the sand and pavers later (Figure 1). Paint or crayon should be used to mark the area of pavers for removal. The trench area can be marked on the pavers as well. Paint may be necessary to establish a more permanent marking than crayon, especially if there is vehicular traffic, or if there will be an extended period of time between marking and excavation. The same paving units will be reused, so in some instances paint on them may not be desirable, especially if there is little traffic to wear it away over time.

Step 2--Remove the First Paver

Locate the first paver to be removed. This is typically at one end of the marked area. Scrape the sand from the joints around the first paver using a putty knife or small trowel (Figure 2). Carefully pry each side upward with one or two large screwdrivers. Begin prying on the short ends of the paver. The paver will rise a small distance with each prying (Figure 3). When the paver is high enough to grasp, wiggle it loose, pulling upward. If necessary, pry with a screwdriver using one hand while pulling upward with the other (Figure 4). Sometimes, one end of the paver can be pulled above the others so a pry bar can be inserted under it. The paver can then be pried out. Paver extractors can also be used to remove the first paver and subsequent ones (Figure 5). They are designed to clamp the paver tightly. These work most efficiently in removing the first paver if some of the joint sand is removed before clamping and pulling. Water can be applied to lubricate the joint sand to facilitate extraction. If the pavement has been subject to vehicular traffic for a length of time, the first paver may be need to be broken in order to be removed. A small sledge hammer (3 lb. maul) applied to an appropriate chisel will break a paver into small pieces. Protective eye goggles should be worn during this procedure. Remove all broken pieces from the space until the bedding sand is completely exposed. Pneumatic hammers or cutting saws are generally not required to remove the first unit.

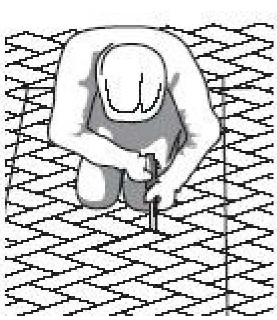

Figure 2. Removing joint sand surrounding the first paver to be removed.

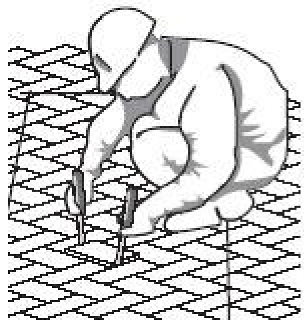

Figure 3. Prying the paver upwards with two large screwdrivers.

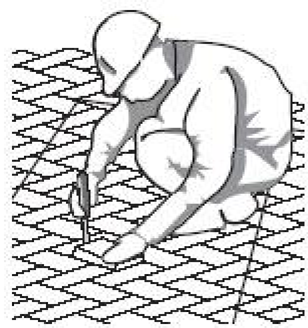

Figure 4. Prying with a screwdriver and pulling the paver out.

Step 3--Remove the Remaining Pavers

After the first one is removed, surrounding pavers can be loosened and pried out (Figure 6). Grab the pavers by the short end, as it offers less resistance than the long side (Figure 7). Remove pavers to the marks on the pavement for the opening. Sand sticking to the sides and bottoms of pavers can interfere with their reinstatement and compaction into the bedding sand. Scrape off sand from each unit as it is being removed. A small trowel, wide putty knife, wire brush, or another paver works well. The direction of removal should consider where pavers are going to stacked. Stack the pavers neatly near the opening, out of the way of excavation equipment such as backhoes or dump trucks. If the pavers need to be removed from the site, stack them on wooden pallets and secure them tightly so there is no loss during transit. Equipment used to move pallets with pavers should be capable of lifting at least 3,000 lbs. (1,365 kg). If the pavers need to be moved only a short distance, then stack them directly on a paver cart at the opening and set them nearby. They will then be ready for pick up by the paver cart when reinstated. For every project, a small stockpile of spare pavers should be stored and used for repairs during the life of the pavement. Weathering, wear and stains may change the appearance of removed pavers compared to spares kept in storage for repairs. When pavers are removed for base or utility repairs, all undamaged units should be retained for future reinstatement. Pavers from the stockpile that replace damaged or broken units should be scattered among the pattern of the existing reinstated pavers. This will reduce the visual impact of color variations.

Figure 5. Using a paver extractor to remove a paver

Figure 6. Prying out the remaining pavers

Removal with Mechanized Equipment - While not commonly done, mechanized equipment can remove large areas of pavers. Some shapes of pavers are compatible with removal by machine. The machines utilize a clamp that grabs about a square yard (1 m 2) at a time, or about 35 to 40 pavers. The exact number of pavers and size of each layer that can be removed depends on the paver shape, laying pattern, and the size of the clamp on the machine. Prior to stacking, sand should be removed from the joints to maintain layer dimensions that will fit into the existing pavement pattern when reinstated. If the removed layers have dry joint sand, it may be removed from handling the layers with the machine clamp. In some cases, the layers may need to be deliberately shaken in order to loosen and evacuate sand from the joints before stacking. Any damaged pavers should be replaced with those having the same dimensions and tolerances as those in the paver layers.

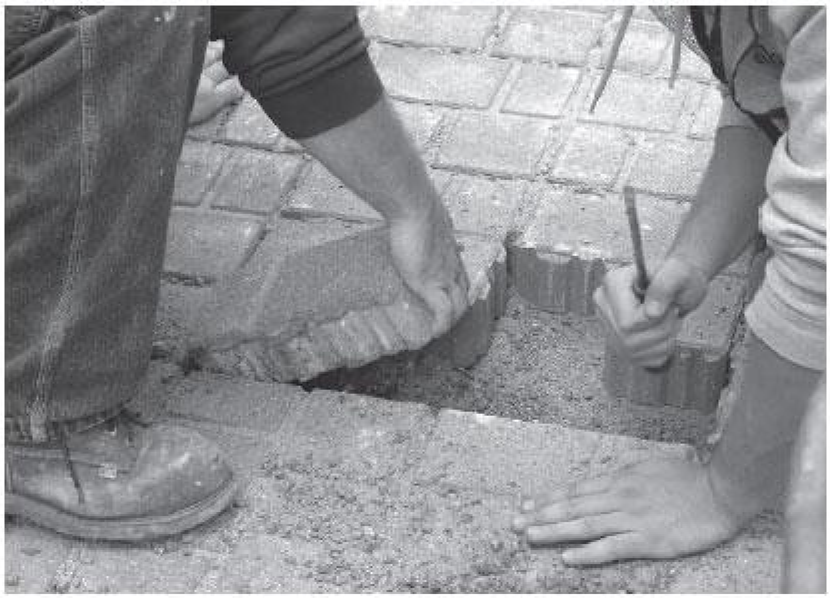

Figure 7. Pulling out a paver by the short end provides greater leverage and makes extraction easier.

Step 4--Remove the Bedding Sand

The removed pavers will reveal compacted bedding sand. It may be removed and reused, or removed during excavation of the base. For some projects with time constraints, the sand will probably be removed during excavation and not re-used. If the sand is re-used, it may need to be loosened with rakes before removal by shoveling. The sand should be neatly stockpiled and kept free from soil, aggregate base, or foreign material. If the sand is mixed with these materials, it should not be reused, and it should be replaced with clean sand. Whether or not it is re-used, always leave an undisturbed area of sand 6 to 12 in. (15 to 30 cm) wide next to the undisturbed pavers. This area will provide a stable support for temporary edge restraints and for screeding the bedding sand after the base is reinstated.

Step 5--Excavate the Base Material and Soil

If aggregate base material is removed, it may be possible to stockpile it near the opening for reuse. Keep the aggregate base material separate from excavated subgrade soil. Any soil removed should be replaced with base material unless local regulations require reinstatement of the native soil. The final shape of the excavated opening should be T-shaped in cross section. (Figure 8). This helps prevent undermining and weakening of the adjacent pavement. Follow local codes on the use of shoring, as it may need to be inserted to prevent collapse of the trench sides. Figure 9 illustrates temporary bracing with plastic or metal edge restraints around the perimeter of the opening. This is recommended practice. The restraints are pinned to the base using metal spikes. Bracing helps keep the undisturbed pavers in place during excavation and fill activities, and will enable reinstatement of units into the existing laying pattern without cutting them to fit.

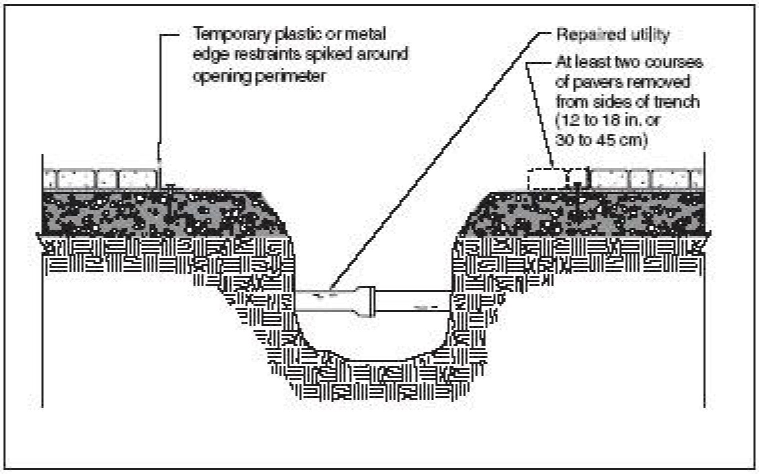

Figure 8. T-shaped cross section of the excavated opening

Step 6--Replace the Base Material

After the repairs are complete, soil at the bottom of the trench should be compacted prior to placing and compacting the base material. Repairs typically use the same base material that was removed. A crushed stone aggregate base should be placed and compacted in 2 to 4 in. (50 to 100 mm) lifts (Figures 10 and 11). If the excavated base material was stabilized with asphalt or cement, it should be replaced with similar materials. Monitoring density of the compacted soil subgrade and base is essential to reinstating any pavement, including interlocking concrete pavements. It will help prevent rutting and premature failure. A dynamic cone penetrometer is an effective means for monitoring the density of each lift while working in the opening. If the soil or base material is too dry during compaction, a small amount of water can be sprayed over each lift prior to compacting. This will help achieve maximum density. A nuclear density gauge is recommended for checking the density of the completed compaction of the soil and base layers. A qualified civil engineer should monitor compaction for conformance to local standards. If there are no local standards for compaction, a minimum of 98% standard Proctor density is recommended for the soil subgrade, and a minimum of 98% modified Proctor density for the base. Compaction equipment companies can provide guidelines on equipment selection and use on the soil and the base. For further guidance on compaction see Interlocking Concrete Pavement Institute Tech Spec 2--Construction of Interlocking Concrete Pavements. The final elevation of the compacted base at the opening perimeter should match the bottom of the existing undisturbed sand layer that surrounds the opening. The elevation of the middle of the base fill placed in the opening should be slightly higher than its perimeter to compensate for minor settlement.

Controlled low-strength materials (CLSM) (sometimes called slurry mix, flowable fill, or unshrinkable fill) can be used in some applications as a replacement for unstabilized base materials (1). The fill can be made from aggregate bound with fly ash, pozzolans, or cement. Because it is poured from a truck, the fill will form around pipes and underground structures where soil or base backfill and compaction are difficult. Low-strength fill can be poured into undercuts and under pipes where it is impossible to fill and compact aggregate base. The material is also self-leveling. Low-strength flowable fill requires a short curing time and can be used in freezing weather. It requires no compaction and with some mix designs, can be opened to traffic in 24 hours. Low-strength fill is stiffer than aggregate base and offers higher resistance to settling and rutting. This reduces deterioration of the pavement surface over time. In order to facilitate re-excavation, flowable fill should be made with a small amount of cement. Check with suppliers on the strength of in-place fill that is at least two years old, and on ease of excavation of these sites. The strength of the fill should not exceed 300 psi (2 MPa) after two years of service. Low-strength fill has been used successfully in Toronto and London, Ontario; Colorado Springs, Colorado; Cincinati, Ohio, Kansas City, Missouri; Peoria, Illinois; and many other municipalities. It is generally more cost-effective than using aggregate base by reducing job time and future pavement repairs. Local ready-mix suppliers can be contacted for available mixes, strengths, installation methods and prices. See Tech Spec 7--Repair of Utility Cuts with Interlocking Concrete Pavements for further information on low-strength fill.

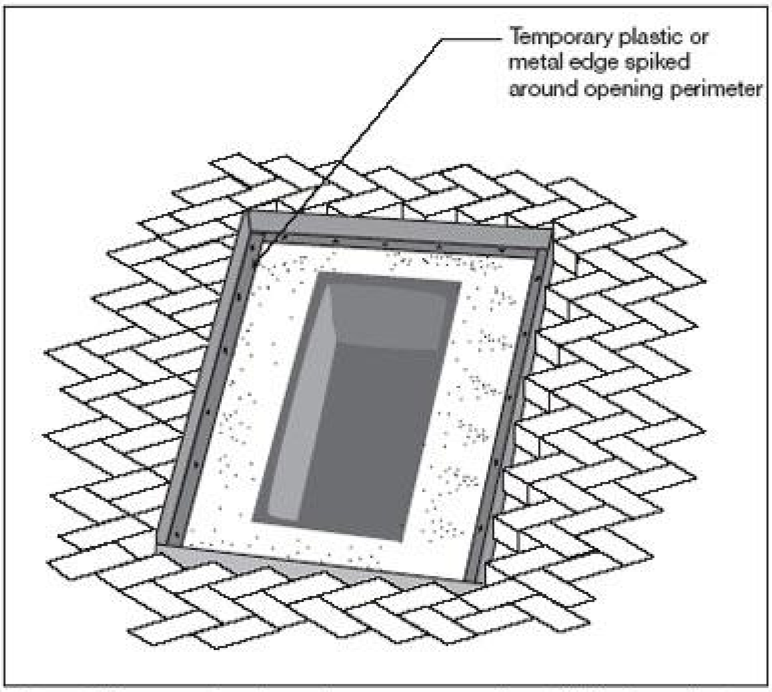

Figure 9. Temporary bracing at the pavement opening will help keep units in place during excavation, repairs and reinstatement.

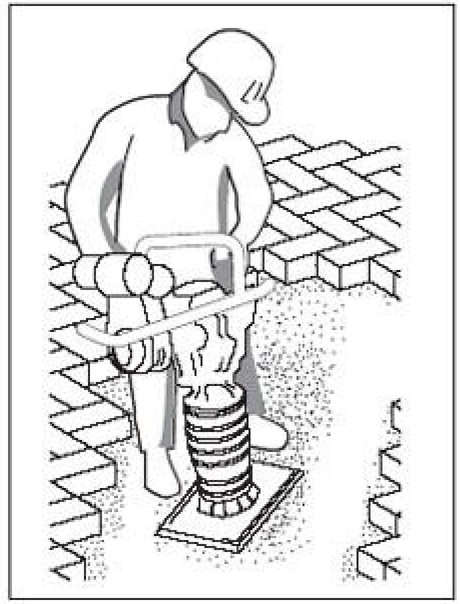

Figure 10. Compaction of the base in 2 to 4 in. (50 to 100 mm) lifts and monitoring density with a dynamic cone penetrometer or a nuclear density gauge are essential to minimizing settlement.

Figure 11. Trench filled with compacted aggregate base. Temporary edge restraints should be used around the opening perimeter.

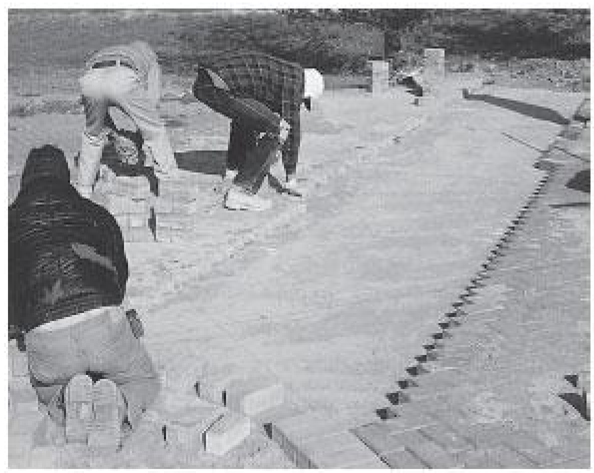

Figure 12. Screeded bedding sand. Note that a few courses of pavers are removed to create even sides for screeding. Installing temporary edge restraints prior to excavating is preferred practice.

Step 7--Replace the Bedding Sand Layer

During the foregoing procedures, it is likely that the pavers and bedding sand around the opening were disturbed especially if no temporary edge restraints were placed to secure the pavers. If so, then remove an additional two rows of pavers, or back to an undisturbed course. Clean sand from these pavers and set them aside with the others. Be sure there is at least 6 to 8 in. (150 to 200 mm) of undisturbed bedding sand exposed after removal of the course(s) of pavers. This area of undisturbed sand can be used to guide screeding of fresh bedding sand over the compacted and leveled base. Prior to screeding, carefully remove any temporary edge restraints so that adjacent pavers remain undisturbed. Spread the bedding sand across the base to about two thirds of its full thickness. Do not use the sand to compensate for low places in the surface of the base. Low areas should be filled with base material and compacted. Spread the remaining thickness of sand. The undisturbed pavers on opposite sides of the opening can be used to guide screeding. It may be necessary to remove a few courses of pavers to straighten the edge of the pavers (Figure 12). Metal screed pipes are placed on the base and in the bedding sand to control its thickness. The base should have a slight "crown" or rise in the center of the reinstated base. A crown helps compensate for minor settling after the pavers are replaced. Furthermore, as the pavers settle slightly from traffic, the reinstated surface will stiffen, increasing its structural capacity.

Step 8--Reinstate the Pavers

Pull and secure string lines across the opening along the pavement joints every 6 to 10 ft. (2 to 3 m). By following the string lines, joints of reinstated pavers will remain aligned with undisturbed ones. Lay the remaining pavers from the smaller end of the opening, generally working "uphill," i.e., from a lower elevation of the pavement to the higher one. Minor adjustments to the alignment and spacing of joints can be made with pry bars or large screw drivers. Make adjustments prior to compacting the pavers (Figure 13). Place the pavers in the original laying pattern and compact them with at least two passes of a minimum 4,000 lbf. (18 kN) plate compactor. The path of the plate compactor should overlap onto the undisturbed pavers. Spread joint sand and compact again until the joints can no longer accept sand (Figure 14). Sweep away excess sand. The elevation of the reinstated pavers after compaction should be no higher than 1 / 8 in. (2 mm) at the edges and 3 / 16 in. (5 mm) at the center. Traffic and minor settlement will compact the pavers to a level surface. After a short period of time, the repaired area will be undetectable (Figure 17). Applications such as airports or gas stations require joint sand stabilizers. If an area is reinstated in such uses, then a stabilizer will need to be re-applied to the joints. See Interlocking Concrete Pavement Institute Tech Spec 5--Cleaning and Sealing Interlocking Concrete Pavements for advice on sealers and joint sand stabilizers. A crew of three or four persons can manually reinstate between 500 and 1,500 sf (50 and 150 m^2) per day. This does not include excavation and replacement of the base material. Crew productivity depends on experience, weather, traffic, site access, a steady flow of materials around the repair site, and the number of pavers to be cut. An experienced crew will reinstate pavers with little or no cutting, aligning reinstated pavers with existing joint lines, pattern, and spacing between the units. Use of mechanical equipment for removal and reinstatement of pavers in large areas can increase productivity substantially above these estimates. Although existing pavers can be used in reinstatement, there may be projects where it is more cost effective to remove and replace the area with new pavers. An experienced paver installation contractor can provide guidance on cost-effective approaches for each reinstatement project. Municipalities, utility companies and other users should use experienced contractors reinstate interlocking concrete pavers. Others may use in-house labor which should be trained in the procedures described above. Contact a local Interlocking Concrete Pavement Institute paver installation contractor member to assist with training. Successful reinstatement using experienced contractors will result in successful reinstatement jobs that leave no ugly patches nor do they weaken the pavement. See Figures 15 and 16.

Figure 13 (Left). Adjusting joint spacing and alignment. Figure 14 (Right). Second and final compaction of the pavers. The first compaction occurs after the pavers are placed (no sand in the joints). The second compaction works the sand on pavers into the joints. This process causes the pavers to interlock.

Figure 15 and 16. Reinstated pavers leave no ugly patches nor do they weaken the pavement.

References

1. Controlled Low Strength Materials (CLSM), ACI 229R-94, American Concrete Institute, Farmington Hills, Michigan, 1994.

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Repair of Utility Cuts Using Interlocking Concrete Pavers

North American cities have thousands of utility cuts made in their streets each year. Figure 1 shows a daily occurrence in most cities: repairs to underground utility lines for water, sewer, gas, electric, steam, phone, fiber-optic, or cable services. A sample is given below of the number of annual utility cuts in a few cities.

Billings, Montana 650730
Boston, Massachusetts 2530,000
Chicago, Illinois 120,000
Cincinnati, Ohio 6,000
Oakland, California 5,000
San Francisco, California 10,000
Seattle, Washington 1020,000
Toronto, Ontario 4,000

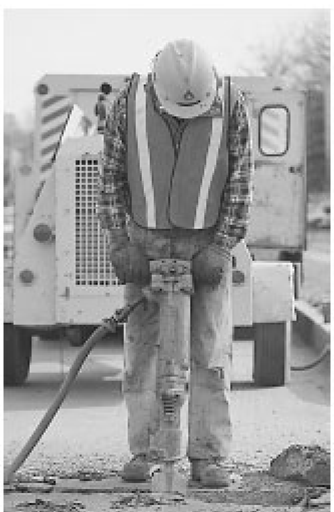

Figure 1. Repairs to utilities are a common sight in cities, incurring costs to cities and taxpayers.

$$\text{Annual cost of pavement damage from utility cuts to one category of streets (local, collector, thoroughfare, etc.)} = \text{Annual cost of resurfacing streets damaged by utility cuts} - \left[\text{Annual cost of resurfacing streets damaged by utility cuts} \times \left(\frac{\text{Number of years of life remaining before resurfacing streets with utility cuts}}{\text{Expected years of life before resurfacing if there are no utility cuts}} \right) \right]$$

Where the:

$$\text{Annual cost of resurfacing streets damaged by utility cuts} = \left(\text{percent of all resurfaced streets that are damaged by cuts} \right) \times \left[\text{Total annual cost of resurfacing all streets} \times \left(\frac{\text{Total miles (km) of streets resurfaced that year of one category (local, collector, thoughfare, etc.)}}{\text{total miles (km) of all streets resurfaced in that year}} \right) \right]$$

A damage fee would be derived by dividing the annual cost of resurfacing a particular category of street damaged by utility cuts by the number of years of life expected from those streets. The fee would be higher if a street to be cut had been recently resurfaced, and lower for a street that is about ready for resurfacing.

Table 1—Annual cost of pavement damage from utility cuts (4).

The Costs of Utility Cuts

The annual cost of utility cuts to cities is in the millions of dollars. These costs can be placed into three categories. First, there are the initial *pavement cut and repair costs*. These include labor, materials, equipment, and overhead for cutting, removing, replacing, and inspecting the pavement, plus repairs to the utility itself. Costs vary depending on the size and location of the cut, the materials used, waste disposal, hauling distances, and local labor rates. Second, there are *user* costs incurred as a result of the repair. They include traffic delays, detours and denied access to streets by users, city service and emergency vehicles. User costs depend on the location of the cut. A repair blocking traffic in a busy center city will impose higher costs and inconvenience from delays than a cut made in a suburban residential street. There are downstream costs to users from utility repairs such as lost productivity due to delays, and damage to vehicles from poor pavement riding quality. While these losses are difficult to quantify, they are very present. The third cost is subtle and long term. It is the *cost of pavement damage* after the repair is made. Cuts damage the pavement. Damage can range from negligible to substantial, depending on the quality of the reinstated area and the condition of the surrounding pavement. The damage reduces pavement life and shortens the time to the next rehabilitation. The need to rehabilitate damaged pavements earlier rather than when normally required has costs associated with it. Several studies have demonstrated a relationship between utility cuts and pavement damage. For example, streets in San Francisco, California, typically last 26 years prior to resurfacing. A study by the City of San Francisco Department of Public Works demonstrated that asphalt streets with three to nine utility cuts were expected to require resurfacing every 18 years (1). This represented a 30% reduction in service life compared to streets with less than three cuts. Streets with more than nine cuts were expected to be resurfaced every 13 years. This represents a 50% reduction in service compared to streets with less than three cuts. The report concludes that while San Francisco has some of the highest standards for trench restoration, utility cuts produce damage that extends beyond the immediate trench. "...even the highest restoration standards do not remedy all the damage. Utility cuts cause the soil around the cut to be disturbed, cause the backfilled soil to be compacted to a different degree than the soil around the cut, and produce discontinuities in the soil and wearing surface. Therefore, the reduction in pavement service life due to utility cuts is an inherent consequence of the trenching process." A 1985 study in Burlington, Vermont, demonstrated that pavements with patches from utility cuts required resurfacing more often than streets without patches. Pavement life was shortened by factors ranging between 1.70 and 2.53, or 41% to 60% (2). Research in Santa Monica, California, showed that streets with utility cuts saw an average decrease in life by a factor of 2.75, or 64% (3). A 1994 study by the City of Kansas City, Missouri, notes that "street cuts, no matter how well they are restored, weaken the pavement and shorten the life of the street." It further stated that permit fee revenue does not compensate the city for the lost value resulting from street cuts (4). A 1995 study by the city of Cincinnati, Ohio, showed that damage to the pavement extends up to three feet (1 m) from the edge of properly restored cuts (5). The cost of pavement damage includes street resurfacing and rehabilitation to remedy damage from cuts. Permit fees charged by cities to those making cuts often do not fully account for pavement damage after the cut pavement is replaced. Some cities, however, are mitigating the long-term costs of pavement cuts by increasing fees or by charging a damage fee. They seek compensation for future resurfacing costs to remedy pavement damage. The rationale for fees to compensate for early resurfacing can be based on the following formula in Table 1. Pavement damage fees may be necessary for conventional, monolithic pavements (asphalt and castin-place concrete) because they rely on the continuity of these materials for structural performance and durability. *Cuts reduce performance because the continuity of the pavement surface, base, and subgrade has been broken.* Traffic, weather, de-icing salts, and discontinuities in the surface, in the compacted base, and in the soil, shorten the life of the repaired cut. When pavement life is shortened, rehabilitative overlays are needed sooner than normal, thereby incurring maintenance costs sooner than normal.

Figure 2. Removal of concrete pavers for a gas line repair in Dayton, Ohio.

Figure 3. Compaction of the base.

Figure 4. Reinstatement of the pavers, bedding and joint sand.

Figure 5. The final paver surface is continuous. There are no cuts or damage to the pavement.

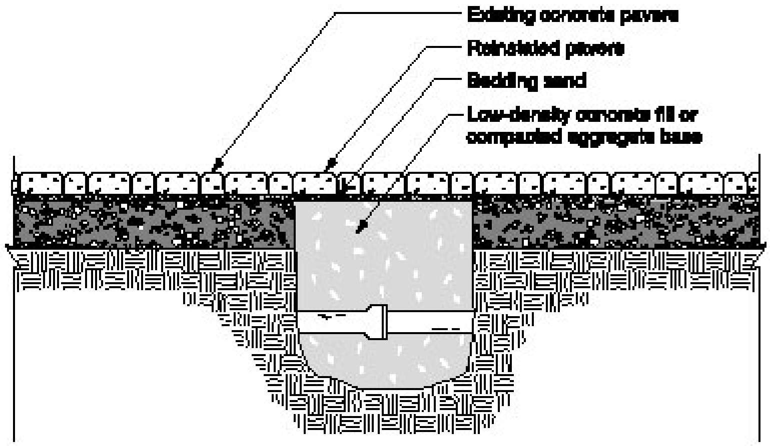

Figure 6. Cross section of reinstated utility cut into interlocking concrete pavement.

Reducing Costs with Interlocking Concrete Pavements
Interlocking concrete pavements can reduce pavement cut and repair costs, and user costs. They can also reduce costs from long term pavement damage, and the fees to rehabilitate them.

Reducing Pavement Cut and Repair Costs Costs to open interlocking concrete pavements can be competitive with monolithic pavements such as asphalt or poured concrete. Cost savings occur because sawcutting equipment and pneumatic jack hammers are not required for removal. Since the same paver units are reinstated, additional savings can result from reducing waste and hauling. Minimizing waste material is important in urban street repairs because of compact working conditions and increased landfill costs.

Reducing User Costs User costs due to traffic interruptions and delays are reduced because concrete pavers require no curing. They can handle traffic immediately after reinstatement, reducing user delays. Furthermore, reinstated concrete pavers preserve the aesthetics of the street or sidewalk surface. There are no patches to detract from the character of the neighborhood, business district, or center city area. With many projects, concrete pavers help define the character of these areas. Character influences property values taxes. Attractive paver streets and walks without ugly patches can positively affect this character.

Reducing Costs of Pavement Damage Since interlocking concrete pavements are not monolithic, they do not suffer damage from cuts. The modular pavers and joints are superior to the cracks from cuts that typically result in accelerated wear to monolithic pavements. The role of joints in interlocking concrete pavement is the opposite from those in monolithic pavements. **Any** break in monolithic pavement, e.g., joints, cuts or cracks, normally shortens pavement life because the continuity of the material is broken. In contrast, the joints of the modular units in interlocking concrete pavements maintain structural continuity. Figures 2, 3, 4, 5 and 6 show the process of repair and illustrate the continuity of the paver surface after it is completed. The reinstated units are knitted into existing ones through the interlocking paving pattern and sand filled joints. Besides providing a pavement surface without cuts, the joints distribute loads by shear transfer. The joints allow minor settlement in the pavers caused by discontinuities in the base or soil without cracking. When pavers are reinstated on a properly compacted base, there is no damage to adjacent, undisturbed units. Unlike asphalt, concrete pavers do not deform, because they are made of high strength concrete. The need for street resurfacing caused by repeated utility cuts is eliminated because concrete pavers are not damaged in the reinstatement process. In addition, the use of low density concrete fill can help re-establish the broken continuity of the base and subgrade. This reduces the likelihood of settlement and helps eliminate damage to the pavement. Therefore, long term costs of pavement damage from utility cuts to interlocking concrete pavement can be substantially lower when compared to monolithic pavements. This makes interlocking concrete pavement very cost effective for streets that will experience a number of utility repairs over their life. Furthermore, lower costs from less damage can mean lower fees for cuts when compared to those for cutting into monolithic pavements.

Utility Cut Repairs in Asphalt Pavements Using Interlocking Concrete Pavers
Tech Spec 6, *Reinstatement of Interlocking Concrete Pavements*, published by the Interlocking Concrete Pavement Institute, provides step-bystep guidance for repairs to vehicular and pedestrian pavements made with concrete pavers. A unique, experimental variation of the techniques in this technical bulletin is demonstrated in London, Ontario, where repairs to utility cuts in asphalt are made with interlocking concrete pavers (6). The local gas company normally reinstates cut pavement in the winter with cold patch asphalt after making repairs to gas lines. In the spring, the cold patch is typically removed and hot mix asphalt is placed in the openings. Figure 7 shows the result of settlement and shrinkage of the cold patch asphalt in a London, Ontario, utility cut. The change in dimensions causes the edge of the cut asphalt to deteriorate, and settlement decreases riding quality. Concrete pavers on low density concrete fill have been successfully used as a replacement for cold patch asphalt (Figures 8 and 9).They were first used as a temporary repair with the intent of being removed in the spring. However, the pavers performed so well that the City of London left them in place indefinitely. Several repairs were in streets subject to heavy truck traffic, as well as residential streets. Costs were less than using cold patch asphalt. All repairs in London with concrete pavers and low-density concrete have produced a smooth surface transition from the asphalt to the pavers. The riding quality and safety has improved to the extent that the transition from one surface to the next can barely be discerned by the driver. The pavers were colored to match the appearance of the asphalt so there would be no substantial differences in appearance. Figure 10 shows such a patch of pavers blending with the surrounding pavement. The base material, controlled low-density concrete fill (sometimes called unshrinkable fill), is a low-strength concrete poured from a ready-mix truck into the trench opening. The concrete fill eliminates the need to replace the aggregate base. The concrete cures to a sufficient strength that

the repair with concrete pavers can be opened to traffic within 24 hours, even in freezing weather.

Figure 7. Pavement damage from settlement and shrinkage of cold patch asphalt.

Figure 8. Utility cut repair in a residential area in London, Ontario.

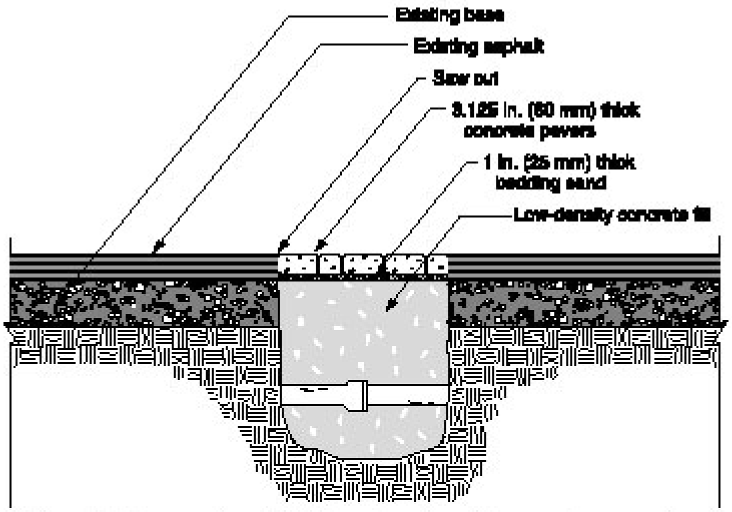

Figure 9. Cross section of utility cut repairs with concrete pavers in London, Ontario.

Repair Guidelines for Using Concrete Pavers for Utility Cuts in Asphalt Pavement
The experimental repairs in London, Ontario, have been in place since 1994 and have performed well. The gas company and City continue to make repairs using this method. The ongoing repairs using this method demonstrate that it has particular application in cold climates as a substitute for cold patch asphalt. The use of low-density concrete fill has resulted in no settlement. The smooth riding pavement has increased the public image of the utility company and the City, and has reduced liability. By eliminating the need to remove cold patch asphalt in the spring, labor forces can be placed on more urgent work. The following are guidelines from experience with many utility repairs with concrete pavers and low-density concrete fill in London, Ontario.

Signing such as warnings, arrows, flashers, cones and/or barricades should be placed around the area to be cut, according to local, state, or provincial standards.
Cuts in the asphalt pavement should be done with a saw using straight lines. A pneumatic hammer should not be used to cut the asphalt. The saw cuts must be vertical and made completely through the existing asphalt layer. In order to provide clean corners along the edge of the cut, the asphalt layer should not be fractured, suffer from alligator cracking, or be raveled. The thickness of the asphalt at the opening should be at least 4 in. (100 mm). The sides of the asphalt provide a restraint for the 3.125 in. (80 mm) thick pavers and approximately 1 in. (25 mm) of bedding sand. The interior of the cut asphalt can be broken with a pneumatic hammer and removed with a front end loader. Pieces along the saw cuts should be removed carefully to prevent damage to the edges. Excavation of the base and soil must be within the limits of the removed asphalt, and care must be taken to not undermine the adjacent pavement. Trench excavation, bracing, shoring, and/or sheeting should be done in accordance with the local authority. Equipment should be kept from the edges of the opening as loads may crack or break pieces from the cut asphalt edges. Excavated soil and base materials should be removed from the site. The trench should be kept free from standing water.
Unshrinkable fill poured into the trench is shown in Figure 11. The fills flows into undercuts, under the edge of the cut asphalt (providing additional support), and in places where the soil or base has fallen from the sides of the trench. These places are normally impossible to fill and compact with aggregate base or backfill material. There are many mixes used for low-density concrete fill (7)(8). Proprietary mixtures include those made with fly-ash that harden rapidly. Others are made with cement. A recommended mix can be

made with ASTM C 150 (9) Type I Portland cement (or Type 3 for winter repairs), or CAN3-A23.5-M type 10 (or type 30 Portland cement) (10). The slump of the concrete should be between 6 and 8 in. (150 and 200 mm) as specified in ASTM C 143 (11) or CAN3A23.2.5C (10). When air entrainment is required to increase flowability, the total air content should be between 4 and 6% as measured in ASTM C 73 (11) or CAN3-A23.2-4C (10). Air content greater than 6% is not recommended as it may increase segregation of the mix. A strength of 10 psi (0.07 Mpa) should be achieved within 24 hours. The maximum 28 day compressive strength should not exceed 50 psi (0.4 Mpa) as measured by ASTM C 39 (11) or CAN3-A23.2-9C (10). Cement content should be no greater than 42 lbs/cy (25 kg/m 3). The low maximum cement content and strength enables the material to be excavated in the future. Mixes containing supplementary cementing materials should be evaluated for excessive strength after 28 days.

Repaired utility lines are typically wrapped in plastic prior to pouring the low density fill. This keeps the concrete from bonding to the lines and enables them to move independently. When the fill is poured, it is self-leveling. It should be poured to within 4 in. (100 mm) of the riding surface of the asphalt.

Bedding sand can be installed when the concrete is firm enough to walk on, generally within a few hours after placement. The bedding sand should be as hard as available and should conform to the grading requirements of ASTM C 33 (11) or CSA A23.1 (10). *Mason sand, limestone screenings or stone dust should not be used.* The sand should be moist, but not saturated or frozen. Screed the bedding with 1 in. (25 mm) diameter screed pipe. Remove excess sand from the opening. Since the low-density concrete fill is self-leveling, it will create a flat surface for the bedding sand. In most cases, there will be a slope on the surface of the street. Adjustments to the thickness of the bedding sand may be necessary for the finished elevation of the pavers to follow the slope on the surface of the street. This can be accomplished by adjusting the height of the screed pipes.

Concrete pavers should be at least 3.125 in. (80 mm) thick and meet the standards in ASTM C 936 (12) or CSA A231.2 (13). They should be delivered in strapped bundles and placed around the opening in locations that don't interfere with excavation equipment or ready-mix trucks. The bundles should be covered with plastic to prevent water from freezing them together. The bundles need to be placed in locations close to the edge of the opening. Most bundles have several rows or bands of pavers strapped together. These are typically removed with a paver cart. The paver bundles should be oriented so that removal of the bands with carts is done away from the edge of the asphalt. Rectangular concrete pavers [nominally 4 in. by 8 in. (100 mm x 200 mm)] should be placed against the cut asphalt sides as a border course. They should be placed in a sailor course, i.e., the long side against the asphalt. No cut paver should be smaller than one third of a unit. Place pavers between the border course in a 90 degree herringbone pattern (Figure 12). Joints between pavers should not exceed 1 / 16 in. (2 mm). Compact the pavers with a minimum 5,000 lbf (22 kN) plate compactor. Make at least two passes with the plate compactor. A small test area of pavers may need to be compacted to check the amount of settlement. The bedding sand thickness should be adjusted in thickness to yield pavers no higher than 1 / 8 in. (3 mm) above the edge of the asphalt. Spread, sweep and compact sand into the joints. The joint sand is typically finer than the bedding sand, and should conform to the grading requirements of ASTM C 144 (11) or CSA A179 (10). The joints must be completely full of sand after compaction. Remove excess sand and other debris. The pavers may be painted with the same lane, traffic, or crosswalk markings as any other concrete pavements (Figure 13).

Figure 10. A patch of barely discernable pavers in a heavily trafficked intersection in London, Ontario.

Figure 11. Low density concrete fill (unshrinkable fill) poured into a utility trench from a ready-mix concrete truck.

Figure 12. Pavers are laid in a 90 degree herringbone pattern between the border courses.

Figure 13. Concrete pavers in utility cuts can be painted as any other pavement.

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Sources for additional information on low-density flowable fill include the Cement Association of Canada, 1500-60 Queen Street, Suite 609, Ottawa, Ontario K1P 5Y7, tel: **613-236-9471** and the National Concrete Ready-Mix Association, 900 Spring Street, Silver Spring, Maryland, 20910, tel: **301-587-9419** . The American Concrete Institute offers publication 229R-94, "Controlled Low Strength Materials (CLSM)" at P.O. Box 9094, Farmington Hills, Michigan 48333-9094, tel: **810...** .

Figures 8, 9, 10 and 11 are courtesy of Gavigan Contracting, Ltd., London, Ontario.

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CONCRETE GRID PAVEMENTS

Perforated concrete paving units as pavement were introduced as hollow concrete building blocks placed in the ground to support cars.

Background

As cities grow, man-made surfaces contribute to urban heat and stormwater runoff. Heat is generated by the high concentration of pavements and buildings. It forms a dome of warm air, or an urban heat island, over cities that can be as much as 12° F (7°C) higher than outlying areas. The urban heat island also increases electricity consumption for air conditioning. This dome of heat traps dust and gases, increasing the concentrations of air pollution from automobile exhaust and industrial sources (1). A high concentration of pavements and buildings, or impervious surfaces, generates additional runoff during rainstorms. Washed from the air and pavements, excess runoff carries pollutants that enter water courses. The runoff generated by impervious surfaces erodes streams, degenerating riparian environments, and pollutes sources of drinking water. Increased runoff volumes and velocities deprive ground water from recharging, decreasing the amount of available water in many communities. Concrete grid pavements or "green parking lots" originated from the need to reduce the urban heat island and stormwater runoff from impervious surfaces. Perforated concrete units as pavement were introduced when hollow concrete building blocks were placed in the ground to support cars. They first appeared in 1961 to handle overflow parking at a major cultural center near Stuttgart, Germany (2). They were a replacement for temporary steel runway matting. Figure 1 shows the genesis of grids. Since then, concrete grids developed in Europe were applied in North America as a method for reducing lakeside and streambank erosion, as well as for ditch liners. Concrete grids were later used for driveways, main and overflow parking areas, shoulders along airfields and highways crossovers on medians, boat launching ramps, emergency fire lanes and for access roads adjacent to buildings. See Figure 2. Figures 3-13 illustrate many uses of concrete grid pavers. This technical bulletin provides guidance on the design, specification, construction, and maintenance of concrete grid pavements for a wide range of applications. Concrete grids are an environmentally friendly technology that can help earn credits under green building rating systems such as LEED ® and Green Globes. For more information on how grids can earn credits see ICPI Tech Spec 16 Achieving LEED ® Credits with Segmental Concrete Pavement.

Figure 1. Grids first used in Germany in 1961 for overflow parking were building blocks placed in the ground. They emerged from the need to cool cities and decrease stormwater runoff.

Figure 2. A typical grid pavement for occasional vehicular traffic

Figure 3. Residential driveway

Figure 4. Lakeside stabilization

Figure 5. Streambank stabilization

Figure 6. Roadway median crossover

Figure 7. Service access lane

Properties of Concrete Grid Paving Units

The properties of concrete grid units are defined in ASTM C 1319, Standard Specification for Concrete Grid Paving Units (3). This specification defines concrete grids as having maximum dimensions of 24 in. long by 24 in. wide (610 mm by 610 mm) and a minimum nominal thickness of 3 1 / 8 in. (80 mm). The minimum required thickness of the webs between the openings is 1 in. (25 mm). Dimensional tolerances should not differ from approved samples more than 1 / 8 in. (3.2 mm) for length, width, and height. The minimum compressive strength of the concrete grid units should average 5,000 psi (35 MPa) with no individual one less than 4,500 psi (31 Mpa). Their average water absorption should not exceed 10 lb/ft 3 (160 kg/m 3). Freeze-thaw durability is based on three years of proven field performance of units that conform to the above web thickness, compressive strength and absorption criteria. Concrete grid unit designs fall into two categories: lattice and castellated as shown in Figure 14. Lattice pavers have a flat surface that forms a continuous pattern of concrete when installed. Castellated grids include protruding concrete knobs on the surface making the grass appear continuous when installed. Concrete grid pavers range in weight from 45 lbs. (20 kg) to 90 lbs. (40 kg). The open area generally ranges between 20% and 50%.


Figure 8. Emergency access lane for fire trucks


Figure 9. Overflow parking


Figure 11. Fence


Figure 12. Picnic area

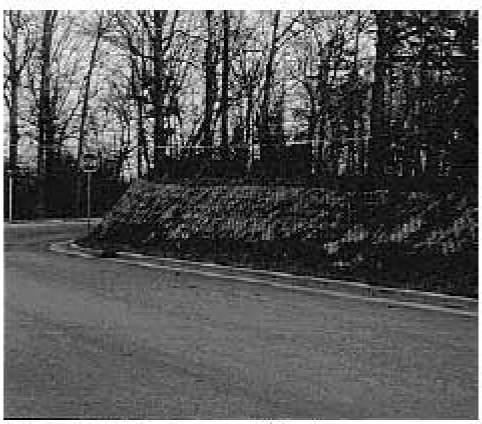
Figure 10. Embankment stabilization


Figure 13. Air for tree roots and a warning for drivers

Design, Construction, and Maintenance Guidelines for Vehicular Pavements
Guidelines are provided for a dense-graded, crushed stone, aggregate base under bedding sand, topsoil and grass or aggregate in the grid openings. The choice of grass or aggregate in the openings depends on the expected intensity of use. Most grasses require at least five hours of sunlight each day to survive. Grass can be placed in the grid openings in intermittent or overflow parking areas, as well as in fire lanes. If a parking area is covered by cars all day for consecutive days, aggregate should be used in the openings as constant shade and engine heat will kill the grass. Before a parking lot is constructed, existing pedestrian paths across the lot should be studied and defined. Parking spaces and pedestrian paths as well as spaces for disabled persons can be delineated with solid concrete pavers. Paths with solid units will make walking more comfortable, especially for pedestrians with high heeled shoes. Likewise, parking spaces accessible to disabled persons and bicycles should be marked with solid pavers (Figure 15).

Design with a dense-graded, crushed stone base -- A typical grid pavement installation consists of compacted soil subgrade, a dense-graded base of compacted crushed stone, 1 / 2 to 1 in. (13 to 25 mm) thick bedding sand, and grids. The openings in the grids are filled with topsoil and grass (Figure 16), or aggregate. Thicknesses required under conventional asphalt pavements are generally sufficient under concrete grids. A minimum of 8 in. (200 mm) of compacted aggregate base is recommended for emergency fire lanes supporting fire trucks, and truck axle loads, defined by AASHTO H20 and HS20 as well as for parking lots and driveways. Thicker bases may be required when extremely heavy vehicular loads are expected. Thicker bases may also be required when the soil subgrade is weak (California Bearing Ratio < 4%) or when it has high amounts of clay or silt. Likewise, thicker bases or those stabilized with cement will be required over a high water table, in low-lying areas subject to flooding, or over continually saturated soils. For unstabilized aggregate bases, geotextile is recommended to separate the compacted soil subgrade from the base material for these situations.

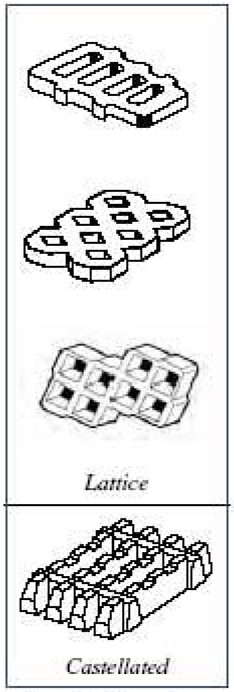

Figure 14. Types of Grid Pavement Units

Figure 15. Solid pavers used for bicycle parking and pedestrian access.

Figure 16. A parking lot with a dense-graded, crushed stone base.

Construction of dense-graded bases -- Prior to placing a dense-graded base, the soil subgrade should be uniformly compacted to at least 95% of standard Proctor density per ASTM D 698 (4). Dense-graded aggregate bases should be compacted to a minimum of 98% standard Proctor density (4). A well-compacted base is essential to shedding water and remaining stable in freeze-thaw conditions. Specifications for crushed stone aggregate base materials typically used under asphalt pavements are suitable under concrete grid pavements. If no local standards exist, gradation of the base material should conform to ASTM D 2940, Standard Specification for Graded Aggregate Material for Bases or Subbases for Highways or Airports (5). Figure 17 illustrates a typical cross-section with a dense-graded aggregate base. For bases over poorly-draining soils, perforated-plastic, geotextile-wrapped drain pipe is recommended for removing excess water. The pipe should be directed to a drainage swale, storm sewer, or stream. If draining soils is impractical, aggregate bases can be stabilized with 4 to 6 percent (by weight) of cement to increase strength during drainage or freeze-thaw. The maximum surface tolerance of the compacted base should be ± 3 / 8 in. (±10 mm) over a 10 ft (3 m) straightedge. The base should extend beyond the perimeter of the grids a minimum of 12 in. (300 mm) when there is no building or curb to restrain them. The extended perimeter increases the stability of the grids and facilitates installation of staked edge restraints. The gradation of the bedding sand should conform to ASTM C 33 (6) or CSA A23.1-FA1 (7). These gradations are given in the guide specification at the end of this bulletin. Limestone screenings, stone dust or masonry sand should not be used. The thickness of the bedding sand should be between 1 / 2 and 1 in. (1325 mm), and screeded to a consistent thickness. If No. 8 stone is used for bedding and openings, this should be screeded to 1 in. (25 mm) thickness. This is typically accomplished with screed rails or bars placed on the compacted base. The bedding sand over the bars is pulled across them with a screed board to establish a consistent sand thickness. The sand should have a consistent moisture content but not be saturated. It should not be disturbed prior to placing the grids. The grids are placed on the screeded bedding sand with the minimum joint spacing of 3 / 16 in. (5 mm). The units shouldn't be pushed or hammered such that they touch each other. If the grids touch, they may crack, chip or spall under repeated traffic. The units should be cut to fill any spaces along the edges prior to compaction. All installed units should be compacted into the bedding sand at the end of each day. Rainfall settles uncompacted sand, preventing the grids from pressing into the sand when compacted. If bedding sand is left uncompacted, it should be covered with plastic to protect it from rain. Otherwise, bedding sand saturated with rainfall prior to compaction will need to dry, be raked and re-screeded or be replaced. If left uncorrected, the grids will settle unevenly and move under traffic. After the grids are placed, topsoil is spread across them and swept into the openings. Fertilizer may be mixed with the topsoil as well. Quantities should account for the concrete surface. The grids are vibrated into the sand with a high frequency (75-90 Hz), low-amplitude plate compactor. It should have a minimum centrifugal compaction force of 4,000 lbs (18 kN). Rollers or a mat should be attached to the plate of the compactor to protect the grids from cracking and chipping. The primary purpose of compaction is to create a level surface among the units. An occasional cracked unit from compaction will not compromise performance. Extensive cracking should be addressed on a job-by-job basis. The openings should be seeded and completely filled with topsoil. Adding topsoil to the entire surface can assist in germination. Straw can be applied to protect the grass while it is growing. While labor-intensive, sod plugs can be inserted into the openings as an alternative to topsoil and seeding. Sod plugs require a reduced amount of topsoil in the openings so space is available for them. The choice of grass variety is important to longevity under tires and drought. A limited amount of research on concrete grid pavers has shown that Merion Kentucky bluegrass, Kentucky 31 tall fescue, and Manhattan perennial ryegrass have a high tolerance to wear, a high potential for recuperation from damage, and a low tendency toward thatch build-up (8). Turfgrass specialists may have further recommendations on species and seeding rates. Sediment from runoff and dust from adjacent areas must be kept from entering the openings during and after establishment of the grass. Sediment clogs the topsoil and prevents grass from growing. The grass should not be exposed to tires until it is well established. A period of time for establishing grass should be part of the construction contract and schedule. This is typically three to four weeks. Edge restraints are required for containing concrete grid pavements and preventing them from shifting under tire traffic. Concrete, plastic, or metal edge restraints are recommended where automobile tires could loosen and damage the edge units. ICPI Tech Spec 3 Edge Restraints for Interlocking Concrete Pavements provides further guidance on their selection (9). For parking applications, tire stops are recommended to help prevent lateral movement of perimeter units. Tire stops should be anchored into the base at least 2 ft. (0.6 m) from the outside edge of the units.

Maintenance -- Concrete grids with grass will require maintenance ordinarily required for lawns such as watering, mowing, removal of weeds and occasional fertilizing. If grass in grid pavements can not be maintained by the project owner or tenant, then crushed stone aggregate should be placed in the openings. Aggregate also should be used if sediment from the site or adjacent areas is expected to wash onto the grids or be deposited on them by vehicles. Snow can be plowed from grids if the plow blade is set slightly above their surface. Rotary brushes for snow removal are not recommended. De-icing salts should never be used on grass because salt will kill it. Re-establishing grass in openings with contaminated soil is difficult without removing and replacing the soil in each opening. Due to their slab-like shape, concrete grids may crack during compaction or while in service. In most situations, one or two cracks in a unit will not diminish structural or functional performance. If units crack from soil or base settlement, they can be removed and replaced. Likewise, the same units can be reinstated after repairs to the base or to underground utilities.

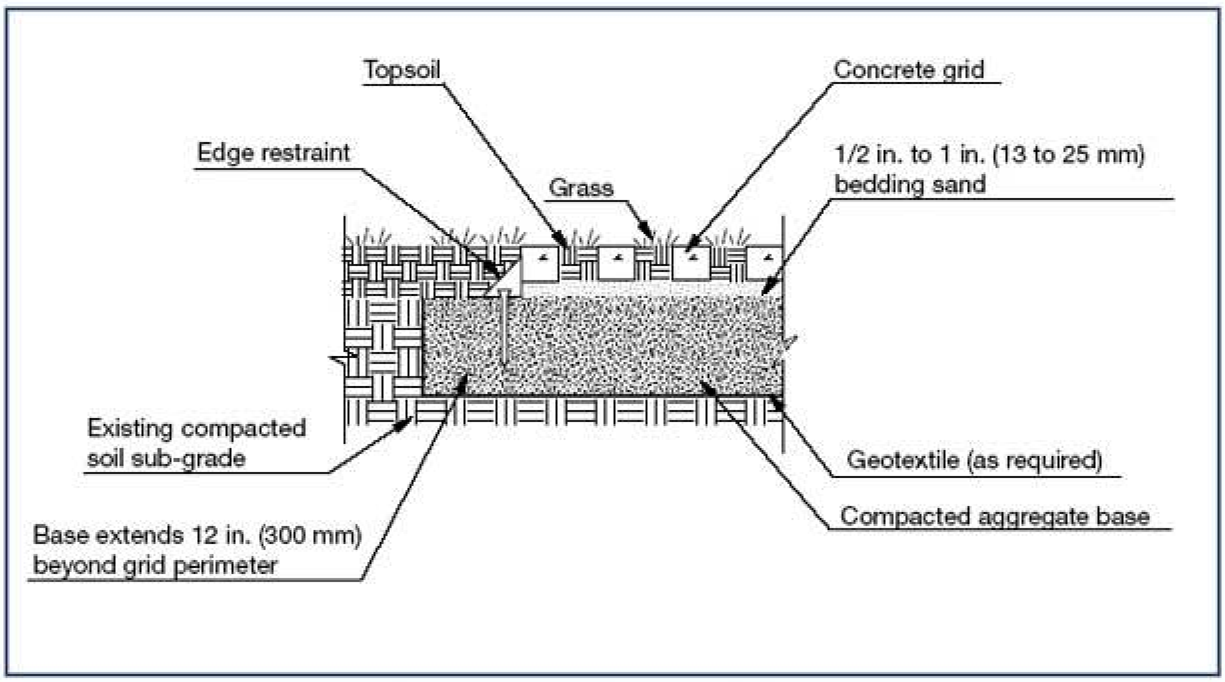

Figure 17. Typical concrete grid pavement over dense-graded base

Design for Runoff and Pollutant Reduction

Concrete grid pavements with an open-graded stone in their openings and bedding can store storm water and allow for partial treatment of pollutants (Figure 18). Grids designed as an infiltration area can improve water quality by reducing sediment and pollutants that enter lakes and streams (10). Because of their hydrologic and pollution abatement benefits, concrete grid pavements are considered by state and federal agencies to be a best management practice (BMP) for reducing stormwater runoff and non-point source pollution. They are one of many techniques that can be used in a system of watershed-wide measures to control excess runoff and nonpoint pollution of storm water. Other techniques can include infiltration trenches, surface or underground retention/detention ponds, roof top/parking lot ponding, street sweeping, filtering systems, permeable interlocking concrete pavement, etc. Many municipalities regulate the quantity and/or rate of stormwater released into sewers and streams. Others regulate both the water quantity and quality of the runoff by controlling the amount of impervious cover. To control water quantity, municipal regulations strive to meet one or more design objectives. Several municipal stormwater objectives are presented below, with ways that concrete grid pavements contribute to meeting them (11). These objectives benefit water quality since the amount of runoff and pollutants in it are decreased.

Figure 18. Concrete grids with aggregate in the openings

· Capture and infiltrate the entire stormwater volume so there is no discharge from the drainage area. This requires a large area of concrete grid pavement. The high cost of capturing all runoff can be offset by reducing or eliminating pipes, inlets, and other drainage appurtenances.
· Infiltrate the increased runoff generated by development and impervious surfaces. This results in runoff volumes equal to or near those prior to development. The runoff volume before and after development are estimated and the difference in volume is stored or infiltrated. Places for storage include gutters, swales, pipes, rooftops, and infiltration areas covered with concrete grid pavements.
· Infiltrate a fixed volume of runoff from every storm. This helps control the "first flush" of concentrated pollutants in the initial inch (25 mm) or so of runoff. The first inch (25 mm) of infiltrated water often represents a large percentage of storms. Concrete grid pavements with No. 8 stone bedding and fill in the openings can be designed to infiltrate the first inch (25 mm) or more of runoff.
· Infiltrate sufficient water to control the peak rate of discharge. Many municipalities establish a maximum rate of peak discharge (in cubic feet/second or liters/second) into specific storm sewers or water courses. The maximum rate can be based on the carrying capacity of the drainage ways, or by rates prior to development. This approach favors detention ponds rather than infiltration as a means to control downstream flooding and can help reduce detention storage requirements and costs.

Peak runoff calculations for storm sewers and water courses are typically determined using the Rational Method. For drainage calculations an average runoff coefficient of 0.25 to 0.4 can be used for grids with established grass on a dense-graded aggregate base (12) (13). These coefficients are substantially lower than the 0.9 to 1.00 for conventional pavements. The runoff coefficient of 0.25 to 0.3 is similar to that for natural grassed areas. Runoff coefficients will be 0.2 to 0.25 when No. 8 stone is used to fill the openings and used as bedding over a dense-graded aggregate base. This open-graded aggregate material provides additional runoff storage. Concrete grids can be placed on a No. 8 bedding layer and open-graded, crushed stone aggregate base such as No. 57 stone. No. 8 stone is placed in the openings. A No. 2 stone subbase under the No. 57 stone can add additional structural support and water storage capacity in it voids. For a detailed design discussion using open-graded aggregate bases for stormwater management, see the ICPI manual, Permeable Interlocking Concrete Pavements. Day et al. (14) reported substantial reductions in nonpoint source runoff pollutants in simulated laboratory experiments with concrete grids with grass over bedding sand, No. 57 open-graded aggregate base, and clay soils. Field studies by Goforth et al. (10) also demonstrated the reduction of pollutants from concrete grid pavement. Likewise, data reported by Claytor and Scheuler (15) illustrate the benefits of infiltration trenches, as well as filtering systems. Some systems are similar to concrete grid pavements. The type of soil subgrade affects the pollution reduction capabilities of infiltration areas. Clay soils with a high cation exchange capacity will capture more pollutants than sandy soils. Debo and Reese (13) recommend that for control of runoff quality, the storm water should infiltrate through at least 18 in. (0.45 m) of soil (typically clay) which has a minimum cation exchange capacity of 5 milliequivalents per 100 grams of dry soil. Some heavy clay soils that are effective pollutant filters do not have a sufficiently high infiltration rate or bearing capacity when saturated, and may not be suitable under infiltration areas subject to vehicular loads. Concrete grid pavement is not recommended in places where grease or oil loads are high. Filter areas such as a settling basins should used to remove grease and oil, as well as sediment before they enter concrete grid pavements.

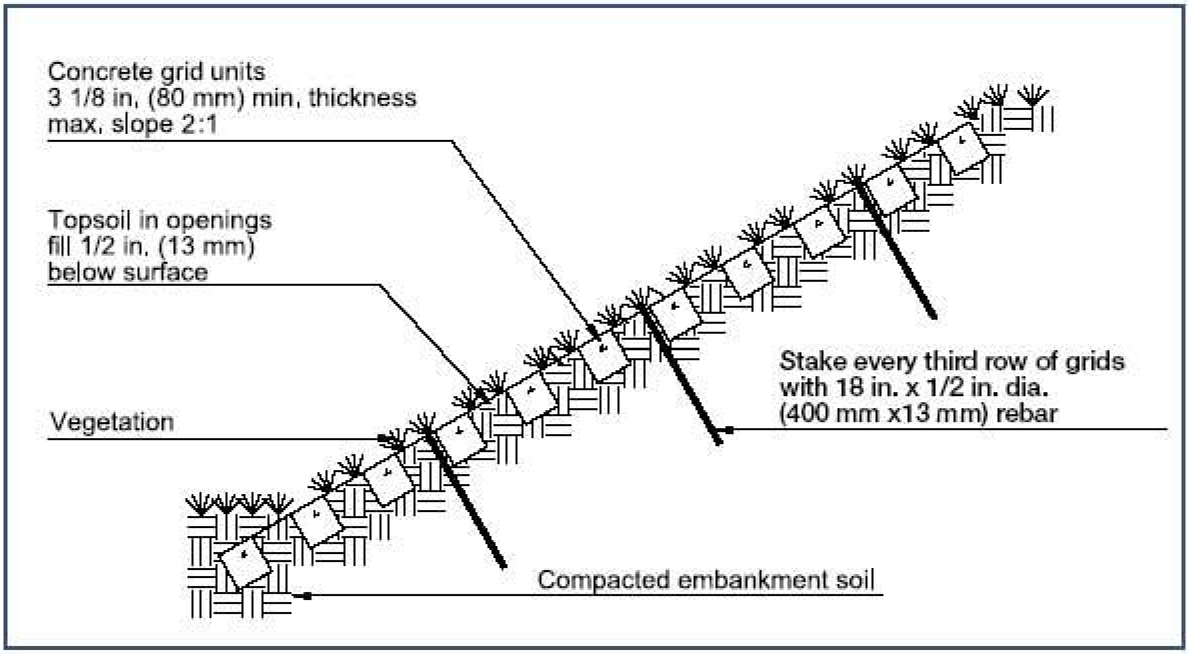

Figure 19. Embankment stabilization with concrete grids

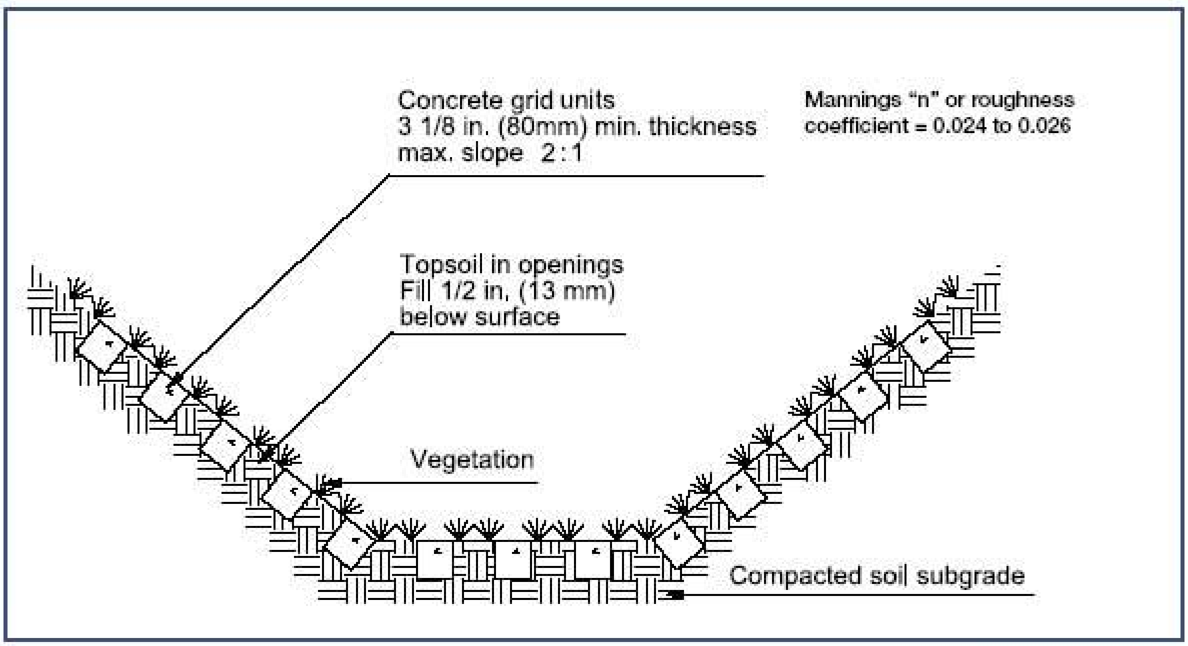

Figure 20. Ditch lined with concrete grid pavers for intermittent flow (17)

Urban Heat Island Control Through Urban Microclimates

Besides abating runoff pollution, concrete grids generate lower temperatures than asphalt. Solid pavements and buildings hold heat, thereby contributing to the urban heat island and capturing urban air pollution. Research has shown that grid pavements have 2° to 4° F (1° to 2° C) lower local air temperatures than asphalt and 4° to 6° F (2° to 4° C) lower radiometric than asphalt (12). Lower temperatures create more comfortable microclimates for pedestrians in urban surroundings. Concrete grid pavements can be an integral part of cooling the urban climate and reducing air pollution. They can be incorporated with tree-lined streets, a managed urban forest, fountains, roof top gardens, vegetation on building walls, plus park spaces to cool areas and filter urban air pollutants. The result is more comfortable, cleaner and livable cities.

Design Guidelines for Erosion Control

Grid pavements provide immediate stabilization of embankments until grass or other vegetation is established. The recommended maximum angle for stabilization is 27° (2:1). Grids can be placed directly on graded and compacted soil, working from the bottom to the top of the embankment. The grids should be staked every third row to secure them while vegetation establishes. Stakes should be steel (Figure 19). Grids are also effective liners for ditches with intermittent flows of water (Figure 20). The grids protect ditches from erosion while the openings accommodate vegetation to increase stability. Preparing the lake sides for concrete grids includes grading and compacting the area above the water prior to placing the units. Aggregate is often placed under grids on banks to further prevent erosion. This layer should be at least 4 in. (100 mm) thick. Geotextile should be placed prior to installing the grids and anchored with large aggregate at the "toe" (bottom) and sides of the installation (Figure 21). Aggregate should be placed in the openings of the submerged grids. Topsoil and riparian vegetation can be planted along the banks in areas subject to high water levels. Grass can be used in areas not subject to frequent inundation. The maximum recommended slope is 18° (3:1) for grids stabilizing slopes. Boat ramps in recreation facilities can be made from concrete grids. They can be installed without partitioning the area and removing the water prior to construction. The design guidelines above for lake sides apply except that a minimum of 8 in. (200 mm) of open-graded aggregate should be compacted to provide a base for the grid pavers (Figure 22). This provides a base for the vehicles and boat trailers. The maximum recommended slope is 12% (5:1) for grid boat ramps.

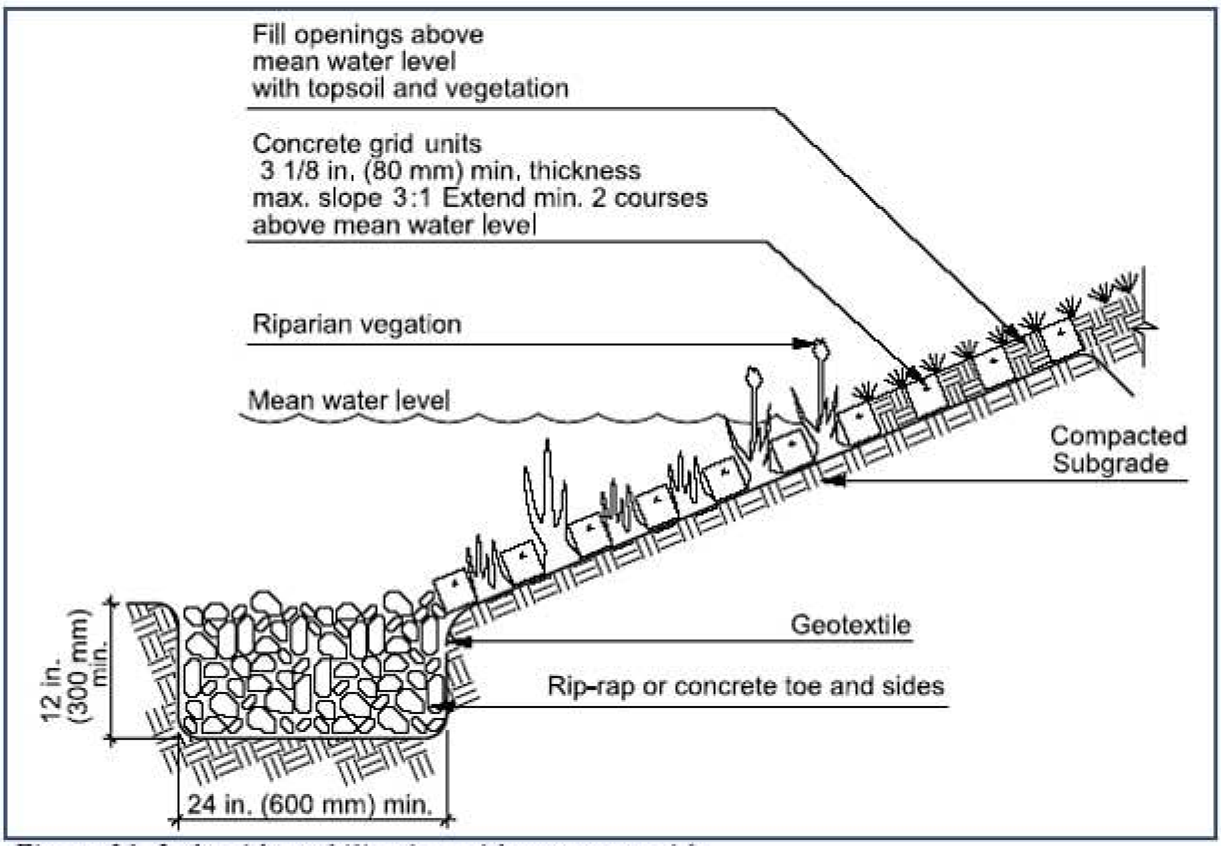

Figure 21. Lake side stabilization with concrete grids

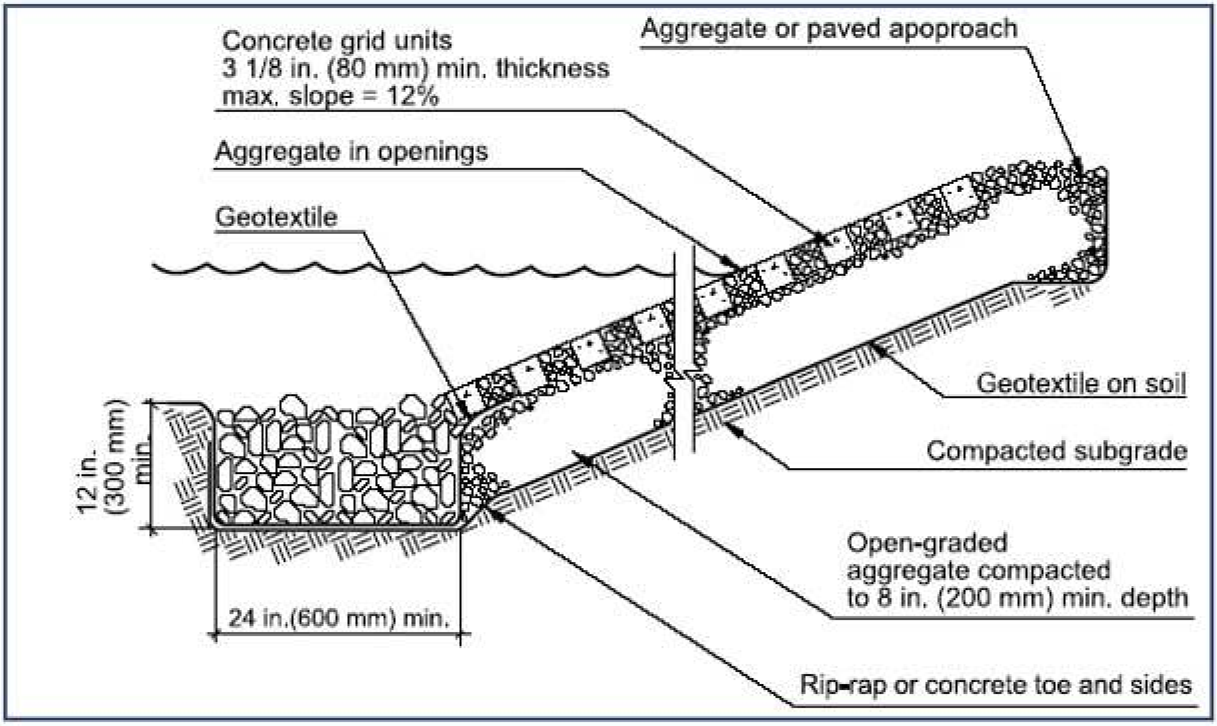

Figure 22. Typical cross-section for boat ramp

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SECTION 32 14 13.19 CONCRETE GRID PAVEMENTS

(1995 MasterFormat Section 02795)
Note: This guide specification is for concrete grid units placed on a sand bedding course over a compacted dense-graded aggregate base. The text allows an option of topsoil and grass in the grid openings over bedding sand or No. 8 open-graded aggregate in the grid openings and for the bedding course. This specification is for limited vehicular applications such as access roads and emergency fire lanes, as well as intermittently used overflow parking areas. This text must be edited to suit specific project requirements for projects. This Section includes the term "Architect." Edit this term as necessary to identify the design professional

in the General Conditions of the Contract. Use U.S. or Canadian references as appropriate. If the area is exposed to recurring vehicular traffic and additional stormwater storage in the base is desired, the specifier should consider using permeable interlocking concrete pavements, as they provide additional structural support to vehicles while providing runoff storage in an open-graded, crushed stone base. In such cases, the specifier should refer to the ICPI manual, Permeable Interlocking Concrete Pavements.

PART 1 GENERAL

1.01 SUMMARY

A. Section includes:
1. Concrete grid units.
2. Bedding sand.
3. Edge restraints.
4. Geotextiles.
5. [Topsoil and grass for the grid openings.]
6. [Open-graded aggregate for the grid openings.]
7. [Open-graded aggregate bedding course].

B. Related Sections:
1. Section [______]: Curbs and drains.
2. Section [______]: Dense-graded aggregate base.
3. Section [______]: Open-graded aggregate base.

1.02 REFERENCES

A. American Society of Testing Materials (ASTM)
1. C 33, Specification for Concrete Aggregates.
2. C 136, Method for Sieve Analysis for Fine and Coarse Aggregate.
3. C 140, Standard Test Methods of Sampling and Testing Concrete Masonry Units.
4. C 979, Standard Specification for Pigments for Integrally Colored Concrete.
5. C 1319, Standard Specification for Concrete Grid Paving Units.
6. ASTM D 698, Standard Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,000 ft-lbf/ft 3 (600 kN-m/m 3)).
7. D 2940, Standard Specification for Graded Aggregate Material for Bases or Subbases for Highways or Airports.
8. D 5268, Specification for Topsoil Used for Landscaping Purposes.

B. Canadian Standards Association (CSA)
1. CSA A23.1, Concrete Materials and Methods of Concrete Construction

C. Interlocking Concrete Pavement Institute (ICPI)
1. Tech Spec technical bulletins.

1.03 SUBMITTALS

A. In accordance with Conditions of the Contract and Division 1 Submittal Procedures Section.
B. Manufacturer's drawings and details: Indicate perimeter conditions, relationship to adjoining materials and assemblies, expansion and control joints, paving slab [layout,] [patterns,] [color arrangement,] installation [and setting] details.
C. Sieve analysis per ASTM C 136 for grading of bedding and base materials.

Note: Include D below if the grid openings will be filled with topsoil and grass seed, or sod plugs.

D. Source and content of topsoil and grass seed [sod].
E. Concrete grid units:
1. Color selected by Architect.
2. [Four] representative full-size samples of each grid type, thickness, color, finish that indicate the extremes of color variation and texture expected in the finished installation.
3. Accepted samples become the standard of acceptance for the work.
4. Test results from an independent testing laboratory for compliance of grid paving unit requirements to ASTM C 1319.
5. Manufacturer's certification of concrete grid units by ICPI as having met applicable ASTM standards.
6. Manufacturer's catalog literature, installation instructions, and material safety data sheets for the safe handling of the specified materials and products.

1.04 QUALITY ASSURANCE

A. Paving Subcontractor Qualifications:
1. Engage an experienced installer who has successfully completed grid pavement installations similar in design, material, and

extent indicated for this Project.
2. Hold a current certificate from the Interlocking Concrete Pavement Institute Concrete Paver Installer Certification program.
B. Single-source Responsibility: Obtain each color, type, and variety of grids, joint materials and setting materials from single sources with resources to provide products and materials of consistent quality, appearance and physical properties without delaying progress of the Work.
C. Regulatory requirements and approvals: [Specify applicable licensing, bonding or other requirements of regulatory agencies.]
D. Mock-up
1. Locate where directed by the Architect.
2. Notify Architect in advance of dates when mock-ups will be erected.
3. Install minimum [100] sf ([10] m 2) of concrete grid units.
4. Use this area to determine the quality of workmanship in to be produced in the final unit of Work including surcharge of the bedding sand layer, joint sizes, lines, pavement laying pattern(s), color(s), and texture.
5. This area shall be used as the standard by which the work is judged.
6. Subject to acceptance by the owner, mock up may be retained as part of the finished work.
7. If mock up is not retained, remove and properly dispose of.

1.05 DELIVERY, STORAGE, AND HANDLING

A. General: Comply with Division 1 Product Requirement Section
B. Deliver concrete grid units to the site in steel banded, plastic banded, or plastic wrapped packaging capable of transfer by forklift or clamp lift. Unload grids at job site in such a manner that no damage occurs to the product or existing construction.
C. Cover sand with waterproof covering to prevent exposure to rainfall or removal by wind. Secure the covering in place.
D. Coordinate delivery and paving schedule to minimize interference with normal use of buildings adjacent to paving.

1.06 ENVIRONMENTAL CONDITIONS

A. Do not install bedding materials or grid units during heavy rain or snowfall.
B. Do not install bedding materials and grid units over frozen base materials.
C. Do not install frozen bedding materials.

1.07 GRID PAVER MAINTENANCE MATERIALS:

A. Supply [ ] sf [(m 2)] of [each type and color of grid unit] in unopened pallets with contents labeled. Store where directed.
B. From the same production run as installed materials.

PART 2 PRODUCTS

2.01 CONCRETE GRID UNITS

A. Manufacturer: [Specify ICPI member manufacturer name.].
1. Contact: [Specify ICPI member manufacturer contact information.].
B. Concrete grid paver units, including the following:
1. Grid unit type: [Specify name of product group, castellated, lattice, etc.]
a. [Material standard: Comply with material standards set forth in [ASTM C 1319.].
b. Color [and finish]: [Specify color.] [Specify finish].
c. Color Pigment Material Standard: Comply with ASTM C 979.
d. Size: [Specify.] inches [([Specify.] mm)] x [Specify.] inches [([Specify.] mm)] x [Specify.] inches [([Specify.] mm)] thick.
C. Manufactured in a plant where paving products are certified by ICPI as having passed ASTM requirements in this specification.

2.03 PRODUCT SUBSTITUTIONS

A. Substitutions: No substitutions permitted.

2.03 BEDDING MATERIALS

Note: If openings are filled with topsoil, use sand bedding. If the openings are filled with open-graded aggregate for additional runoff storage, the same aggregate should be used for the bedding. Edit 2.03 and 2.04 accordingly.

A. General Sieved per ASTM C 136.
B. Bedding Sand

Note: The type of sand used for bedding is often called concrete sand. Sands vary regionally. Contact contractors local to the project and confirm sand(s) successfully used in previous similar applications. Bedding sand is not used in ditch liner applications, slope protection, riparian stabilization or with boat ramps constructed with concrete grid units.

1. Washed, clean, hard, durable crushed gravel or stone, free from shale, clay, friable materials, organic matter, frozen lumps, and

other deleterious substances.
2. Conforming to the grading requirements in Table 1 below.
3. Do not use limestone screenings.

Table 1

Grading Requirements for Bedding Sand

ASTM C33 or **CSA A23.1-FA1**

Sieve Size	Percent Passing	Sieve Size	Percent Passing
3/8 in. (9.5 mm)	100	10 mm	100
No. 4 (4.75 mm)	95 to 100	5 mm	95 to 100
No. 8 (2.36 mm)	85 to 100	2.5 mm	80 to 100
No. 16 (1.18 mm)	50 to 85	1.25 mm	50 to 90
No. 30 (0.600 mm)	25 to 60	0.63 mm	25 to 65
No. 50 (0.150 mm)	0 to 30	0.315 mm	10 to 35
No. 100 (0.150 mm)	2 to 10	0.160 mm	2 to 10

-OR

B. Washed, open-graded stone.

Note: Finer gradations such as ASTM No. 89 stone may be used.

1. Conforming to the grading requirements in Table 2 below.

Table 2

ASTM No. 8

Gradation for Fill or Bedding Course

Sieve Size	Percent Passing
1/2 in. (12.5 mm)	100
3/8 in. (9.5 mm)	85 to 100
No. 4 (4.75 mm)	10 to 30
No. 8 (2.36 mm)	0 to 10
No. 16 (1.18 mm)	0 to 5

2.04 FILL MATERIALS FOR GRID OPENINGS

A. Topsoil: Conform to ASTM D 5268. Note: Consult with local turf grass specialists for recommendations on grass seed mixture or sod materials.
B. Grass seed [Sod]: [mixture and source].

-OR

A. Open-graded aggregate.
B. Conforming the gradation requirements in Table 2. Do not use gravel.

Note: Local, state or provincial standards for aggregate base materials for roads should be used for the gradation and quality of densegraded aggregate base materials under concrete grid pavements. If no standards exist, follow ASTM D 2940, Standard Specification for Graded Aggregate Material for Bases or Subbases for Highways or Airports. The gradation for base material from this standard is given in Table 3 below. This material should be compacted to a minimum of 95% standard Proctor density.

Table 3

ASTM D 2940

Gradation for Dense-Graded, Crushed Stone Base

Sieve Size	Percent Passing
2 in. (50 mm)	100
1 1/2 in. (37.5 mm)	95 to 100
3/4 in. (19.0 mm)	70 to 92
3/8 in. (9.5 mm)	50 to 70
No. 4 (4.75 mm)	35 to 55
No. 30 (0.600 mm)	12 to 25
No. 200 (0.075 mm)	0 to 8

2.04 EDGE RESTRAINTS

A. Provide edge restraints installed around the perimeter of all concrete grid paving unit areas as follows:
1. Manufacturer: [Specify manufacturer].
2. Material: [Plastic] [Concrete] [Aluminum] [Steel] [Precast concrete] [Cut stone].
3. Material standard: [Specify material standard].

2.05 ACCESSORIES

A. Provide accessory materials as follows:
1. Geotextile fabric:
a. Material Type and Description: [Specify material type and description].
b. Material Standard: [Specify material standard.].
c. Manufacturer: [Acceptable to concrete grid unit manufacturer] [Specify manufacturer.].

PART 3 EXECUTION

3.01 ACCEPTABLE INSTALLERS

A. [Specify acceptable paving subcontractors.].

3.02 EXAMINATION

Note: Compaction of the soil subgrade is recommended to a minimum of 95% standard Proctor density per ASTM D 698 for pedestrian and lightly trafficked vehicular areas. Stabilization of the subgrade and/or base material may be necessary with weak or saturated subgrade soils.

Note: Local aggregate base materials typical to those used for highway flexible pavements are recommended, or those conforming to ASTM D 2940. Compaction of aggregate is recommended to not less than 95% Proctor density in accordance with ASTM D 698 is recommended for pedestrian and vehicular areas. Mechanical tampers are recommended for compaction of soil subgrade and aggregate base in areas not accessible to large compaction equipment. Such areas can include that around lamp standards, utility structures, building edges, curbs, tree wells and other protrusions. The recommended base surface tolerance should be ±3/8 in. (±10 mm) over a 10 ft. (3 m) straight edge.

Note: The elevations and surface tolerance of the aggregate base determine the final surface elevations of concrete grids. The installation contractor cannot correct deficiencies in the base surface with additional bedding materials. Therefore, the surface elevations of the base should be checked and accepted by the General Contractor or designated party, with written certification to the paving subcontractor prior to placing bedding materials and concrete gridsw.

A. Acceptance of site verification conditions:
1. Contractor shall inspect, accept and verify in writing to the grid installation subcontractor that site conditions meet specifications for the following items prior to installation of bedding materials and concrete grid units:
a. Verify that drainage and subgrade preparation, compacted density and elevations conform to specified requirements.
b. Verify that geotextiles, if applicable, have been placed according to drawing and specifications.
c. Verify that base materials, thickness, [compacted density,] surface tolerances and elevations conform to specified requirements.
d. Provide written density test results for the soil subgrade, base materials to the Owner, Contractor, and grid installation subcontractor.

2. Do not proceed with installation of bedding materials and concrete grids until [subgrade soil and] base conditions are corrected by the Contractor or designated subcontractor.

3.03 PREPARATION

A. Verify that base is dry, certified by Contractor as meeting material, installation and grade specifications [and geotextile] are ready to support sand, [edge restraints,] grids and imposed loads.
B. Edge Restraint Preparation:
1. Install edge restraints per the drawings [and manufacturer's recommendations] [at the indicated elevations.].
2. Mount directly to finished base. Do not install on bedding sand.
3. The minimum distance from the outside edge of the base to the spikes shall be equal to the thickness of the base.

3.04 INSTALLATION

A. Spread the sand [No. 8 stone] evenly over the compacted, dense-graded base course and screed uniformly to ½ to 1 in. (13 to 25 mm). Place sufficient sand [stone] to stay ahead of the laid grids.
B. Ensure the grid units are free from foreign materials before installation.
C. Lay the grid units on the bedding sand in the pattern(s) shown on the drawings. Maintain straight joint lines.
D. Joints between the grids shall not exceed [3 / 16 in. (5 mm)].
E. Fill gaps at the edges of the paved area with cut grid pavers or edge units.
F. Cut grid pavers to be placed along the edge with a double-bladed splitter or masonry saw.
G. Sweep [top soil][No. 8 aggregate] into the joints and openings until full.
H. Sweep the grid surface clear prior to compacting.
I. Compact and seat the grids into the screeded [bedding sand] [No. 8 aggregate] using a low-amplitude, 75-90 Hz plate compactor capable of at least 4,000 lbs. (18 kN) centrifugal compaction force. Use rollers or a rubber or neoprene pad between the compactor and grids to prevent cracking or chipping. Do not compact within 6 ft (2 m) of the unrestrained edges of the grid units.
J. All work to within 6 ft (2 m) of the laying face must be left fully compacted at the completion of each day.
K. [Broadcast grass seed at the rate recommended by seed source.][Place sod plugs into openings.] [Add topsoil to the surface to cover the seeds.]
L. Remove excess [topsoil][No. 8 aggregate] on surface when the job is complete.
M. [Distribute straw covering to protect germinating grass seed [sod]. Water entire area. Do not traffic pavement for [30] days.] if seeded.

3.05 FIELD QUALITY CONTROL

A. After removal of excess top soil/aggregate, check final elevations for conformance to the drawings. Allow 1 / 8 to 1 / 4 in. (3 to 6 mm) above specified surface elevations to compensate for minor settlement.
B. The final surface tolerance from grade elevations shall not deviate more than ± 3 / 8 in. (10 mm) over a 10 ft (3 m) straightedge.
C. The surface elevation of grid units shall be 1 / 8 to 1 / 4 in. (3 to 6 mm) above adjacent drainage inlets, concrete collars or channels.
D. Lippage: No greater than 1 / 8 in. (3 mm) difference in height between adjacent grid units.

3.06 PROTECTION

A. After work in the section is complete, the Contractor shall be responsible for protecting work from damage due to subsequent construction activity on the site.

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ICPI TECH SPEC NUMBER · 9

GUIDE SPECIFICATION FOR THE CONSTRUCTION OF INTERLOCKING CONCRETE PAVEMENT

SECTION 32 14 13.13 (02780) INTERLOCKING CONCRETE PAVERS

Note: This guide specification for manually installed concrete paver applications in the U.S. and Canada. Contact ICPI for current information and guide specifications for mechanical installation. This document should be edited to fit project conditions and location. Brackets [ ] indicate text for editing. Notes are provided on the use of a compacted aggregate base under the bedding sand and pavers. Other bases can be used such as cement or asphalt-treated aggregate, concrete or asphalt, as well as other setting materials. The user should refer to Interlocking Concrete Pavement Institute (ICPI) Details & Specifications for Interlocking Concrete Pavement at www.icpi.org for various guide specifications and detail drawings. This Section includes the term "Architect." Edit this term as necessary to identify the design professional in the General Conditions of the Contract. Coordinate all Sections with the General Conditions as well.

PART 1 GENERAL

1.01 SUMMARY

A. Section Includes:
1. Interlocking Concrete Paver Units (manually installed).
2. Bedding and Joint Sand.
3. Edge Restraints.

B. Related Sections:
1. Section: [ ]-Curbs and Drains.
2. Section: [ ]-Aggregate Base.
3. Section: [ ]-Cement Treated Base.
4. Section: [ ]-Asphalt Treated Base.
5. Section: [ ]-Pavements, Asphalt and Concrete.
6. Section: [ ]-Roofing Materials.
7. Section: [ ]-Geotextiles.

Note: Pavements subject to vehicles should be designed in consultation with a qualified civil engineer, in accordance with established flexible pavement design procedures, ICPI Lockpave software, and in accordance with the ICPI Tech Spec technical bulletins. Use the current year reference. Edit ASTM and CSA references below and throughout this Section according to project location.

1.02 REFERENCES

A. American Society for Testing and Materials (ASTM):
1. ASTM C 33, Standard Specification for Concrete Aggregates.
2. ASTM C 136, Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates.
3. ASTM C 140, Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units.
4. ASTM C 144, Standard Specification for Aggregate for Masonry Mortar.
5. ASTM C 936, Standard Specification for Solid Concrete Interlocking Paving Units.
6. ASTM C 979, Pigments for Integrally Colored Concrete.
7. ASTM D 698, Standard Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,000 ftlbf/ft 3 (600 kN-m/m 3)).
8. ASTM D 1557, Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft 3 (2,700 kN-m/m 3)).
9. ASTM D 2940, Specification for Graded Aggregate Material for Bases or Subbases for Highways or Airports.

B. Canadian Standards Association (CSA):
1. A231.2, Precast Concrete Pavers.

2. A23.2A, Sieve Analysis of Fine and Coarse Aggregates.
3. A23.1-FA1, Concrete Materials and Methods of Concrete Construction.
4. A179, Mortar and Grout for Unit Masonry.

C. Interlocking Concrete Pavement Institute (ICPI):
1. ICPI Tech Spec technical bulletins.

1.03 SUBMITTALS

A. In accordance with Conditions of the Contract and Division 1 Submittal Procedures Section.

B. Manufacturer's drawings and details: Indicate perimeter conditions, relationship to adjoining materials and assemblies, [expansion and control joints,] concrete paver [layout,] [patterns,] [color arrangement,] installation [and setting] details.

C. Sieve analysis per [ASTM C 136][CSA A23.2A] for grading of bedding and joint sand.

D. Concrete pavers:
1. [Four] representative full-size samples of each paver type, thickness, color, finish that indicate the range of color variation and texture expected in the finished installation. Color(s) selected by [Architect] [Engineer] [Landscape Architect] [Owner] from manufacturer's available colors.
2. Accepted samples become the standard of acceptance for the work.
3. Test results from an independent testing laboratory for compliance of paving unit requirements to [ASTM C 936][CSA A231.2].
4. Manufacturer's certification of concrete pavers by ICPI as having met applicable [ASTM][CSA] standards.
5. Manufacturer's catalog product data, installation instructions, and material safety data sheets for the safe handling of the specified materials and products.

E. Paver Installation Subcontractor:
1. A copy of Subcontractor's current certificate from the Interlocking Concrete Pavement Institute Level I Concrete Paver Installer Certification program.

Note: ICPI certifies that installers have passed an exam on installation knowledge and does not certify or guarantee the quality of installation. Job references should be carefully reviewed and verified to assist in identifying competent contractors.

2. Job references from projects of a similar size and complexity. Provide Owner/Client/General Contractor names and phone numbers.

1.04 QUALITY ASSURANCE

A. Paving Subcontractor Qualifications:
1. Utilize an installer having successfully completed concrete paver installation similar in design, material, and extent indicated on this project.
2. Utilize an installer holding a current certificate from the Interlocking Concrete Pavement Institute Concrete Paver Installer Certification program.

B. Regulatory Requirements and Approvals: [Specify applicable licensing, bonding or other requirements of regulatory agencies.].

C. Mock-Ups:

Note: A site visit and approval by the owner's representative during the first day of paving may substitute for a mock-up.

1. Install a 7 ft x 7 ft (2 x 2 m) paver area.
2. Use this area to determine surcharge of the bedding sand layer, joint sizes, lines, laying pattern(s), color(s) and texture of the job.
3. Evaluate the need for protective pads when compacting paving units with architectural finishes.
4. This area will be used as the standard by which the work will be judged.
5. Subject to acceptance by owner, mock-up may be retained as part of finished work.
6. If mock-up is not retained, remove and properly dispose of mock-up.

1.05 DELIVERY, STORAGE & HANDLING

A. General: Comply with Division 1 Product Requirement Section.

B. Refer to manufacturer's ordering instructions and leadtime requirements to avoid construction delays.

C. Delivery: Deliver materials in manufacturer's original, unopened, undamaged containers packaging with identification labels

intact.
1. Coordinate delivery and paving schedule to minimize interference with normal use of buildings adjacent to paving.
2. Deliver concrete pavers to the site in steel banded, plastic banded or plastic wrapped packaging capable of transfer by fork lift or clamp lift.
3. Unload pavers at job site in such a manner that no damage occurs to the product.

D. Storage and Protection: Store materials protected such that they are kept free from mud, dirt, and other foreign materials. [Store concrete paver cleaners and sealers per manufacturer's instructions.]

1.06 PROJECT/SITE CONDITIONS

A. Environmental Requirements:
1. Do not install sand or pavers during heavy rain or snowfall.
2. Do not install sand and pavers over frozen base materials.
3. Do not install frozen sand or saturated sand.
4. Do not install concrete pavers on frozen or saturated sand.

1.07 MAINTENANCE

A. Extra Materials: Provide [Specify area] [Specify percentage.] additional material for use by owner for maintenance and repair.

PART 2 PRODUCTS

2.01 INTERLOCKING CONCRETE PAVERS

Note: In addition to ASTM or CSA conformance, ICPI recommends a maximum 3:1 aspect ratio (length ÷ thickness) and a minimum 3 1 / 8 in. (80 mm) thickness for vehicular applications. Residential driveways and pedestrian applications should use a minimum 2 3 / 8 in. (60 mm) thick units with a maximum 4:1 aspect ratio.

A. Manufacturer: [Specify ICPI member manufacturer name.].
1. Contact: [Specify ICPI member manufacturer contact information.].

B. Interlocking Concrete Paver Units, including the following:
1. Paver Type: [Specify name of product group, family, series, etc.].
a. Material Standard: Comply with material standards set forth in [ASTM C 936][CSA A231.2].
b. Color [and finish]: [Specify color.] [Specify finish].
c. Color Pigment Material Standard: Comply with ASTM C 979.

Note: Concrete pavers may have spacer bars on each unit. Spacer bars are recommended for mechanically installed pavers and for those in heavy vehicular traffic. Manually installed pavers may be installed with or without spacer bars. Verify with manufacturers that overall dimensions do not include spacer bars.

d. Size: [Specify.] inches [({Specify.}mm)] x [Specify.] inches [({Specify}mm)] x [Specify.] inches [({Specify.} mm)] thick.

Note: If 3 1 / 8 in. (80 mm) thick pavers are specified, their compressive strength test results per ASTM C 140 should be adjusted by multiplying by 1.18 to equate the results to that from 2 3 / 8 in. (60 mm) thick pavers. Contact ICPI for adjustment factors for pavers exceeding 3 1 / 8 in. (80 mm) thickness.

Note: For ASTM C 936 use the following material characteristics:

e. Average Compressive Strength: 8,000 psi (55 MPa) with no individual unit under 7,200 psi (50 MPa).
f. Average Water Absorption (ASTM C 140): 5% with no unit greater than 7%.
g. Freeze/Thaw Resistance (ASTM C 67): Resistant to 50 freeze-thaw cycles with no greater than 1% loss of material. Freeze-thaw testing requirements shall be waived for applications not exposed to freezing conditions.

Note: For CSA A231.2 use the following material characteristics:

h. Minimum average cube compressive strength of 7,250 psi (50 MPa) for laboratory cured specimens or 5,800 psi (40 MPa) for unconditioned field samples.
i. Resistance to 28 freeze-thaw cycles while immersed in a 3% saline solution with no greater mass lost than 225 g/m 2 of surface area after 28 years, or 500 g/m 2 after 49 cycles.

2.02 PRODUCT SUBSTITUTIONS

A. Interlocking concrete pavers: as specified or approved equal.

2.03 BEDDING AND JOINT SAND

A. Provide bedding and joint sand as follows:
1. Clean, non-plastic, free from deleterious or foreign matter, symmetrically shaped, natural or manufactured from crushed rock.
2. Do not use stone dust.
3. Do not use limestone screenings or sand for the bedding that does not conform to the grading requirements of [ASTM C 33][CSA A23.1-FA1].
4. Do not use mason sand, or sand conforming to [ASTM C 144][CSA A179] for the bedding sand.

Note: If the pavement will be exposed to heavy traffic with trucks, i.e., a major thoroughfare with greater than 1.5 million 18-Kip (80 kN) equivalent single axle loads, see ICPI Tech Spec 17Bedding Sand Selection for Interlocking Concrete Pavements in Vehicular Applications for test methods and criteria for assessing bedding sand durability. Limestone screenings will typically not meet the durability requirements outlined in Tech Spec 17. However, there are some granite materials that meet these requirements. Tech Spec 17 recommends using concrete sand as a first preference.

4. Where concrete pavers are subject to vehicular traffic, utilize sands that are as hard as practically available.
5. Sieve according to [ASTM C 136][CSA A23.2A].
6. Bedding Sand Material Requirements: Conform to the grading requirements of [ASTM C 33][CSA A23.1-FA1] with modifications as shown in Table 1.

Note: Coarser sand than that specified in Table 2 below may be used for joint sand including C 33 or A23.1 material as shown in Table 1. Use material where the largest sieve size easily enters the smallest joints. For example, if the smallest paver joints are 2 mm wide, use sand 2 mm and smaller in particle size. If C 33 or A23.1 sand is used for joint sand, extra effort may be required in sweeping material and compacting the pavers in order to completely fill the joints.

Table 1

Grading Requirements for Bedding Sand			
ASTM C 33		CSA A23.1-FA1	
Sieve Size	Percent Passing	Sieve Size	Percent Passing
3/8 in.(9.5 mm)	100	10 mm	100
No. 4 (4.75 mm)	95 to 100	5 mm	95 to 100
No. 8 (2.36 mm)	80 to 100	2.5 mm	80 to 100
No. 16 (1.18 mm)	50 to 85	1.25 mm	50 to 90
No. 30 (0.600 mm)	25 to 60	0.630 mm	25 to 65
No. 50 (0.300 mm)	10 to 30	0.315 mm	10 to 35
No. 100 (0.150 mm)	2 to 10	0.160 mm	2 to 10
No. 200 (0.075 mm)	1	0.075 mm	1

Table 2

Grading Requirements for Joint Sand				
	ASTM C 144	ASTM C 144	CSA A179	
Sieve Size	Natural Sand Percent Passing	Manufactured Sand Percent Passing	Sieve Size	Percent Passing
No. 4 (4.75 mm)	100	100	5 mm	100
No. 8 (2.36 mm)	95 to 100	95 to 100	2.5 mm	90 to 100
No. 16 (1.18 mm)	70 to 100	70 to 100	1.25 mm	85 to 100
No. 30 (0.600 mm)	40 to 75	40 to 100	0.630 mm	65 to 95
No. 50 (0.300 mm)	10 to 35	20 to 40	0.315 mm	15 to 80
No. 100 (0.150 mm)	2 to 15	10 to 25	0.160 mm	0 to 35
No. 200 (0.075 mm)	0 to 1	0 to 10	0.075 mm	0 to 1

7. Joint Sand Material Requirements: Conform to the grading requirements of [ASTM C 144][CSA-A179] as shown with modifications in Table 2 or meet the requirements for bedding sand in Table 1.

Note: Specify specific components of a system, manufactured unit or type of equipment. See ICPI Tech Spec 3Edge Restraints for Interlocking Concrete Pavements for guidance on selection and design of edge restraints.

2.04 EDGE RESTRAINTS

A. Where not otherwise retained, provide edge restraints installed around the perimeter of all interlocking concrete paving unit areas as follows:
1. Manufacturer: [Specify manufacturer.].
2. Material: [Plastic] [Concrete] [Aluminum] [Steel] [Pre-cast concrete] [Cut stone] [Concrete].
3. Material Standard: [Specify material standard.].

2.05 ACCESSORIES

A. Provide accessory materials as follows:

Note: Delete article below if geotextile is not used.

1. Geotextile Fabric:
a. Material Type and Description: [Specify material type and description.].
b. Material Standard: [Specify material standard.].
c. Manufacturer: [Acceptable to interlocking concrete paver manufacturer] [Specify manufacturer.].

Note: Delete article below if cleaners, sealers, and/or joint sand stabilizers are not specified.

2. [Cleaners] [Sealers] [Joint sand stabilizers]
a. Material Type and Description: [Specify material type and description.].
b. Material Standard: [Specify material standard.].
c. Manufacturer: [Specify manufacturer.].

PART 3 EXECUTION

3.01 ACCEPTABLE INSTALLERS

A. [Specify acceptable paving subcontractors.].

3.02 EXAMINATION

A. Acceptance of Site Verification of Conditions:

1. General Contractor shall inspect, accept and certify in writing to the paver installation subcontractor that site conditions meet specifications for the following items prior to installation of interlocking concrete pavers.

Note: Compaction of the soil subgrade is recommended to at least 98% standard Proctor density per ASTM D 698 for pedestrian areas and residential driveways. Compaction to at least 98% modified Proctor density per ASTM D 1557 is recommended for areas subject to heavy vehicular traffic. Stabilization of the subgrade and/or base material may be necessary with weak or saturated subgrade soils.

a. Verify that subgrade preparation, compacted density and elevations conform to specified requirements.
b. Verify that geotextiles, if applicable, have been placed according to drawings and specifications.

Note: Local aggregate base materials typical to those used for highway flexible pavements are recommended, or those conforming to ASTM D 2940. Compaction of aggregate is recommended to not less than 98% Proctor density in accordance with ASTM D 698 is recommended for pedestrian areas and residential driveways. Minimum 98% modified Proctor density according to ASTM D 1557 is recommended for vehicular areas. Mechanical tampers are recommended for compaction of soil subgrade and aggregate base in areas not accessible to large compaction equipment. Such areas can include that around lamp standards, utility structures, building edges, curbs, tree wells and other protrusions. Note: Prior to screeding the bedding sand, the recommended base surface tolerance should be ± 3 / 8 in. (10 mm) over a 10 ft. (3 m) straight edge. See ICPI Tech Spec 2Construction of Interlocking Concrete Pavements for further guidance on construction practices.

Note: The elevations and surface tolerance of the base determine the final surface elevations of concrete pavers. The paver installation contractor cannot correct deficiencies in the base surface with additional bedding sand or by other means. Therefore, the surface elevations of the base should be checked and accepted by the General Contractor or designated party, with written certification to the paving subcontractor, prior to placing bedding sand and concrete pavers.

c. Verify that [Aggregate] [Cement-treated] [Asphalt-treated] [Concrete] [Asphalt] base materials, thickness, [compacted density], surface tolerances and elevations conform to specified requirements.
d. Provide written density test results for soil subgrade, [aggregate] [cement-treated][asphalt-treated][asphalt] base materials to the Owner, General Contractor and paver installation subcontractor.

e. Verify location, type, and elevations of edge restraints, [concrete collars around] utility structures, and drainage inlets.

2. Do not proceed with installation of bedding sand and interlocking concrete pavers until [subgrade soil and] base conditions are corrected by the General Contractor or designated subcontractor.

3.03 PREPARATION

A. Verify base is dry, certified by General Contractor as meeting material, installation and grade specifications.

B. Verify that base [and geotextile] is ready to support sand, [edge restraints,] and, pavers and imposed loads.

C. Edge Restraint Preparation:
1. Install edge restraints per the drawings [and manufacturer's recommendations] [at the indicated elevations].

Note: Retain the following two subparagraphs if specifying edge restraints that are staked into the base with spikes.

2. Mount directly to finished base. Do not install on bedding sand.
3. The minimum distance from the outside edge of the base to the spikes shall be equal to the thickness of the base.

3.04 INSTALLATION

A. Spread bedding sand evenly over the base course and screed to a nominal 1 in. (25 mm) thickness. Spread bedding sand evenly over the base course and screed rails, using the rails and/or edge restraints to produce a nominal 1 in. (25 mm) thickness, allowing for specified variation in the base surface.
1. Do not disturb screeded sand.
2. Screeded area shall not substantially exceed that which is covered by pavers in one day.
3. Do not use bedding sand to fill depressions in the base surface.

Note: When initially placed on the bedding sand, manually installed pavers often touch each other, or their spacer bars if present. Joint widths and lines (bond lines) are straightened and aligned to specifications with pry bars as paving proceeds.

B. Lay pavers in pattern(s) shown on drawings. Make horizontal adjustments to laid pavers as required.

Note: Contact manufacturer of interlocking concrete paver units for recommended joint widths.

C. Provide joints between pavers between [1 / 16 in. and 3 / 16 in. (2 and 5 mm)] wide. No more than 5% of the joints shall exceed 1 / 4 in. (6 mm) wide to achieve straight bond lines.

D. Joint (bond) lines shall not deviate more than ± 1 / 2 in. (15 mm) over 50 ft. (15 m) from string lines.

E. Fill gaps at the edges of the paved area with cut pavers or edge units.

F. Cut pavers to be placed along the edge with a [double blade paver splitter or] masonry saw.

Note. Specify requirements for edge treatment in paragraph below.

G. [Adjust bond pattern at pavement edges such that cutting of edge pavers is minimized. All cut pavers exposed to vehicular tires shall be no smaller than one-third of a whole paver.] [Cut pavers at edges as indicated on the drawings.]

H. Keep skid steer and forklift equipment off newly laid pavers that have not received initial compaction and joint sand.

I. Use a low-amplitude plate compactor capable of at least minimum of 5,000 lbf (22 kN) at a frequency of 75 to 100 Hhz to vibrate the pavers into the sand. Remove any cracked or damaged pavers and replace with new units.

J. Simultaneously spread, sweep and compact dry joint sand into joints continuously until full. This will require at least 4 to 6 passes with a plate compactor. Do not compact within 6 ft (2 m) of unrestrained edges of paving units.

K. All work within 6 ft. (2 m) of the laying face must shall be left fully compacted with sand-filled joints at the end of each day or compacted upon acceptance of the work. Cover the laying face or any incomplete areas with plastic sheets overnight if not closed with cut and compacted pavers with joint sand to prevent exposed bedding sand from becoming saturated from rainfall.

L. Remove excess sand from surface when installation is complete.

Note: Excess joint sand can remain on surface of pavers to aid in protecting their surface especially when additional construction occurs after their installation. If this is the case, delete the article above and use the article below. Designate person responsible for directing timing of removal of excess joint sand.

M. Allow excess joint sand to remain on surface to protect pavers from damage from other trades. Remove excess sand when directed by [Architect]. N. Surface shall be broom clean after removal of excess joint sand.

3.05 FIELD QUALITY CONTROL

A. The final surface tolerance from grade elevations shall not deviate more than ± 3 / 8 in. (10 mm) over 10 ft (3 m). Use a straightedge, flexible straightedge or transit depending on surface slope and contours.

B. Check final surface elevations for conformance to drawings.

Note: For installations on a compacted aggregate base and soil subgrade, the top surface of the pavers may be 1 / 8 to 1 / 4 in. (3 to 6 mm) above the final elevations after compaction. This helps compensate for possible minor settling normal to pavements.

C. The surface elevation of pavers shall be 1 / 8 in. to 3 / 8 in. (3 to 10 mm) above adjacent drainage inlets, concrete collars or channels.

Note: For pedestrian access routes maximum elevation should not exceed 1 / 4 in. (6 mm).

D. Lippage: No greater than 1 / 8 in. (3 mm) difference in height between adjacent pavers.

Note: Cleaning and sealing may be required for some applications. See ICPI Tech Spec 5Cleaning and Sealing Interlocking Concrete Pavements for guidance on when to clean and seal the paver surface, and when to stabilize joint sand. Delete article below if cleaners, sealers and or joint sand stabilizers are not applied.

3.06 [CLEANING] [SEALING] [JOINT SAND STABILIZATION]

A. [Clean] [Seal] [Apply joint sand stabilization materials to concrete pavers in accordance with the manufacturer's written recommendations.]

3.07 PROTECTION

A. After work in this section is complete, the General Contractor shall be responsible for protecting work from damage due to subsequent construction activity on the site.

END OF SECTION

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ICPI TECH SPEC NUMBER · 10

Application Guide for Interlocking Concrete Pavements

This technical bulletin provides an overview of interlocking concrete pavements for a range of applicatons. The Interlocking Concrete Pavement Institute (ICPI) publishes other technical bulletins, brochures, design manuals, and software that address many of the applications in greater detail.

Interlocking concrete pavements are typically constructed as flexible pavements on a compacted soil subgrade and compacted aggregate base.

Product Description
Applications: Interlocking concrete pavements are appropriate for any application that requires paving. These areas include patios, driveways, pool decks, sidewalks, parking lots, pedestrian plazas, roof plaza decks, roof ballast, roof parking decks, embankment stabilization, gas stations, medians, streets, industrial pavements, ports, and airports.

Composition and Materials: Interlocking concrete pavers are composed of portland cement, fine and coarse aggregates. Color is often added. Admixtures are typically placed in the concrete mix to reduce efflorescence. These materials are combined with a small amount of water to make a "zero slump" concrete. Pavers are made in factory-controlled conditions with machines that apply pressure and vibration. The result is a consistent, dense, high strength concrete that can be molded into many shapes. Special surface finishes can be produced to give an upscale architectural appearance. These include unique aggregates, colors, tumbling, shot blasting, bush hammering, and polishing.

Technical Data
Physical Characteristics: When manufactured in the U.S., interlocking concrete pavers made by ICPI members typically meet the requirements in ASTM C 936, Standard Specifications for Solid Interlocking Concrete Paving Units. Concrete pavers produced by Canadian ICPI members typically conform to the standard published by the Canadian Standards Association, CSA-A231.2, Precast Concrete Pavers. ICPI offers certification of test results to help ensure that the products meet applicable ASTM or CSA standards.

Applications Standards: For pedestrian applications and residential driveways, 2 3 / 8 in. (60 mm) thick pavers are recommended. Pavements subject to vehicular traffic typically require pavers that are 3 1 / 8 in. (80 mm) thick. Units with an overall length to thickness (aspect) ratio greater than 4 should not be used in vehicular applications. Those with aspect ratios between 3 and 4 may be used in areas with limited vehicular use such as residential driveways. Units with aspect ratios of 3 or less are suitable for all vehicular applications. Interlocking concrete pavements are typically constructed as flexible pavements on a compacted soil subgrade and compacted aggregate base. Concrete pavers are then placed on a thin layer of bedding sand (1 to 1 1 / 2 in. or 25 to 40 mm), compacted, sand swept into the joints, and the units compacted again. When compacted, the pavers interlock, transferring vertical loads from vehicles to surrounding pavers by shear forces through the joint sand. The sand in the joints enables applied loads to be spread in a manner similar to asphalt, reducing the stresses on the base and subgrade.

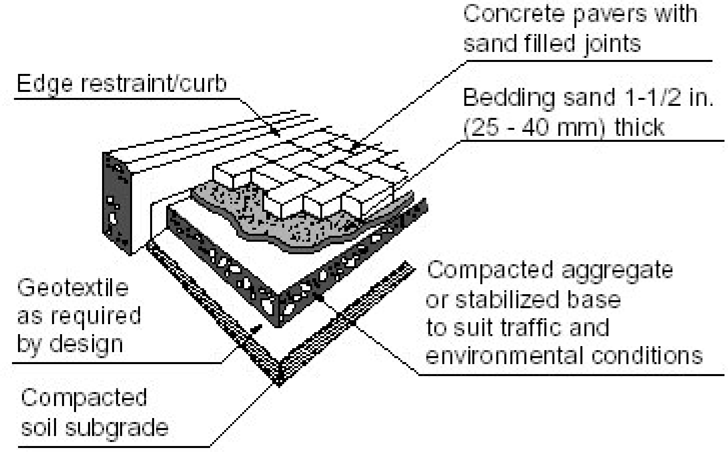

Figure 1. Typical components of an interlocking concrete pavement system.

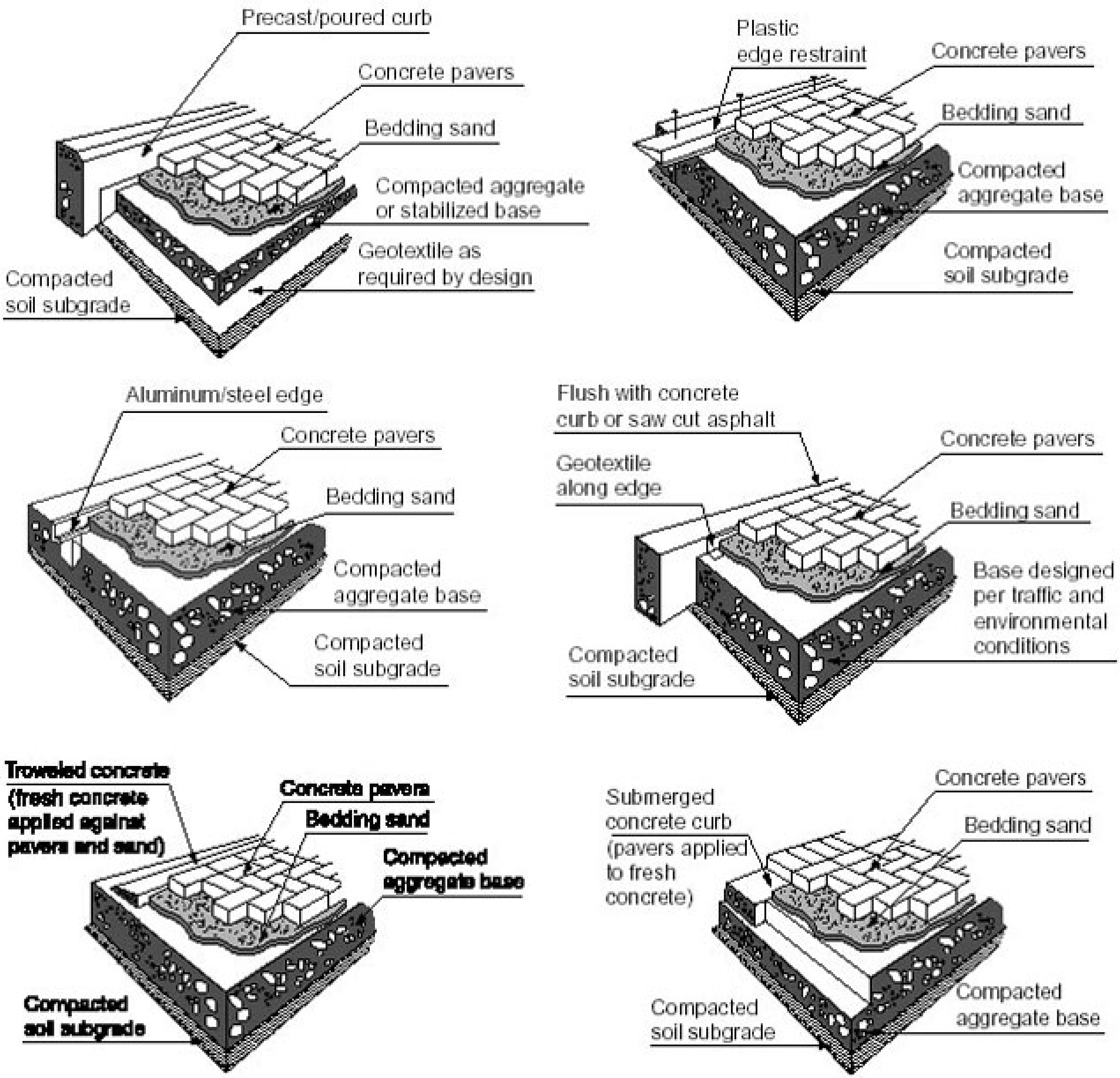

Figure 2. Edge Restraints. Note: Troweled concrete and submerged concrete curbs are recommended in non-freeze thaw areas only.

Benefits: As interlocking concrete pavements receive traffic, they stiffen and increase their structural capacity over time. *The structural contribution of the interlocking pavers and sand layer can exceed that of an equivalent thickness of asphalt.* The interlock contributes to the structural performance of the pavement system. ICPI *Tech Spec 4* provides additional information on structural design of the pavers, sand, and base. Concrete pavers do not require time to cure. They arrive at the site ready to install, ready for traffic immediately after paving. This can reduce construction time and restore access quickly. The joints between each paver eliminate cracking normal to conventional asphalt and concrete pavement. Unlike concrete or asphalt, concrete pavers do not rely on continuity of their material for structural integrity. Therefore, utility cuts can be reinstated without damage to the pavement surface. Repair to underground utilities and to local deformations in the base materials can be accessed by removing and later reinstating the same pavers. No pavement materials are wasted or hauled to the landfill. Jackhammers are not required to open interlocking pavements. The modular units enable changes in the layout of the pavement over its life. Colored units can be used for lane and parking delineations, traffic direction markings, utility markings, and artistic super graphic designs. Various colors, shapes, and laying patterns can support control and direction of pedestrian or vehicular traffic, and can be used as detectable warnings on pedestrian ramps at intersections. The chamfered joints in the pavement surface facilitate removal of surface water. This decreases nighttime glare when wet and enhances skid resistance. Pedestrian slip resistance meets or exceeds guidelines recommended in the Americans with Disabilities Act (ADA). ICPI *Tech Spec 13* includes further information on slip and skid resistance of concrete pavers. Snow is removed as with any other pavement. Concrete pavers have greater resistance to deicing salts than conventional paving materials due to high cement content, strength, density, and low absorption.

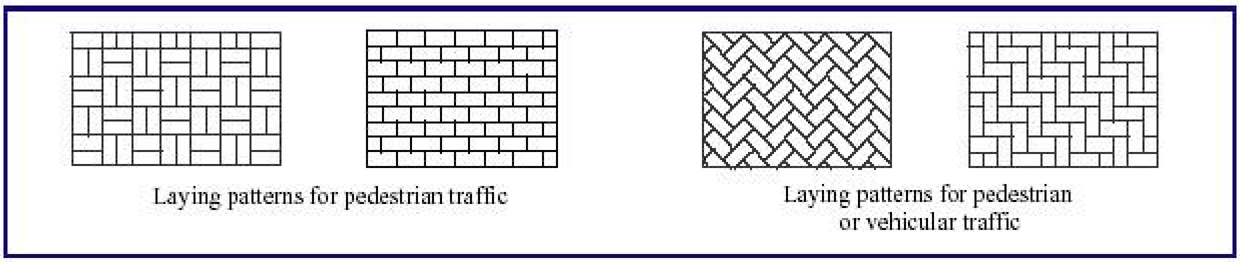

Figure 3. Typical laying patterns.

Installation
It is recommended that installation be performed by experienced contractors who hold a current certificate in the ICPI Concrete Paver Installer Certification Program. Contractors holding this certificate have been instructed and tested on knowledge of interlocking concrete pavement construction. Interlocking concrete pavements typically consist of a soil subgrade, an aggregate base, bedding sand, concrete pavers, edge restraints, and drainage (see Figure 1). Geotextiles are sometimes used under the base, over fine, moist subgrade soils to extend the life of the base and reduce the likelihood of deformation. The installation guidelines below apply to pedestrian and many vehicular applications. For street, industrial, port and airport pavement designs, consult with a qualified civil engineer familiar with local soils, pavement design methods, ICPI resources for these applications, materials, and construction practices. ICPI also has information on design, construction, and maintenance of permeable interlocking concrete pavements for control of runoff and nonpoint storm water pollution.

Soil Subgrade: Once excavation has been complete, the soil subgrade should be compacted prior to placing the aggregate base. Compaction should be at least 98% Proctor density (per ASTM D 698) for pedestrian areas and residential driveways, and at least 98% modified Proctor density (per ASTM D 1557) for areas under constant vehicular traffic. Consult compaction equipment manufacturers' recommendations for applying the proper equipment to compact a given soil type. Some soils may not achieve these recommended minimum levels of density. These soils may have a low bearing capacity or be continually wet. If they are under a base that will receive constant vehicular traffic, the soils may need to be stabilized, or have drainage designed to remove excess water.

Aggregate Base: Aggregate base materials should conform to that used under asphalt. If no local, state, or provincial standards exist, then the requirements for aggregate base in ASTM D 2940 are recommended. The base should be compacted in 6 in. (150 mm) maximum lifts. The thickness of the base depends on the strength of the soil, drainage, climate, and traffic loads. Base thickness used under asphalt can typically be used under interlocking concrete pavers. Minimum aggregate bases for walks should be 4 to 6 in. (100 to 150 mm), driveways 6 to 8 in. (150 to 200 mm), and streets 8 to 12 in. (200 to 300 mm). Thickness may be adjusted depending on site conditions and traffic. Compaction of the aggregate base under pedestrian and residential driveway pavements should be at least 98% of standard Proctor density (per ASTM D 698). The aggregate base should be compacted to at least 98% modified Proctor density (per ASTM D 1557) for vehicular areas. Compaction equipment suppliers can provide information on the appropriate machines for compacting base material. These density recommendations for areas next to curbs, utility structures, lamp bases, and other protrusions in the pavement are essential to minimize settlement. Site inspection and testing of the compacted soil and base materials are recommended to ensure that compaction requirements have been met. Compacted base materials stabilized with asphalt or cement may be used in heavy load applications or over weak soil subgrades. The surface of the compacted base should be smooth with a maximum tolerance of ± 3 / 8 in. (10 mm) over a 10 ft. (3 m) straight-edge.

Bedding Sand: Bedding sand should conform to the grading requirements of ASTM C 33 or CSAA23.1-FA1. Do not use mason sand. Stone dust or waste screenings should not be used, as they can have an excessive amount of material passing the No. 200 (0.075 mm) sieve. The sand should be screeded to an even thickness of 1 in. to 1 1 / 2 in. (2540 mm). Do not use the sand to fill depressions in the base. These eventually will be reflected in the surface of the finished pavement. Fill any depressions with base material and compact. Geotextile may be applied under the bedding sand in certain places. These areas are adjacent to curbs, roof parapets, drains, utility structures, and over asphalt or cement stabilized bases to prevent migration of the bedding sand into joints or cracks. When applied in these locations the fabric should be turned up against vertical surfaces to contain the bedding sand.

Joint Sand: Bedding sand may be used as joint sand, however, extra time and effort may be required in sweeping and forcing the sand between the pavers. For that reason, fine, dry sand may be used that conforms to the grading requirements of ASTMC144 or CSA-

A179. This sand is often called mason sand and is used to make mortar. This sand should not be used for bedding sand.

Concrete Pavers: The shape of the concrete pavers determines the range of laying patterns (Figure 3). 45 ° to 90 ° herringbone patterns are recommended in areas subject to continual vehicular traffic. They will give the maximum interlock and structural performance. Some patterns have "edge" pavers specifically designed to fit against the edge restraints. Concrete pavers can be cut with a splitter or masonry saw to fit along the edge of the pavement. For streets and industrial areas exposed to tire traffic pavers should be no smaller than one-third of a unit along the edge of the pavement. Once the pavers are placed in their specified pattern(s), they are compacted into the bedding sand with a plate compactor. The compactor should have a minimum force of 5,000 lbs. (22 kN) and frequency of 75 to 100 hz. After the pavers are compacted, sand is swept and vibrated into the joints until they are full. All pavement within 3 ft (1 m) of unfinished edges should have the joints full and be compacted at the end of each day. See ICPI *Tech Spec 2* for further information on construction. ICPI *Tech Spec 9* provides a guide specification for installation.

Edge Restraints: Edge restraints around interlocking concrete pavement are essential to their performance (Figure 2). The pavers and sand are held together by them, enabling the system to remain interlocked. For walks, patios, and driveways, edge restraints can be steel, aluminum, troweled concrete and submerged concrete curb, or plastic edging specifically designed for concrete pavers. Concrete restraints are recommended for crosswalks, parking lots, drives, streets, industrial, port, and airport pavements. Precast concrete and cut stone curbs are suitable for streets, drives, and parking lots. Edge restraints are typically placed before installing the bedding sand and concrete pavers. Some edge restraints such as plastic, steel, and aluminum can be installed after placing the concrete pavers. See ICPI *Tech Spec 3* for further information on edge restraints.

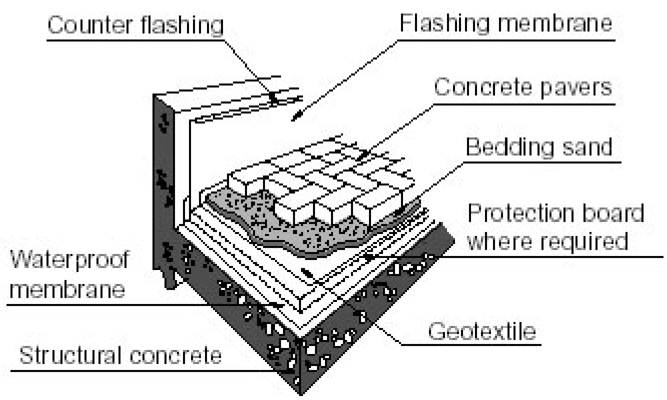

Figure 4. Roof assembly.

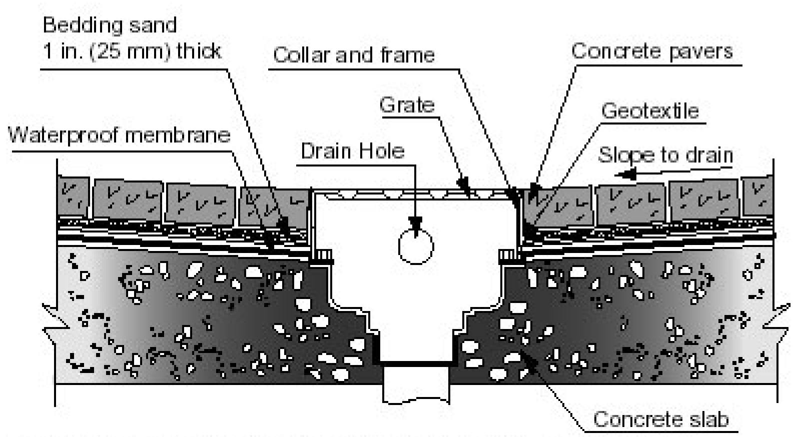

Figure 5. Roof drain with drain holes at bottom of bedding sand layer.

Drainage: Surface and subsurface drainage systems, as well as pavement grades, should conform to that used for any other flexible pavement.

Swimming Pools: High slip-resistance and rapid drainage of water make concrete pavers a desirable surface around commercial or residential swimming pools. The pavers and bedding sand can be placed on a compacted aggregate or concrete base. If placed on a concrete base, drain holes are necessary at the lowest elevations to remove excess moisture in the bedding sand. A urethane or neoprene sealant and backer rod should be placed between the course of pavers and the pool coping. Sealing the pavers and joints is recommended.

Roof Plaza/Parking Decks: Interlocking concrete pavements can be placed on parking garage roofs and pedestrian roof plazas. Concrete pavers provide an attractive ballast for the waterproof membrane (Figure 4). As a heat sink, the pavers reduce thermal stress on the membrane. The roof structure should be waterproofed, designed to withstand loads, and be sloped at least 2% to drain. Protection board should be applied according to the recommendations of the waterproof membrane manufacturer. Geotextile is applied around roof drains to prevent the migration of bedding sand. The drains should have holes at the level of the waterproof membrane to allow removal of subsurface water (Figure 5). See *Tech Spec 14* for further information on roof plaza deck applications.

Gas Stations: For new and refurbished gas stations, concrete pavers provide a safe, oil and fuel-resistant surface. When concrete pavers are removed for repairs to underground power lines, pipes, and storage tanks, they can be reinstated with no ugly patches or time wasted for curing. Stabilized bases are recommended under the pavers and bedding sand to withstand loads from fuel trucks or other heavy vehicles. After installation of the base, bedding sand, concrete pavers, and joint sand, a liquid, fuel-resistant sealer should be applied to and allowed to soak into the joints. Upon curing, the sealer reduces the likelihood of infiltration of petroleum products from drippings and occasional minor spills.

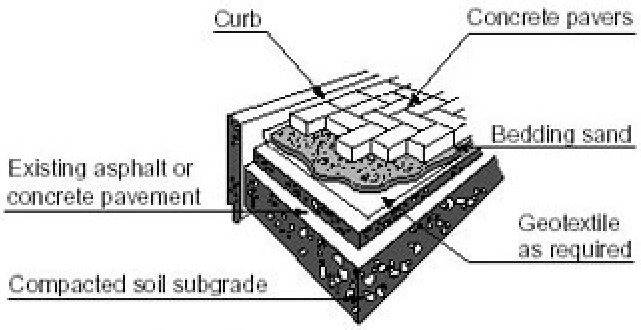

Figure 6. Typical overlay/inlay on existing pavement.

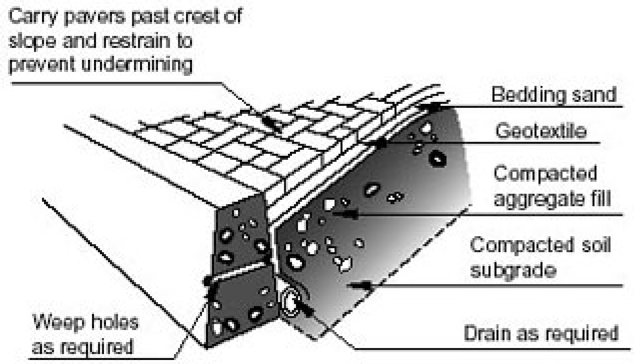

Figure 7. Embankment with concrete pavers.

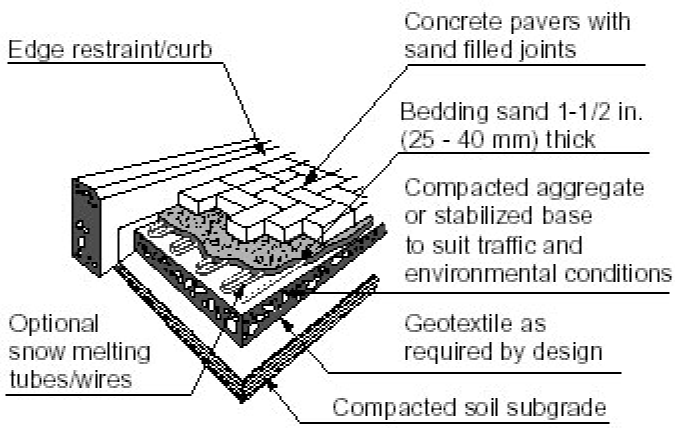

Figure 8. Snow melting system with concrete pavers.

Pavement Overlay/Inlay: New or existing asphalt or concrete pavements can be overlaid or inlaid with concrete pavers (Figure 6). The surface of the existing pavement can be ground out and bedding sand and pavers placed in the milled area. Considerations should be given to drainage of excess moisture in the bedding sand during the early life of the pavement overlay/inlay. Drainage can be achieved by drilling/ casting vertical holes at the lowest elevations of the pavement, or directing drain holes to catch basins. The drain holes should be covered with geotextile to prevent loss of bedding sand. Geotextile may need to be applied at pavement joints and cracks. Cracks 3 / 8 in. (10 mm) or larger in width should be patched prior to placing geotextile, bedding sand, and pavers.

Embankments and Vehicular Pavements with High Slopes: Pavers provide a durable surface for control of soil erosion from embankments. A backfill of open-graded aggregate with drains at the bottom of the slope is recommended to relieve hydrostatic pressure (Figure 7). Concrete pavers restrained at the sides and top of the slope should have adjacent areas graded and slope in such a manner that water runs away from the restraints. Vehicular pavements with slopes over 8% may require concrete header beams. The presence and spacing of beams is subject to the designer's discretion. Drainage of water in the bedding sand and base is essential along the upslope side of the concrete headers. For concrete pavers and bedding sand over aggregate base, removal of water can be accomplished with prefabricated geocomposite drains. When pavers and bedding are over concrete or asphalt, there should be several geotextile-covered drain holes in these pavements on the upslope side of the header. The water collected by these drain holes or geocomposite drains should be directed beyond the edge restraints of the pavement. The overall dimensions of, and the steel reinforcement within the concrete headers will depend upon traffic loads and base design. Minimum recommended dimensions are 6 in. (150 mm) wide and 12 in. (300 mm) deep. The joint sand between the pavers should be stabilized with a sealer to prevent washout. The crossfall of the pavement should be at least 2% from the center.

Snow Melting Systems: Interlocking concrete pavements can accommodate snow melting systems for pedestrian and vehicular applications (Figure 8). The systems consist of hot, liquid-filled tubing or radiant wires placed in the bedding sand, in compacted aggregate concrete, or asphalt base. Snow melt systems turn on automatically when a snowstorm starts, eliminating plowing, ice hazards, and the need for de-icing salts. The result is less potential for injuries from slipping on ice and decreased liability. An aggregate base can be used to support the tubing or wires for pedestrian areas and residential driveways. Both systems must be secured to the base prior to placing the bedding sand. The systems are installed by specialty contractors (electricians and/or plumbers). The bedding sand may be as much as 2 in. (50 mm) thick to cover and protect the tubing or wires. For other vehicular areas, the tubing or wires should be in placed in a concrete or asphalt base. See ICPI *Tech Spec 12* for further information on snow melting systems.

Figure 9. Mechanical installation equipment places concrete pavers rapidly.

Rigid Pavements: Construction of rigid pavements is slower and more expensive compared to sand-set installations. Concrete pavers can be set on a sand-asphalt setting bed with neoprene modified asphalt mastic. The base under the asphalt is typically concrete. Joints are filled with sand, and may also be filled with cement-stabilized sand. Caution should be taken in preventing the pavers from becoming stained by the cement in the sand. Bitumen-set pavers can be placed in vehicular areas. Attention should be given to draining excess water from the base supporting the bitumen setting bed. While bitumen-set concrete pavers perform adequately, the preferred setting bed is sand. Bitumenset concrete pavers will increase the cost of the installation when compared to sand set installations. This installation method requires a concrete base and additional costs from handling the asphalt setting bed and mastic. Small areas are installed in the following sequence. A prime coat is placed on a concrete base, the asphalt bed is placed, screeded, and then compacted. Mastic is applied to the bed and the pavers are placed on it. Should the surface of the pavers be stained with mastic, it is very difficult to remove. Reinstatement of bitumen-set pavers is impossible because the asphalt material adheres to the bottom of the pavers when removed. It is less expensive to discard the pavers rather than remove the asphalt from the units and attempt to reinstate them. Bitumen-set concrete pavers are not recommended on asphalt or aggregate bases. Pavers can be mortared directly to a concrete base using an acrylic fortified mortar bed. Mortared applications work best in pedestrian areas in non-freezethaw regions. Polymer adhesives specially designed for adhering concrete pavers to concrete enable faster installation without the chance of accidentally staining the surface of the pavers with mortar. These adhesives can be used in areas with freezing climates. Mortared pavers and those set with adhesives are not recommended for vehicular areas.

Mechanical Installation: Certain laying patterns can be installed mechanically, saving construction time. Specialized installation equipment enables over a square yard (m^2) of concrete pavers to be placed in succession, rather than one paver at a time (Figure 9). Contact a local ICPI supplier for availability of laying patterns and for contractors experienced with mechanical installation equipment. See ICPI *Tech Spec 11 and 15* for further information on mechanical installation.

Availability and Price

Availability: Interlocking concrete pavers are available from ICPI members throughout the U.S. and Canada. Check with a local member for available shapes, thicknesses, and colors.

Price: Prices will vary depending on the site location, pattern, thickness, color, area, base requirements, edge restraints, and drainage.

Warranty

ICPI paver suppliers will typically certify that the specified product meets the requirements of ASTM C 936 or CSA A231.2 as applicable. It is recommended that the manufacturer have a current product certification from ICPI. This certifies that concrete pavers submitted by the manufacturer to an independent testing laboratory passed applicable ASTM or CSA tests.

Maintenance

When properly installed, interlocking concrete pavements require practically no maintenance. As with all pavements, they will become soiled over time depending on the amount of use. Contact a local ICPI supplier for information on cleaning concrete pavers. ICPI publishes other technical bulletins on cleaning, sealing, (ICPI *Tech Spec 5*) and reinstatement of concrete pavers (ICPI *Tech Spec 6*).

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ICPI TECH SPEC NUMBER · 11

Mechanical Installation of Interlocking Concrete Pavements

Mechanical installation originated in Germany and the Netherlands in the late 1970s. The growth of street, port, and airport projects required timely installation with fewer workers. Machines were developed to increase productivity while reducing fatigue and injury (14). Today, over 5,000 mechanical installation machines operate in Germany alone with thousands more in use throughout Europe. They are used for projects as small as 10,000 sf (1,000 m^2) (5). Mechanical equipment was first introduced in North America in the early 1980s. The first mechanically installed project was placed in 1981, a 1,000,000 sf (93,000 m^2) container terminal in Calgary, Alberta. Since then, hundreds of commercial, municipal, port, and airport jobs have been installed mechanically in most states and provinces across North America. Some examples include city streets in Dayton, Ohio (the first mechanically installed street in the U.S.) (6); Cincinnati, Ohio; Toronto, Ontario; Northbrook, Illinois; Naples, Florida; and Palm Desert, California; container yards in Tampa, New Orleans, Baltimore, and Oakland; and an airfield at St. Augustine, Florida. To demonstrate the use of mechanical installation in North America, the ICPI offers a 10-minute video entitled, "Engineered Paving Systems for Ports, Airports and Roadways-the Economical Advantage of Machine-Laid Interlocking Concrete Pavers." Mechanical installation must be viewed as a system of material handling from manufacture to on-site placement of the concrete pavers. This technical bulletin provides guidelines for the manufacturer, designer, and contractor of mechanically installed pavements in order to realize high efficiencies from this system of material handling. Successful mechanical installation relies on four factors that affect efficiency and costs. These include: 1. Equipment specifically designed to efficiently handle (a) transport of packaged concrete pavers onto/around the site, (b) screeding of bedding sand, (c) installation of the concrete pavers. 2. The shape of the paver and configuration of the laying pattern. 3. Careful job planning by the contractor with support from the manufacturer before the job begins. 4. Systematic and efficient execution of the installation on the job site. As of 2003, ICPI has released Tech Spec 15 *A Guide for Construction of Mechanically Installed Interlocking Concrete Pavements*. The guide is intended for large, mechanically installed projects and is for facility owners, design professionals, contractors, and manufacturers. It provides requirements for quality control of materials and their installation, including bedding sand and pavers. It includes a Quality Control Plan jointly developed and implemented by the paver installation contractor, the paver manufacturer and the general contractor. The specification guide facilitates planning and coordination among these entities, and it supports a systematic approach to manufacture, delivery, installation, and inspection.

Figure 1. Mechanical installation equipment at Port of Tampa, Florida.

Figure 2. A cube of 90° herringbone pattern rectangular pavers ready for installation.

Figure 3. (below) Non-motorized equipment used to set a small layer of pavers.
Figure 4. (right) Motorized equipment with a mechanical clamp.

1. Equipment for Mechanical Installation
Mechanized equipment includes an operator-activated clamp that lifts one layer or cluster of pavers at a time. Each layer can consist of 20 to 72 paving units. The pavers are manufactured in their prescribed laying pattern within the layer. In rare cases, two smaller layers are manufactured and combined in the factory to make one large layer. Layers are packaged in a "cube," i.e., each layer typically stacked 8 to 10 units high. The cubes arrive at the site with each layer ready to be lifted by the mechanical equipment and placed on the screeded bedding sand. Figure 2 shows a cube of pavers opened and ready for installation by mechanical equipment. When grasped by the clamp, the pavers remain together in the layer. They interlock from lateral pressure provided by the clamp while being lifted. Each layer or cluster is typically about a square yard (m 2) in area. The exact layer area varies with each paver pattern. The area covered by the layer can be provided by the manufacturer.

Figure 5. Motorized equipment with a hydraulic clamp.

Figure 6. The vacuum head over the paver layer.

Types of Equipment--Mechanized equipment may be either non-motorized or motorized. *Nonmotorized* equipment consists of a wheeled hand cart and clamp that grabs a half layer, or about 15 to 20 pavers. While it is not as efficient as motorized equipment, a hand-held cart can save time and strain on the installation crew (see Figure 3). Nonmotorized equipment has not been used extensively in North America. However, it may be useful on jobs where noise from vehicles is not permitted (e.g., hospitals), or places with weight limitations and very limited working space, such as roofs. Most *motorized* equipment prevalent in North America is no heavier than a small automobile and is almost as quiet while operating. This equipment can use three different kinds of clamps for placing concrete pavers. The first type is a *mechanical* clamp shown in Figure 4 (7). This clamp consists of many levers that are adjusted to conform to the dimensions of the paver layer prior to starting the job. The initial adjustment of the clamp ensures a tight fit against the layer when activated. When the clamp closes and picks up the layer, the movement in the levers compensates for possible slight misalignment of pavers. Misalignment can be from minor dimensional differences among the pavers in the layer, or caused by small bits of dirt that occasionally lodge between them. When activated by the machine operator, the clamp levers close in unison to pick up a layer. The clamp tightens against its sides while being lifted. The operator then aligns the layer next to the other pavers on the bedding sand. The layer is released from the straight while attempting to wedge the pavers between layers. Wider joints result in a loss of interlock which may reduce the structural integrity and stability of the pavement surface. Therefore, consistent paver dimensions throughout the job helps the crew work efficiently by maintaining straight lines, uniform joint widths, while contributing to interlock. Dimensional growth of pavers is managed by periodically changing molds during manufacturing. This will enable pavers to enlarge consistently while staying within specified tolerances. The number of cycles a mold can run prior to changing will depend on its quality and the abrasiveness of the concrete mix. Dimensional growth is also managed by periodically checking the paver dimensions. This distribution can be done with a ruler, template, or a gauge. An example of a gauge is shown in Figure 16. Dimensional growth is further managed by unloading and installing the largest pavers first. However, loads would need to be marked and distributed on the site in the order of production. This distribution may not be possible on some jobs. Pavers should have straight, square sides to ensure a secure grip by mechanical or hydraulic clamps. Pavers with bulged or slightly rounded, "bellied" sides can drop while being held by these clamps (12). Furthermore, straight lines and consistent joint widths cannot be maintained and interlock decreases. Bulged sides usually result from excessive water in the concrete mix.

Establishing lines--Job site configuration determines the starting point for mechanical installation. Prior to starting, a string line is pulled or chalk line snapped on the screeded bedding sand. The line is perpendicular to the starting face (which may be a curb if it is square to the line) and several layers are placed on the line to establish straight and square courses of layers. Aligning the layers and joint lines at the beginning of the laying process is essential to keeping joints tight and the pattern "in square" as the job proceeds. The lines can guide manual installation of the starting courses (if required) as well as mechanical laying. Parallel string lines are pulled and spaced at intervals equal to several paver layer widths. The distance between string lines should represent the maximum width of the paver layers, i.e., taking into account growth in the layer width from mold wear. The allowable growth, and means of measurement of layers, should be agreed upon between the manufacturer and installer prior to laying the pavers.

Bedding sand--Besides a consistent flow of pavers, there must be a sufficient area of bedding sand screeded and ready to receive the pavers. An oversize area will not get filled with pavers by the end of the day. A small area will fill rapidly, and the crew must work quickly to prepare more screeded sand. The optimum area to screed depends on the productivity of the machine operator and the continuous flow of pavers. This area is different for each project. Spreading of bedding sand can be accomplished with a powered screed bucket as shown in Figure 17 or with an asphalt machine, illustrated in Figure 18.

Figure 17. Powered screed bucket accelerates spreading of bedding sand. The width of the bucket can be adjusted.

Figure 18. An asphalt spreading machine is modified to evenly and rapidly spread bedding sand.

ICPI INTERLOCKING CONCRETE PAVEMENT INSTITUTE ® TECH SPEC

NUMBER • 12

Snow Melting Systems for Interlocking Concrete Pavements

Snow melting systems reduce the fatigue and expense related to removing snow. They can reduce the damaging effects of freeze-thaw cycles, and from the use of de-icing salts experienced by most pavements in cold climates.

A mobile and ambulatory population requires reduction of pedestrian-related accidents. Snow melting systems for pavements can reduce accidents as well as liability exposure from injuries due to slipping on ice and snow. Moreover, snow melting systems reduce the fatigue and expense related to removing snow. In addition, they can reduce the damaging effects of freeze-thaw cycles, and of de-icing salts experienced by most pavements in cold climates. The inconvenience of spreading de-icing salts is eliminated and interior floor materials are kept cleaner and last longer. Snow melting systems for interlocking concrete pavements can be used on patios, walkways, residential driveways, building entrances, sidewalks, crosswalks, and streets. A successful project in downtown Holland, Michigan included a snow melting system in three blocks of concrete paver sidewalks and in the asphalt street (see Figure 1). Holland receives about 75 to 100 inches (190 to 250 cm) of snow each year. By melting the snow, the 167,000 ft 2 (15,500 m 2) heated pavements reduce pedestrian and vehicular accidents. They also reduce wear on the pavements because practically no deicing salts are needed. Neither the merchants nor the city crews remove snow in this area of the business district, and the floors inside the stores are kept cleaner. In addition to exterior applications, heating systems under concrete pavers have been used in interior areas such as around swimming pools, hot tubs, and saunas. The heat creates a comfortable, low-slip walking surface for bare feet and it also warms the room.

Figure 1. A snow melting system under concrete pavers in downtown Holland, Michigan has performed well since 1988.

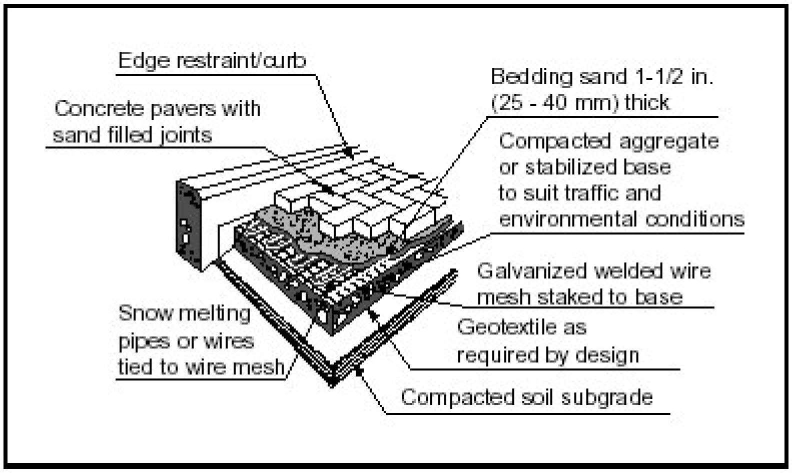


Figure 2. Typical components of a snow melting system for interlocking concrete pavements.

Types of Systems

Two kinds of systems are used to convey heat to the pavement surface: electric or liquid. Electric systems use wires to radiate heat. Generally, electric systems have a lower initial cost, but a substantial operating cost. They involve a series of control switches, thermostats, and snow-sensing apparatus. One electric system consists of heat tapes (flat wires) that automatically stop heating when sufficient energy is released. When they cool, the wires automatically allow more heat through them. Liquid systems (also known as hydronic systems) use a mix of hot water and ethylene or propylene glycol mix in flexible pipes. They have a higher initial cost but a lower operating cost. Hot water systems consist of flexible pipes, pipe manifolds, pumps, switches, a water heater, thermostats, and snow sensors. They typically rely on a boiler that is also used to heat a building. Figure 2 illustrates the typical components of an interlocking concrete pavement with a snow melting system. Snow melting systems generally do not completely dry the pavement surface. Rather, they melt the snow to water which drains away. Completely evaporating the water on the pavement surface is not economically practical since it requires more energy than for melting snow to water. Occasionally, snowfall or drifting may exceed the heat output of the snow melting system. While some snow remains, it will be easier to remove due to the warm pavement surface. Snow melting systems can be part of new construction or added later. For driveways, pipes or wires can be placed in the wheel tracks to reduce installation costs. However, the remaining snow may require removal if it blocks the movement of vehicles. The performance of a snow melting system is measured in inches (cm) of snow melted per hour. Its performance is based on heat output measured in BTUs (British Thermal Units) or watts per square foot (m 2) of pavement. Performance depends on consideration of three overall design factors. First is the rate of snowfall. Second is the temperature of the snow influenced by the air temperature. About 90% of all snow falls between 35 ° F (2 C °) and 10 ° F (-12 ° C). On average, snow falls at about 26 ° F (-3 ° C). The lower the air temperature, the less dense the snow. For warmer, wetter, and more dense snow, more energy per area of pavement is required to melt it. Third, wind conditions greatly influence performance of a snow melting system. Strong winds remove heat from a pavement faster than calm air. Location of buildings, walls, landscaping, and fences will influence the amount of wind across a pavement, heat loss, and ultimately the design and performance of snow melting systems. Rate of snow melting will vary with the application. For example, "Melting 1 in. (25 mm) of snow per hour is usually acceptable for a residence but may be unacceptable for a sidewalk in front of a store. Hospital entrances and parking ramp inclines need to be free of snow and ice at all times"(1). Most manufacturers of liquid and electric snow melting systems also provide design guidelines and/or software to calculate the BTUs per square foot (watts/m 2) required to melt a range of snow storms for a given region. The guidelines work through a series of calculations that consider the snow temperature (density), ambient temperature, exposure of the pavement to wind, and unusual site conditions. They provide recommendations on the size and spacing of pipes or wires required, as well as the temperature of the fluid, its rate of flow, or the electricity required. The Radiant Panel Association (Internet: http://www.rpainfo.com) provides design guidelines for liquid snow melt systems. Controls for activating the snow melting system can include a thermostat in the bedding sand to maintain its temperature above freezing. Another kind of control is located near the pavement and activates the heating system when snow or ice falls. Sometimes a low level of heat is maintained in the pipes or wires and is increased by the sensor when snow falls.

Table 1. Gradation for Crushed Stone Aggregate Base

ASTM D 2490	
Sieve Size	**Percent Passing**
2 in. (50 mm)	100
1 in. (377.5 mm)	95 to 100
3/4 in. (19.0 mm)	70 to 92
3/8 in. (9.5 mm)	50 to 70
No. 4 (4.75 mm)	35 to 55
No. 30 (0.600 mm)	12 to 25
No. 200 (0.075 mm)	0 to 8

Construction Guidelines

Snow melting systems with concrete pavers can be built with three types of bases: concrete, asphalt, or crushed stone aggregate. Concrete and asphalt bases are recommended for roads and crosswalks. While these bases may be used for driveways and pedestrian applications, a crushed stone aggregate base may be more cost-effective.

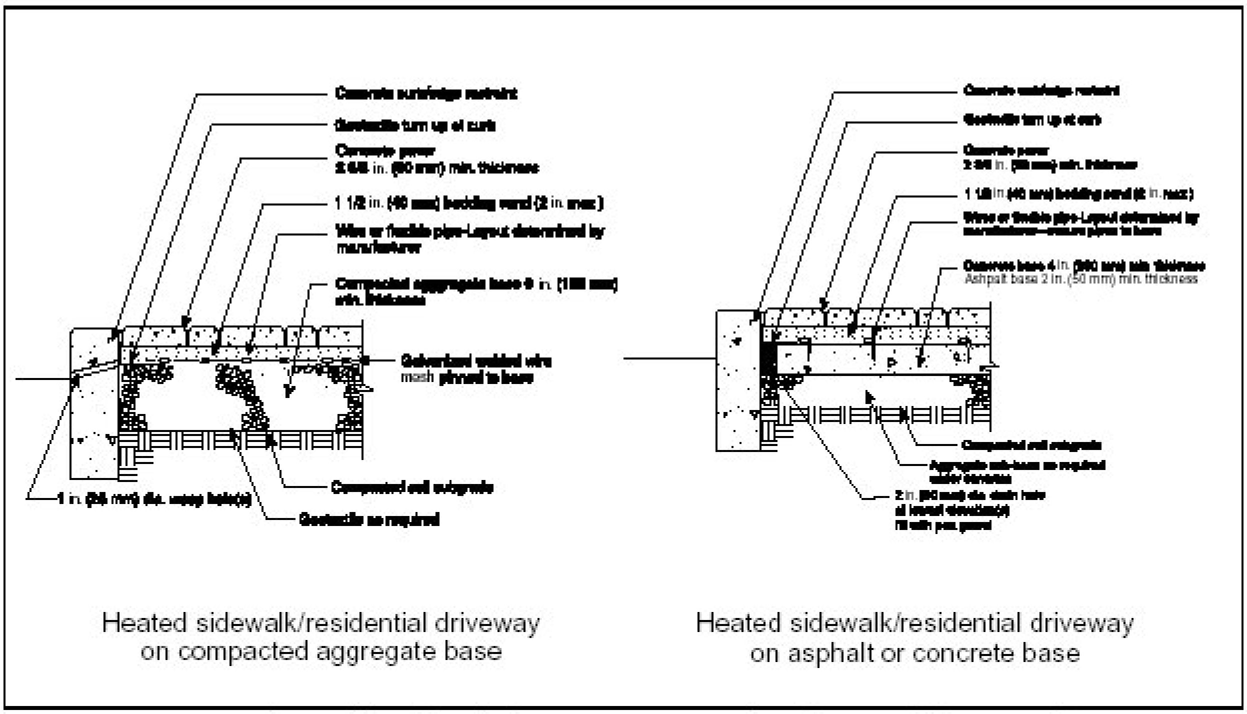
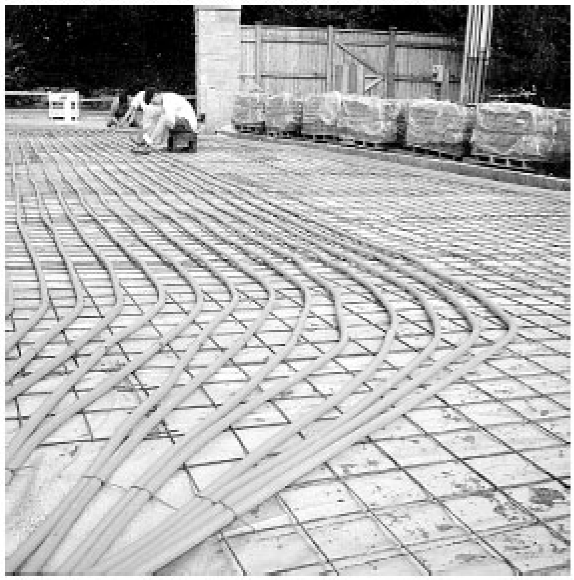


Figure 3. Cross sections of a typical heated interlocking concrete pavement for pedestrian and driveway applications.

Aggregate bases for pedestrian and driveway applications

Subgrade Preparation--ICPI Tech Spec 2-*Con struction of Interlocking Concrete Pavements* should be reviewed with this technical bulletin, as it offers guidelines for subgrade preparation, base materials, and installation of bedding sand and concrete pavers. Preparation and monitored compaction of the soil subgrade and the aggregate base are essential to longterm performance. The soil subgrade and base aggregate should be compacted to a minimum of 98% standard Proctor density, per ASTM D 698 (2). Geotextile is recommended over compacted clay soils and silty soils. The geotextile separates the aggregate from the soil, keeping the base consolidated through long-term changes in moisture and temperature, as well as freezing and thawing. Drain pipes may be required in slow draining soils, especially under vehicular applications.

Figure 4. The heating system is tied to a wire mesh anchored into the compacted aggregate base.



Base materials and preparation--Recommended gradations for aggregate base materials are those typically used under asphalt pavements that meet standards published by the local, state, or provincial departments of transportation. If no standards exist, the gradation shown per ASTM D 2490, *Standard Specification for Graded Aggregate Material for Bases or Subbases for Highways or Airports* in Table 1 is recommended (3). The minimum thickness of the base should be at least 6 in. (150 mm) for pedestrian areas and 10 in. (250 mm) for driveways. Thicker bases, or those stabilized with cement or asphalt, may be required in areas of weak soils subgrades (California Bearing Ratio < 4), in low-lying areas where the soil drains slowly, or in areas of extreme cold and frost penetration. The minimum surface tolerance of the compacted base should be ± 3 / 8 in. over a 10 ft (± 10 mm over a 3 m) straightedge. Density and surface tolerances should be checked before proceeding with installation of the snow melting wires or pipes. Prior to placing the wires or pipes, a galvanized wire mesh is placed over the surface of the base. The wire mesh is secured to the base with stakes. The wires or pipes are tied with plastic ties to the wire mesh. Figure 3 illustrates a typical assembly for a pedestrian or driveway application. Figure 4 shows a heating system for a residential driveway tied to the wire mesh. In some instances, rigid foam insulation may be required over the base. The insulation is placed under the bedding sand with wires or pipes in pedestrian applications only. Insulation may be required on heated pavements over a high water table, when the heating system is operated manually, or when the perimeter of the heated area is large in relation to the total area, as with a long sidewalk. The manufacturer of the heating system should be consulted for specific guidance on insulation thickness, as well as when and where to use it. Some contractors install the wires or pipe into the top of the base without wire mesh. This is accomplished by installing the pipes or wires in the last inch (25 mm) or so of compacted base surface. Base material is added and compacted to bring the level of the base to it final grade. The pipe or wire is exposed and flush with the compacted surface of the base. The absence of wire mesh will facilitate screeding of the bedding sand.

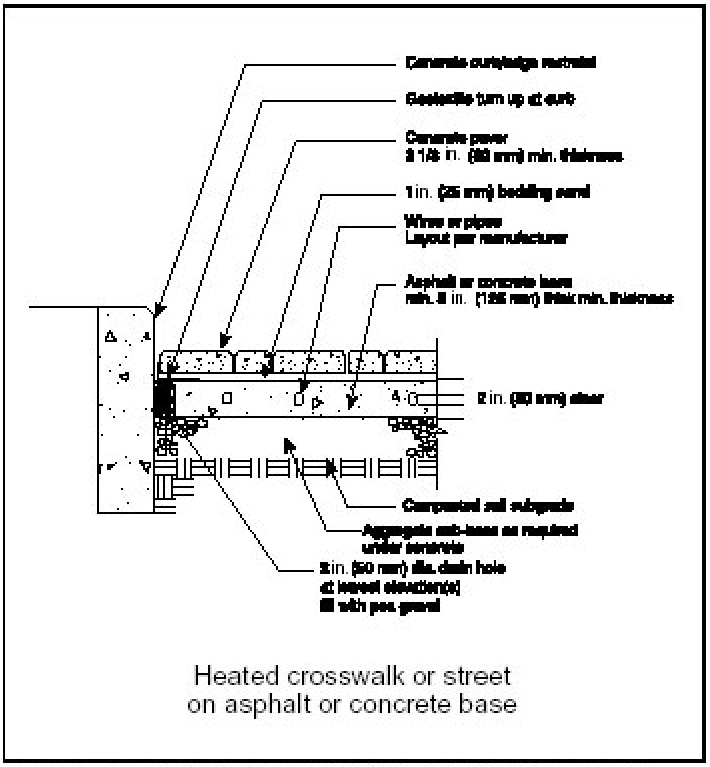
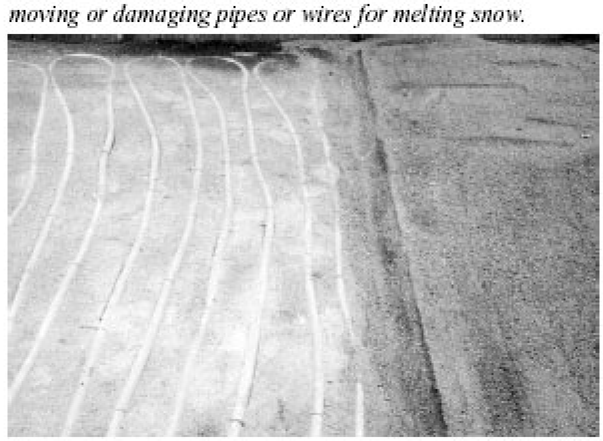


Figure 5. A typical cross section of a heated interlocking concrete pavement for crosswalks and roads subject to vehiclular traffic.

Figure 6. Experienced electrical and plumbing contractors should install snow melting systems.

Figure 7. Screeding bedding sand must be done without moving or damaging pipes or wires for melting snow.



Asphalt and concrete bases for vehicular applications

For areas subject to constant vehicular traffic such as crosswalks or roads, wires or pipes should be placed in a concrete slab or in asphalt (rather than on top of these materials). This will protect the pipes or wires from damage due to wheel loads. Bedding sand and pavers are placed over them. Figure 5 illustrates a typical construction assembly. Asphalt or concrete pavement materials and thicknesses should be designed to local standards. The manufacturer of the snow melting system can provide additional guidance on the location and detailing of wires or pipes in asphalt or concrete. Generally, they are placed within the asphalt pavement or in the concrete slab with a minimum 2 in. (50 mm) clearance from the top and bottom. Asphalt has a lower heat transfer rate than concrete so asphalt may require more costly, closer spacing of the pipes or wires. When using an asphalt or concrete base, drainage of excess water in the bedding sand is recommended. Drainage can be achieved by weep holes through the pavement and base at the lowest points. These holes should be 2 in. (50 mm) in diameter and covered with geotextile to prevent loss of bedding sand into them.

Table 2. Grading Requirements for Bedding Sand

ASTM C 33		or	CSA A23.1-94	
Sieve Size	Percent Passing		Sieve Size	Percent Passing
9.5 mm	100		10 mm	100
4.75 mm	95 to 100		5 mm	95 to 100
2.36 mm	85 to 100		2.5 mm	80 to 100
1.18 mm	50 to 85		1.25 mm	50 to 90
0.600 mm	25 to 60		0.630 mm	25 to 65
0.300 mm	0 to 30		0.315 mm	10 to 35
0.150 mm	2 to 10		0.160 mm	2 to 10
0.75 mm	0 to 1		0.075 mm	0 to 1

Layout of the heating system
After receiving consultation and design recommendations from the manufacturer, the installation of wiring or pipe should be done by an electrical and/or plumbing contractor experienced with installing these systems (Figure 6). The installed system should be tested *before* placing sand or pavers over it. Liquid systems should have their pipes filled and placed under pressure prior to placing asphalt or concrete over them. The wires are generally no thicker than 3 / 4 in. (19 mm). Pipes can vary in diameter from 1 / 2 in. (13 mm) to 1 in. (25 mm) depending on the area to be heated and system flow requirements. For example, one manufacturer recommends that for areas less than 5,000 ft 2 (500 m 2) a 5 / 8 in. (16 mm) inside diameter pipe can be used. For areas larger than 5,000 ft 2 (500 m 2) or when the area to be melted is very long and narrow such as a sidewalk, 7 / 8 in. (22 mm) inside diameter pipes are recommended.

Bedding sand--Normally, a consistently thick layer between 1 to 1 1 / 2 in. (25 to 40 mm) is recommended under concrete pavers. With snow melt systems, up to 2 in. (50 mm) (before compaction) of bedding sand may be required to cover and protect the wires or pipes. The gradation of the bedding sand should conform to ASTM C 33 (3) or CSA A23.1-94 (5) as shown in Table 2. Limestone screenings or stone dust should not be used as they often have material passing smaller than the No. 200 (0.075 mm) sieve. This fine material slows the drainage of the bedding sand layer. The bedding should be moist when screeded but not saturated. Screed bars (for screeding bedding sand) will need to be carefully placed so as to not disturb or damage the pipe or wires during screeding of the bedding sand. (See Figure 7.) All pavers should be compacted, their joints filled with sand and compacted again at the end of each day. If the paver installation takes more than one day, the screeded bedding sand should not extend more than a few feet (1 m) beyond the edge of the open pattern at the end of each day. If there is a chance of rain, this area should be covered with a waterproof covering to prevent the bedding sand from becoming saturated. If the bedding sand is exposed to rain, it will become saturated and will have to be replaced or left to dry for many days. Saturated bedding sand is impossible to compact effectively and often requires removal. This will be very difficult and time-consuming since the pipes or wires will slow bedding sand removal considerably.

Figure 8. Spreading joint sand over the installed concrete pavers.

Figure 9. Final compaction of the pavers and settling of the sand into the joints.

Concrete pavers--Concrete pavers should meet the requirements for strength and durability in ASTM C 936 (6) or CSA A231.2 (7). For pedestrian and driveway applications, 2 3 / 8 in. (60 mm) thick pavers are recommended, and 3 1 / 8 in. (80 mm) thick for vehicular uses. Once the bedding sand is screeded smooth, place the pavers in the prescribed laying pattern. All pavers should be constrained by edge restraints. ICPI Tech Spec 3*Edge Restraints for Interlocking Concrete Pavements* offers guidance on the selection and application of edge restraints for all applications. The concrete pavers should be compacted into the bedding sand with a 75100 Hz plate compactor having a minimum centrifugal compactive force of 5,000 lbf (22 kN). Bedding sand is then spread across the surface of the pavers. A finer sand may be used to fill the joints that conforms to the grading requirements of ASTM C 144 (8) or CSA A179 (9). In either case, the joint sand should be dry so that it easily enters the joints between the pavers. The concrete pavers are then compacted again and sand swept into the joints between them until they are completely full. Figures 8 and 9 show spreading the joint sand and the final compaction of the pavers. Excess sand is removed. Check with the manufacturers of snow melting systems to see if cleaners and sealers can be applied with no adverse effects. For additional guidance on the selection of cleaners and sealers, see ICPI Tech Spec 5, *Cleaning and Sealing Interlocking Concrete Pavements-A Maintenance Guide*. The minimum recommended slope of the finished pavement surface should be 2%. Water should not drain onto other pavements where it might collect and freeze.

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ICPI TECH SPEC NUMBER · 13

Slip and Skid Resistance of Interlocking Concrete Pavements

Introduction
Slip resistance for pedestrians and skid resistance of tires on the road are important to safety in traversing walks and streets. While many variables influence slip and skid resistance, interlocking concrete pavements offer surface characteristics that provide resistance and added safety when compared to other pavement surfaces. This technical bulletin describes the slip and skid characteristics of concrete pavers and how they can be used to increase safety for pedestrians and drivers.

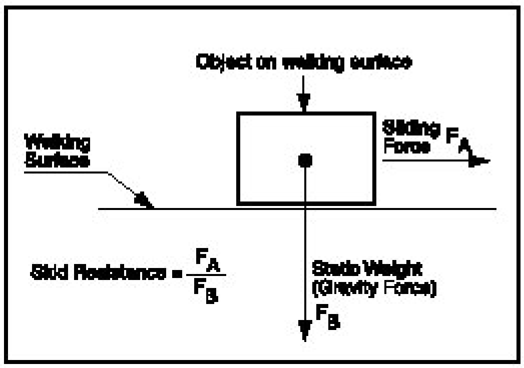

Figure 1. Definition of Slip Resistance

Slip Resistance for Pedestrians
A slip resistant surface is one that provides friction necessary to keep a shoe heel or crutch tip from slipping under a range of conditions. Many human and surface characteristics influence slip resistance. They encompass the texture of the surface, footwear, wetness, contamination of the surface, the speed and style of walking, running, turning sharply, going up or down a ramp or steps. In addition, the alertness of an individual to surface conditions, physical condition, and walking style, as well as the ability to adjust one's gait to varying surface conditions also influences slip resistance. Slip resistance under dry conditions is approximated by measuring the static coefficient of friction, i.e., the horizontal force required to initiate sliding at the instant of motion divided by the static weight (gravity force). For example, a coefficient of friction of 0.7 means that seven tenths of the force holding an object in place will be necessary to initiate movement tangential to the surface on which it is resting. Figure 1 illustrates the definition of slip resistance. By comparison, the dynamic coefficient of friction is the ratio of horizontal to vertical forces when movement occurs at a constant velocity. The static coefficient of friction is ideally measured with no time delay between the application of the sliding force against the gravity force. The sliding force can then be used to measure the slip resistance of wet surfaces. Strictly speaking, the slip resistance of a wet surface cannot be precisely equated to static coefficient of friction. In fact, a false friction force may develop. This is due to the development of adhesion when a measuring device such as a drag meter is placed upon a wet surface (even an instant before it is pulled). The force can often result in the anomalous result where the presence of water can actually improve measured slip resistance. The Americans with Disabilities Act (ADA) was made U.S. law in 1990 to protect the civil rights of individuals with disabilities. The law provides protection to disabled persons at their place of employment (Title I), from state of local government services (Title II), from public accommodations (Title III), and with telecommunications (Title IV). Title II covers minimum design standards for transportation facilities and Title III covers standards for new construction, as well as alterations to public places and commercial facilities. The U.S. Departments of Justice and Transportation have issued minimum design standards through the Americans with Disabilities Act Accessibility Guidelines (ADAAG). These guidelines for construction were developed by the U.S. Architectural and Transportation Barriers Compliance Board (ATBCB), also known as the Access Board. The guidelines are subject to periodic revisions and the latest version should be referenced when designing handicapped facilities. Section 4.5.1 of ADAAG states, "Ground and floor surfaces along accessible routes and in accessible rooms and spaces including floors, walks, ramps, stairs, and curb ramps shall be stable, firm, and slip resistant and shall comply with (Appendix) 4.5" (1). The Appendix includes recommendations for slip resistance expressed as a minimum coefficient of friction of 0.6 for accessible routes and 0.8 for ramps (dry surfaces) (2). These are advisory recommendations and are not standards. Design and testing standards may be required by the Occupational Safety and Health Administration (OSHA) for workplace safety, by other federal, state, provincial, or local regulations.

Figure 2. The NIST-Brungraber Mark II Tester for Slip Resistance

Measuring Slip Resistance

There is no single established test method for measuring slip resistance. There are several different methods recommended in publications from the Access Board. These include Horizontal Pull Slipmeter (3) and the PTI Drag Sled Tester (2). The test device recommended as the best currently available for measuring slip resistance, and that recommended by the Interlocking Concrete Pavement Institute (ICPI), is the NIST-Brungraber Tester (2). The test procedure can be conducted by Slip Test, P.O. Box 8, Spring Lake, NJ 07762, tel: 732-4491789, fax: 732-449-4746. The tester, called the Mark I, can be also be purchased from Slip Test and the test procedure can be mastered in about 30 minutes. The test can be conducted by independent testing laboratories as well. The Mark I device was developed for testing dry surfaces. Slip Test has developed a more advanced model, the Mark II, for testing both wet and dry surfaces (See Figure 2). The Mark I and II are recognized by the Access Board as the suitable testing machines for slip resistance. Both machines are simple to use and are available from Slip Test.

Slip Characteristics of Concrete Pavers

Concrete pavers can be made with or without surface treatments, and some may be sealed after installation. Treatments include high sand and cement content in the surface, or those with machine-polished surfaces. Others include stone-like textures made by shot-blasting, hammering, washing, or tumbling the surface. Regardless of the presence or absence of surface treatments/sealers, most concrete pavers can meet the ADAAG recommendations for slip resistance. (Pavers with polished surfaces, however, may require testing since their surfaces can be as smooth as marble or other ground surfaces.) The manufactured, textured walking surfaces are typically consistent from paver to paver thus maintaining a high coefficient of friction. Therefore, there is generally not a need to test many paving units. Should a need for testing arise, designers and purchasers may wish to verify the wet slip resistance of concrete pavers made by ICPI members for specific applications by using the Brungraber Tester. In some cases, the slip resistance of concrete pavers may exceed the ADAAG recommendations. In some applications they can contribute an additional measure of safety. Such areas can be any area that, when wet, can be a potential slipping hazard, especially for walking impaired people, or those in wheel chairs. Some examples include crosswalks, ramps, or areas traversed by crutch users and those with artificial legs, and places crossed by wheel chairs including curb ramps at intersections. Most concrete pavers are manufactured with chamfers on the edges of the wearing surface. The chamfers are small, typically 45° bevels, 4 or 6 mm wide, or they can be rounded. Should the units become vertically misaligned in service, the chamfers help provide a smooth transition from unit to unit, thereby reducing the tripping hazard. Like all pavement surfaces, extreme settlement or heaving can create dangerous tripping hazards and such areas should be repaired. Unlike asphalt and cast-in-place concrete, pavers that are vertically misaligned do not need to be discarded and replaced with a new surface. In most cases, the surface is not destroyed from cracking. Therefore, the concrete pavers can be removed, repairs made to the base, and the same units reinstated without waste or unsightly patches. For further information on reinstatement procedures, see *ICPI Tech Spec 7, Reinstatement of Interlocking Concrete Pavement*. Other ICPI Tech Specs should be consulted for advice on construction specifications, construction procedures, and on edge restraints.

Skid Resistance for Vehicles

Skid resistance is the resistance to motion between the pavement and vehicle tires. Pavement-tire friction is influenced by the following factors (4):

Pavement characteristics such as texture, roughness, and rutting

Pavement texture consists of microtexture and macrotexture. Macrotexture is defined as 0.2 in. (0.5 mm) or greater deviations in the surface (from a true planar surface) that affect tire-pavement interaction. A pavement with good macrotexture contributes to skid resistance of vehicles traveling over 25 mph (40 kph). Concrete pavers with chamfers offer a unique macrotexture that can benefit skid resistance at these speeds. Specifically, the chamfers form small drainage channels on the pavement surface to help disperse water under moving tires. Microtexture is defined by smaller deviations in the surface, those less than 0.2 in. (0.5 mm). Microtexture is the primary influence on skid resistance of vehicle tires traveling less than 25 mph (40 kph). Microtexture varies with the hardness of the aggregate in concrete pavers. Harder aggregates are less likely to polish under concentrated braking or accelerating tires thus maintaining a high degree of variation in the texture of the surface. In many cases, concrete pavers conforming to applicable American (ASTM) or Canadian (CSA) standards do not require special aggregates to maintain skid resistance equal to that of asphalt or PCC pavement surfaces. Like other paving materials, selection of aggregates (hardness, sharpness) and surface texture can be controlled in the mix design and manufacturing process for concrete pavers. Should the need arise for special aggregates with high skid-resistant properties, laboratory research on a range of aggregates has provided some criteria for selecting aggregates with high skid resistance (5)(6) for conventional pavements. These can apply to concrete pavers. The criteria include the following: · Results of petrographic analysis that show hard minerals combined with some softer minerals. · Angular and large mineral grains in the individual aggregate particles. · Aggregates with a high range of hardness as measured by the Mohs' scale. · Sand-sized and total insoluble residue in carbonate aggregates when subjected to acid solubility tests. · Resistance to wear in jar mill abrasion tests, small, laboratory circular test tracks, and relating these results to laboratory skid tests on sample pavements. Roughness is described as large deviations in pavement surface, most of which affect ride comfort and dynamics of the vehicle. A rough pavement can cause the wheels to bounce and this can reduce friction. Rutting in wheel paths also reduces friction, especially when they fill with water from rainfall.

Tire characteristics including tire type, tire tread, and inflation pressure
Tire design and rubber formulations are often a trade-off between wearing and frictional characteristics. Harder rubber tires wear longer but do not offer the same frictional performance as softer rubber. Deep-treaded tires offer better frictional characteristics because they disperse more water. This is especially important at high speeds where the time for dispersing water from under tires is very short. Excess or low tire inflation pressure also can decrease the skid resistance.

Vehicle operational characteristics such as speed, tire slip, axle load, and the type of vehicle.
Speed of the vehicle is one of the dominant factors in skid resistance. As speed increases, the amount of time to disperse water decreases and water on the pavement has a lubricating effect. When the brakes are applied, the velocity of tires decrease. If a tire's velocity decreases at a rate higher than the vehicle's velocity, the tires will slip on the pavement surface. When the brakes lock, the slipping becomes skidding. Anti-lock brake systems (ABS) are designed to balance the speed of the tires with that of the vehicle during braking, thereby preventing skidding and reducing slipping. Tire-pavement friction generally decreases as axle load increases and trucks generally have a lower coefficient of friction than passenger cars. This is due to differences in tire compounds and hardness, and the higher temperatures at which truck tires operate.

Environmental factors involving wetness, ice and snow, contamination, and temperature
Engineers and road safety officials are most interested in the skid performance of pavement when it is wet since there is a dramatic difference between wet and dry skid characteristics. A pavement does not have to be completely flooded to realize a decrease in skid resistance. A film of water as thin as 0.002 in. (0.05 mm) can substantially decrease skid resistance. Ice, snow, and contamination (mud, oil, gravel, etc.) are all obvious contributors to the loss of skid resistance. Skid resistance decreases as ambient air and tire temperatures rise. When considering road safety, pavement skid resistance is one of several factors, all of which may contribute to skid-related accidents, near misses, and ultimately characterize a pavement as safe or unsafe. Others influences on pavement skid resistance include: · Traffic characteristics such as average daily traffic, posted speed, and the percent of trucks in the traffic mix; · Curves and slopes in the road; and · Driving difficulty such as the number of turning lanes, access points, traffic signals, and surrounding land use. Skid resistance is one of many factors influencing agency decisions on when to resurface or reconstruct a road. The age, traffic, a rough ride due to settlement and rutting, and citizen complaints are some other factors. Each agency has its own decision criteria for pavement maintenance and rehabilitation.

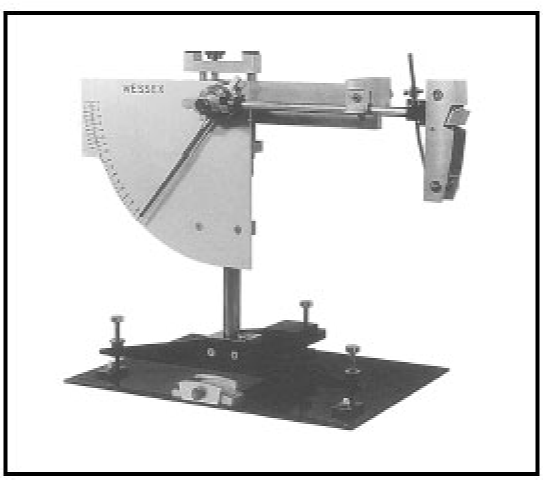

Figure 3. A British Pendulum Tester.

Figure 4. ASTM E 274 Test Equipment consists of a truck and trailer assembly. A tire within the trailer is towed a given speed, locked, and skidded across water dispensed on the pavement in front of it.

Measuring Pavement Skid Resistance
There are two approaches to measuring skid resistance; static and dynamic. Static measuring devices measure resistance while moving across a small portion of the pavement. They do not involve the use of a tire. Dynamic devices make measurements with a tire while moving at a constant velocity across the pavement surface. A common device used for static measurement is the portable British Pendulum Tester. See Figure 3. This test method is described in ASTM E 303, *Standard Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester* (7). This device is used for laboratory or on-site testing of skid resistance on surfaces. It consists of a small rubber shoe at the end of spring-loaded pendulum. The tester measures frictional resistance between the

rubber shoe and the point of contact with the pavement. The contact area of the shoe against the test surface is about 3 in. 2 (19 cm 2), so measurements are influenced only by microtexture of the surface. To perform a test, the test surface is wetted, the pendulum is pulled back, and the shoe rubs across the surface. Friction resistance is read on a scale on the machine as the British Pendulum Number or BPN. A BPN rating between 45 and 55 indicates a satisfactory surface in only favorable weather and vehicle conditions. A rating of 55 or greater indicates an generally acceptable skid resistance in all but the most severe weather conditions. A 65 and above rating indicates a good to excellent skid resistance in all conditions. The BPN correlates with the performance of a vehicle braking with locked wheels on a wet pavement stopping from 30 mph (50 kph). The tester is not designed to give ratings above 30 mph (50 kph) and results do not readily correlate to results from full-scale dynamic tests using a tire and trailer. The BPN test generally gives higher skid resistance ratings than dynamic tire and trailer tests. Most dynamic skid resistance measurement methods assess the interaction between a pavement and a locked, non-rotating tire. These test methods employ a standard-sized tire towed in a wheeled device behind a vehicle. A standard amount of water is applied ahead of the tire while moving, the tire is locked while the vehicle maintains a constant speed and the resistance between the tire and the wet pavement is measured. Some dynamic skid testing devices include the Stradograph, the Sideways Force Coefficient Routine Investigation Machine (SCRIM)(8), and the Mu Meter (9). In the North America, 40 state and provincial agencies use the test procedure described in ASTM E 274, *Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire* (10). Figure 4 illustrates the equipment. This test uses a standard test tire towed in a device behind a vehicle. A standard amount of water is applied ahead of the tire while moving, the tire is locked while the vehicle maintains a constant speed, usually 40 mph (65 kph), and the resistance between the tire and the wet pavement is measured. The force required to slide the tire is divided by the wheel load and multiplied by 100. The results are expressed as a skid number (SN) or friction number (FN). Skid resistance measurements on asphalt pavements will vary with the time of year and weather. Since much skid data has been collected over the years for asphalt pavement, normalization procedures are used to eliminate influences of the season and weather. Weather and seasonal influences on portland cement concrete (PCC) pavements produce less predictable results in skid testing. Therefore, no normalization procedures yet exist for PCC pavements.

Table 1—BPN Results by Clifford (12)

Location	BPN Range
1-year old city vehicle maintenance yard	48-61
8-year old residential pavement	54-59
20-year old residential pavements	41-55
5-year old access road to wind tunnel test facility	48-72
3-year old loading and servicing area next to government buildings	52-57
3 to 8-year old main and secondary roads at botanical gardens	45-85

Table 2—SCRIM Tests by Clifford (12)

Location	Average*	Range
1-year old city vehicle maintenance yard	63-71	25-85
5-year old Access road to wind tunnel test facility	62-77	45-85
3 to 8-year old main and secondary roads at botanical gardens	68-72	35-85

*Averages of measurements taken at several locations within the site

Skid Resistance Values for Interlocking Concrete Pavements
A review of the literature on skid resistance of concrete pavers shows their skid resistance to be equal *Figure 3. A British Pendulum Tester Figure 4. ASTM E 274 Test Equipment consists of a truck and trailer assembly. A tire within the trailer is towed a given speed, locked, and skidded across water dispensed on the pavement in front of it.* or better than asphalt. Most indicate that, subject to the proper mix design and manufacturing controls, concrete pavers can maintain good skid resistance values throughout the life of the pavement. Studies of static skid resistance by different researchers in various countries used the British Pendulum Tester to assess new and trafficked concrete pavers. A summary of test results follows: · Shackel (11) measured a bus route in Durban, South Africa after 17 years of traffic. BPN values averaged 61 with a standard deviation of 4.3. · Clifford (12) conducted numerous tests at various locations in South Africa for the National Institute of Road Research. These tests included the locations and results listed in Table 1. · Mavin (13)(14) measured BPNs in Melbourne, Australia, at 3 parking lots and on a quarry access road that received high truck traffic. BPNs on the new parking lots averaged 81 and declined to 53 with over three years of use. While BPNs for new concrete pavers dropped after use in the parking lots, the values did not fall below accepted standards. The 80kN Equivalent Single Axle (ESA) loads on the quarry road ranged from 0 to 150,000 over three years and BPNs increased from 45 initially to 62-65 at 75,000 to 150,000 ESAs. · Muira et al. (15) compared the performance of concrete pavers to asphalt put into service at the same time in a lightly trafficked street in Japan. After 12 months of service, BPNs for both the concrete pavers and the asphalt were 56-59. · Sharp and Armstrong (16) showed that concrete pavers at a full-scale test track in Australia had an initial BPN of 70 and progressively decreased after installation and reached a minimum value of 57 after 460 ESAs. · Garrett and Walsh (17) tested an experimental access road leading to a industrial park and freight facility near Maidstone, England. After one year of testing pavers made by eight different manufacturers, results showed BPNs between 44 and 56. These values were considered above those for county roads with similar traffic and risk levels. · Lesko (18) performed tests on 7 different areas of concrete pavers in a climbing lane with a 5% slope on a

highway in Denmark. Initial BPNs ranged between 65 and 70 with values measured two years later between 49 and 60. · Domenichini et al. (19) recorded BPNs on an 11-year old, 830 ft (253 m) long street with a 8% to 10% slope in the center of Recoara Terme, a small town in northern Italy. The average daily traffic was 1,230 vehicles in both directions with approximately 4% commercial trucks and buses Test results indicated BPNs of 49 on concrete pavers located in the wheel tracks and 69 outside the trafficked areas. The study noted that European standards for interlocking concrete pavers recommends a minimum surface BPN of 45. The first dynamic testing on concrete pavers was by Lesko (18) at 20, 60, and 80 kph using a Stradograph, a towed, treadless tire pitched at an oblique angle and locked while riding on wet pavement. Test results on 7 different (wet) concrete paver road sections over two years at these speeds showed values did not fall below 0.40 which is considered a satisfactory value for skid resistance. The SCRIM device was used by Clifford (12) on concrete pavers at three of the sites as part of the aforementioned study that involved a British Pendulum Tester. SCRIM tests are typically at 50 kph or 80 kph using a treadless tire mounted on a vehicle at 20° to the line of travel. The vehicle applies water in front of the loaded test wheel and the side force friction on the tire is measured. Tests by Clifford with the SCRIM device were conducted at 50 kph. In South Africa, the SCRIM target value for collector roads is 0.45; for arterial roads, 0.50; and for thoroughfares, 0.55. Results in Table 2 show a range from 0.25 to 0.85 with averages between 0.71 and 0.35. The Interlocking Concrete Pavement Institute (ICPI) engaged The Pennsylvania Transportation Institute (PTI) to conduct skid measurements on two sections of new interlocking concrete pavement (20). Each section was 2 ft (0.6 m) wide by 150 ft (45 m) long and laid in a 90° herringbone pattern. See Figures 5 and 6. Five skid resistance measurements were performed at three speeds; 25, 40 and 50 mph (40, 65, and 80 kph) using the test method described in ASTM E 274. The test used a standard grooved test tire described in ASTM E 501, *Standard Specification for Standard Tire for Pavement Skid Resistance Tests* (21). Tests were conducted in October 1997. The average results from the two sections are shown in Table 3. These are expressed as Skid Numbers (SN).

Figure 5. The test track section and concrete paver surface at The Pennsylvania Transportation Institute test facility.

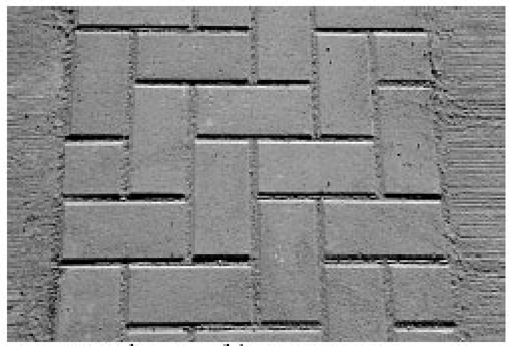

Figure 6. A close-up of the concrete paver surface at the PTI test track.

Table 3—Average SN Values for Interlocking Concrete Pavement Sections (15)

Test Section	Speed mph (kph)	SN	Standard Deviation
A	25 (40)	51.9	0.5
A	40 (65)	46.5	1.1
A	50 (80)	40.0	1.5
B	25 (40)	57.2	1.1
B	40 (65)	49.6	3.0
B	50 (80)	43.1	0.5

Table 4—Recommended Minimum Skid Number for Main Rural Highways (23)

Traffic Speed mph (kph)	SN Measured at traffic speed	SN measured at 40 mph (65 kph)
30 (50)	36	31
40 (65)	33	33
50 (80)	32	37
60 (95)	31	41
70 (110)	31	46

Skid Resistance Requirements
Some states and provinces have minimum skid resistance requirements in construction specifications for new pavements. These help ensure that the new pavement meets certain texture requirements before opening them to traffic. These requirements will vary based on the type of highway pavement, available materials and construction methods. For testing in-service pavements, some consistency

exists among highway agencies on test methods. Many use the ASTM E 274 test method; other states and provinces use the Mu Meter, or have developed their own tire and trailer equipment to derive a skid coefficient or `f' value. In most cases, the results from these test methods can be correlated to results using the ASTM E 274 test method. Since test methods and traffic speeds vary over a wide range of conditions, no universal, minimum standard for skid resistance has been established. Typically, pavement engineers utilize the skid number measured using test method ASTM E 274 at 40 mph (65 kph) (i.e., SN 40) as a reference value. Some researchers have attempted to define minimum skid requirements at certain speeds, on types of roads, and in particular regions. These can be used as overall guidelines rather than strict requirements when comparing skid resistance of conventional surfaces to interlocking concrete pavements. One study for roads in Virginia (22) suggested a minimum SN 40 of 30 for Interstate and other divided highways, and a minimum SN 40 of 40 for two-lane highways. Another study by the National Cooperative Highway Research Project (NCHRP) in 1967 (23) recommended minimum skid numbers for main rural highways. Table 4 shows the minimum skid numbers at various traffic speeds, and those measured at 40 mph (65 kph) on roads with various traffic speeds. The test results on new interlocking concrete pavement test at PTI indicate skid values well above those regarded by engineers as the minimum, and by the studies in references 22 and 23.

Reducing Traffic Accidents with Concrete Pavers
An important study in Japan demonstrates the ability of interlocking concrete pavements to reduce accidents and increase safety at intersections (24). Accidents were monitored over 12 months and vehicle braking distances were measured with a high speed video camera at an asphalt-paved intersection in Ichihara City. Daily traffic volumes on each street from 7:00 a.m. to 7:00 p.m. ranged between 3,479 and 7,119 vehicles. After 6 months of monitoring traffic volume and accidents, the asphalt within and on the approaches to the intersection was removed and replaced with concrete pavers. The change in pavement surface reduced the number of accidents by nine from December to May compared accidents counted in the previous June to November period. The concrete pavers also reduced braking distances. A light-duty van was tested with three drivers on wet and dry conditions stopping from 20, 40, and 60 kph. Stopping distances were shorter on the concrete pavers and the greatest improvement was a reduction of 5 m (16 ft.) at 60 kph as shown in Table 5. The contribution of the chamfers in the surface of the concrete pavers towards dispersing water may explain the reduction in stopping distances at this speed.

Table 5—Stopping distance in meters on asphalt and concrete pavers (24)

	20 kph (12.5 mph)		40 kph (25 mph)		60 kph (37 mph)	
	Dry	Wet	Dry	Wet	Dry	Wet
Asphalt	1.70	3.20	5.85	9.60	14.2	26.7
Concrete pavers	1.68	2.50	5.23	8.15	13.6	21.3

Skid Resistance of Aircraft Pavements
Since 1983, over 12 million ft 2 (1.2 million m 2) of interlocking concrete pavements have been used in airfield applications. Tests conducted by airports and the U.S. National Aeronautics and Space Ad ministration (NASA) demonstrate the skid resistant properties of concrete pavers. A NASA study (25) tested concrete pavers at 5 knots and 100 knots/hour speed at the Aircraft Landing Dynamics Facility in Langley, Virginia. The tests utilized a tire and 123 kN loads and 1.l7 MPa pressure typical to a Boeing 737 or DC-9 aircraft. Figure 7 illustrates the test equipment and Figure 8 illustrates the test surfaces. The test results demonstrated substantially higher side force friction values for concrete pavers under wet conditions than plain portland cement concrete surfaces. The report indicated "that for aircraft ground steering maneuvers under wet conditions, the paver blocks would provide better friction than the conventional smooth concrete surface (25)." Other skid resistance tests include that by Dallas/Fort Worth International Airport where a Saab skid tester was used to evaluate new interlocking concrete pavements in 1990. The values derived from the test were 0.63 to 0.69 with 0.65 being the average value, all considered very good for a new airfield pavement (26).

Harmonization of Skid Testing
ASTM E 1960, *Standard Practice for Calculating International Friction Index of a Pavement Surface*, (27) has harmonized skid resistance measurements through the calculation of the International Friction Index (IFI) based on measurement of pavement macrotexture and wet pavement friction. The IFI was developed by the PIARC (World Road Association) to compare and harmonize pavement texture and skid resistance measurements. The IFI allows for the harmonizing of friction measurements with different equipment to a common calibrated index. This practice provides for harmonization of friction reporting for devices that use a smooth tread test tire.

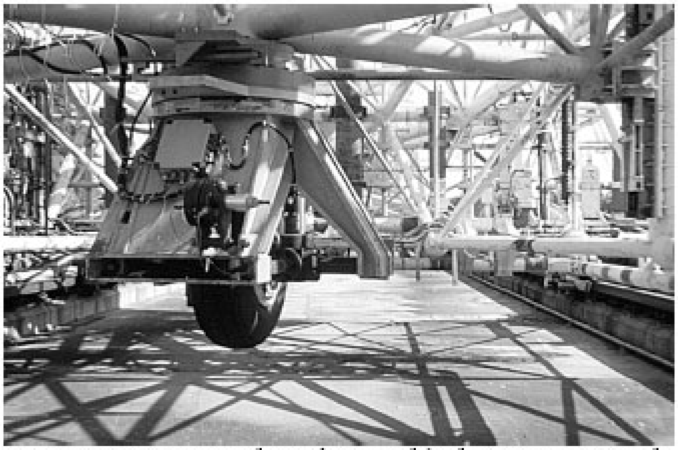

Figure 7. Test equipment for evaluation of the friction properties of concrete pavers at NASAs Aircraft Dynamics Landing Facility (ADLF) in Langley, Virginia.

Figure 8. Test surface at the NASA ADLF facility.

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Concrete Paving Units for Roof Decks

Introduction
An increasing amount of new and rehabilitated roof decks use segmental concrete paving units to support pedestrian and vehicular applications. The units provide an attractive, durable walking surface for pedestrian plaza decks. They can be used to create outdoor space, usable exterior living environments at commercial and residential buildings e.g. next to offices, hotels, hospitals, universities, observation areas on commercial buildings and at cultural cen ters. See Figure 1. Parking structures and the roof decks of underground buildings use concrete pavers to support vehicular traffic as shown in Figure 2. Segmental concrete paving units protect roofing materials from damage due to foot traffic, equip- ment, hail and vehicles. Concrete provides a heat sink that reduces the thermal stress and deterioration of waterproofing materials. The units flex with the movement of the structure as well as with vehicular and seismic loads. Additionally, the units provide a slip-resistant surface and are especially attractive when viewed from adjacent buildings. They can exhibit high durability under freeze-thaw and deic ing salt conditions. A primary role of segmental concrete units is ballast for roofing materials to prevent uplift from high winds. When caught by high winds, gravel ballast on roofs can shift and distribute unevenly. This leaves roof materials exposed to winds, thereby increasing the risk of their uplift. In some cases the gravel can be blown from roofs creating a hazard for glass, pedestri ans and vehicles. Concrete units are preferred over gravel ballast because they provide a consistent, evenly distributed weight for protection from wind uplift and damage. Furthermore, concrete unit paving is required by many building codes as roof ballast for high-rise buildings. This Tech Spec provides guidance on the design and construction of roof assemblies using precast con crete pavers or concrete paving slabs using with vari ous setting methods for pedestrian and vehicular applications. There are many kinds of roof assemblies placed under these types of paving units. The compat ibility of paving units and setting methods with the components of roofing assemblies such as waterproof membrane, protection board and insulation should always be verified with the manufacturers of such components. Vegetated, low-slope roof surfaces or "green roofs" are receiving increased attention from designers and clients interested in reducing building energy costs and the urban heat island. This trend is changing the aerial view of our cities. Furthermore, sustainable building rating systems such as LEED ® recognize green roof technology as well as highly reflective roof surfaces. Concrete unit paving offers designers a reflective surface that can be easily integrated into green roof projects while earning LEED ® credits. ICPI Tech Spec 16-Acheiving LEED ® Credits with Segmental Concrete Pavement provides additional information on how to integrate green roofs with concrete unit paving.

Figure 1. Concrete pavers provide a durable and attractive roof plaza deck surface. At left is the observation deck on the 86th floor of Empire State Building in New York City. At center is a hotel plaza deck constructed with concrete paving slabs.

Figure 2. Concrete pavers serve vehicular traffic and parking over a concrete parking structure next to a residential development.

Plaza Deck Components
Concrete pavers and slabs--There are two cate gories of segmental concrete deck materials for roofs, concrete pavers and slabs. See Figure 3. Concrete pav ers are units that are a mini mum thickness of 2 3 / 8 in (60 mm) and whose length to thickness (aspect ratio) does not exceed 4 to 1. They con form to the requirements of ASTM C 936 (1) in the U.S. or CSA A231.2 (2) in Canada. These units can be used in pedestrian and vehicular applications. Concrete pavers 2 3 / 8 in. (60 mm) thick are commonly used in pedestrian plaza or terrace applications. When the capacity of the structure is limited to addi tional weight, units as thin as 1 1 / 2 in. (40 mm) have been used in pedestrian applica tions. For vehicular uses, the recommended minimum thickness of units is 3 1 / 8 in. (80 mm). Precast concrete paving slabs Open joints for drainage Roof drain Plastic pedestal Protection board (as required) Waterproof membrane Roof deck min. 2% slope to drain Figure 5 Figure 5. Paving slabs on

pedestals Precast concrete paving slabs range in nominal size from 10 x 10 in. (250 x 250 mm) to 36 x 36 in. (910 x 910 mm). Like pavers, concrete paving slabs can be manufactured with a variety of colors, special aggre gates and architectural finishes to enhance their appear ance. Surface finishes include shot-blasted, hammered and ground or polished. They differ from pavers in that slabs typically require at least two hands to lift and place them, and the length to thickness (aspect ratio) is 4 to 1 or greater. Paving slabs generally range in thick ness from 1 1 / 2 in. to 2 in. (40 to 50 mm) and thicker units are also applied to roofs. Slabs are only for pedes trian plaza applications and are not recommended for vehicular use. Slabs risk tipping, cracking from bend ing forces, and shifting under repeated forces from turning and braking tires. Concrete paving slabs made in Canada should con form to CSA A231.1 (3). This standard applies to paving slabs used on roofs as well as at-grade con struction. The standard requires a minimum average flexural (bending) strength of 650 psi (4.5 MPa), freeze-thaw durability when exposed to deicing salts and conformance to dimensional tolerances. Flexural (rather than compressive strength) is used to assess unit strength since the larger slabs are exposed to bend ing and cracking. Compressive strength is excluded from the standard because it is not a true measure of the performance of the concrete. It can increase as the thickness of the tested unit decreases. Therefore, a high compressive strength test result required from a thin slab gives a false indication of a slab's resistance to bending since thinner slabs will break in bending more readily than thicker ones. Unit dimensions are measured on samples and compared to the dimensions of the manufacturer's product drawings. Allowable tolerances for length and width in CSA A231.1 are 1.0 to +2.0 mm from the manufacturer's product drawings. Height should not vary ±3.0 mm. Units should not warp more than 2 mm on those up to 450 mm in length and/or width. For units over 450 mm, warping should not exceed 3 mm. There is no standard for precast concrete paving slabs in the U.S. There are some lightweight, low-flexural strength ballast slabs (mistakenly named roof pavers) manufac tured with a tongue-and-groove or bevels along their sides to increase their interlock. Other designs include plastic fasteners to connect one unit to the next. These methods of joining the sides to one another provide greater resistance to uplift from wind. Figure 4 illus trates one type of unit with tongue and grooved sides (not visible) and connecting tabs between each unit. Some of these types of units are made with lightweight concrete, or are thinner in order to reduce the dead load on the roof structure. Some designs have grooves on their bottom surface. When installed, these follow the roof slope to help remove water. These types of units offer limited architectural enhancement from patterns, colors, or surface finishes. ASTM has issued C 1491, Standard Specifi cation for Concrete Roof Pavers (5). This product specification is appropriate for ballast-only type pav ing units (pavers or slabs) used only in direct contact with roof materials and only for limited pedestrian use such as walkways for maintenance personnel. Products that meet this standard should not be subject to constant pedestrian use, not placed on pedestals and never be subject to vehicles. Specifiers and contractors are advised to use roof paving products for vehicular and pedestrian applications that meet the previously mentioned ICPI guidelines or CSA standards. ICPI takes a conservative approach by not recognizing differences among shapes with respect to structural and functional performance. Certain manufacturers may have materials and data that discuss the potential benefits of shapes that impact functional and structural performance.

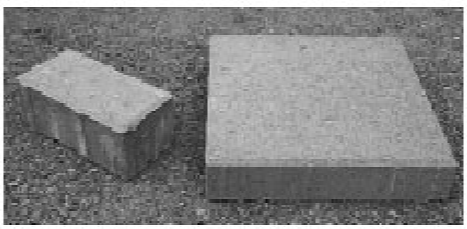

Figure 3. Concrete paver (left) and a concrete paving slab (right): similar paving products with varying applications for roof decks.

Figure 4. Some ballast-type slabs for roof decks are made with lightweight concrete materials. They can be joined with tongue-and-grooves and/or with connectors to resist wind uplift. This is one of several designs available.

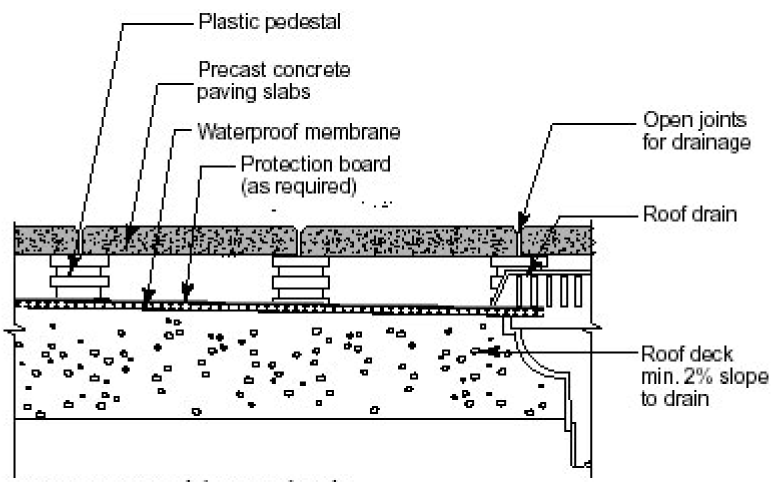

Figure 5. Paving slabs on pedestals

Setting materials

Pedestals--Paving slabs for plaza decks are often placed on plastic or fiberglass pedestals. The result is a level deck, concealment of slope and drains and water storage space under the units during very heavy rainfalls. Pedestal-set paving units install quick ly and enable fast removal for repair of waterproofing materials and for maintenance of deck drains. The units can be reinstated after repair with no visible evi dence of movement. Damaged paving units can also be easily removed and replaced. Figure 5 shows a diagram of a pedestal system with paving slabs. In most pedestal-set applications, units are 18 x 18 in. (450 x 450 mm) or larger. The corners of pav ing units rest on a plastic pedestal. These units usu ally require shimming after placement. Shims are inserted under the corners of a nonaligned paving unit until its surface is even with adjacent units. Some plastic pedestals have a built-in leveling device to reduce the amount of labor involved with shimming. Some are telescoping cylinders whose length can be changed by rotating an adjustable sleeve within another. Other designs have a base that tilts slightly to compensate for the slope of the roof. Vertical spacers are often molded in the plastic pedestals to ensure uniform joint widths among the paving units. The open joints allow runoff to pass through them onto the waterproof membrane and into roof drains. The joint created by the spacer should not exceed 3 / 16 in. (5 mm) and this will minimize the like lihood of tripping. Another type of pedestal system consists of 8 in. (200 mm) square extruded polystyrene blocks (typi cally 2 in. or 50 mm thick) glued together, spaced on a grid across the deck and adhered to a polystyrene insu lation board that rests on the waterproof membrane. Many contractors use 60 psi (0.4 MPa) polystyrene blocks to support the paving units. The bottom block of foam may have grooves in contact with roofing materials to facilitate drainage. The grooves should point toward drains. A patented leveling system trims the tops of the polystyrene blocks to the required height. Shimming is not necessary except for the occasional paving unit that might be slightly out of dimension. Spacing is typi cally maintained with neoprene rubber spacer tabs adhered to the corners of the paving units, although plastic pedestals can be used. This pedestal system supports units up to 36 x 36 in. (910 x 910 mm). The foam pedestals can extend as high as 2 ft (0.6 m). Figure 6 shows the foam pedestals in place and receiving the paving slabs (6).

Figure 6. Foam pedestal system

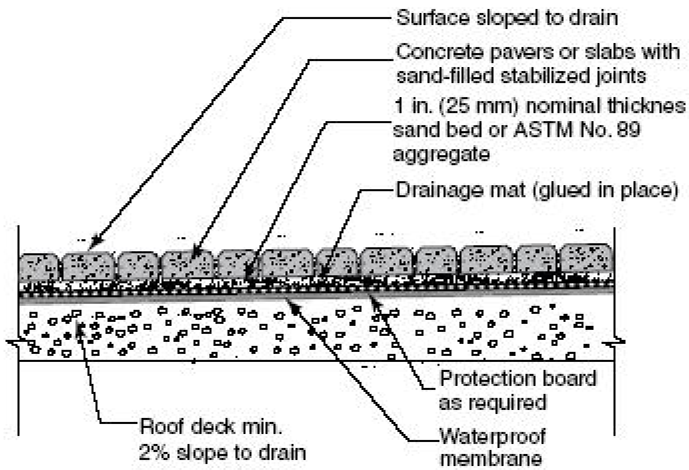

Figure 7. Sand-set concrete pavers or slabs for a pedestrian roof plaza deck. Units no larger than 12 x 12 in. (300 x 300 mm) length and width are recommended for sand-set applications to avoid tipping.

Bedding and Joint Sand for Pedestrian Applications--Sand-set pavers and slabs (up to 12 x 12 in. or 300 x 300 mm) are common options for pedestrian applications. The typical sand thickness is nominal one inch (25 mm). Figure 7 illustrates a sand-set applica tion for pedestrians. A key design consideration is not allowing the bed ding sand to become saturated. Continually saturated sand and joints can support moss or vegetation that eventually clogs roof drains. Saturated sand can increase the potential for efflorescence that might exist in some concrete paving units. While not attractive, efflorescence will eventually disappear and it is not detrimental to structural performance. The risk of saturated bedding sand is reduced by adequate slope of the roof structure and correct sand gradation. Sand requires at least a minimum deck slope of 2% to drain. Gradation of the bedding sand for pedestrian applications should conform to ASTM C 33 (7) or CSA A23.1 "FA 1" (8). It is important that no material (fines) pass the No. 200 (0.075 mm) sieve as the pres ence of this size of material will greatly slow the movement of water through the bedding sand. Recommended gradations for pedestrian applications are provided in Table 1. Limestone screenings or stone dust should not be used since they typically have fines passing the No. 200 (0.075 mm) sieve. It is accepted con struction practice to use bedding sand for joint sand. Additional effort in sweeping and compacting joint sand may be required to work the larger particles down the joints. The sand should be dry when applied so that it flows freely into the joints.

Grading Requirements for Bedding Sand

ASTM C33		CSA A23.1FA1	
Sieve Size	Percent Passing	Sieve Size	Percent Passing
3/8 in.(9.5 mm)	100	10 mm	100
No. 4 (4.75 mm)	95 to 100	5 mm	95 to 100
No. 8 (2.36 mm)	85 to 100	2.5 mm	80 to 100
No. 16 (1.18 mm)	50 to 85	1.25 mm	50 to 90
No. 30 (0.600 mm)	25 to 60	0.630 mm	25 to 65
No. 50 (0.300 mm)	10 to 30	0.315 mm	10 to 35

Table 1. Bedding and Joint Sand Gradation for Concrete Pavers and Paving Slabs for Roof Decks

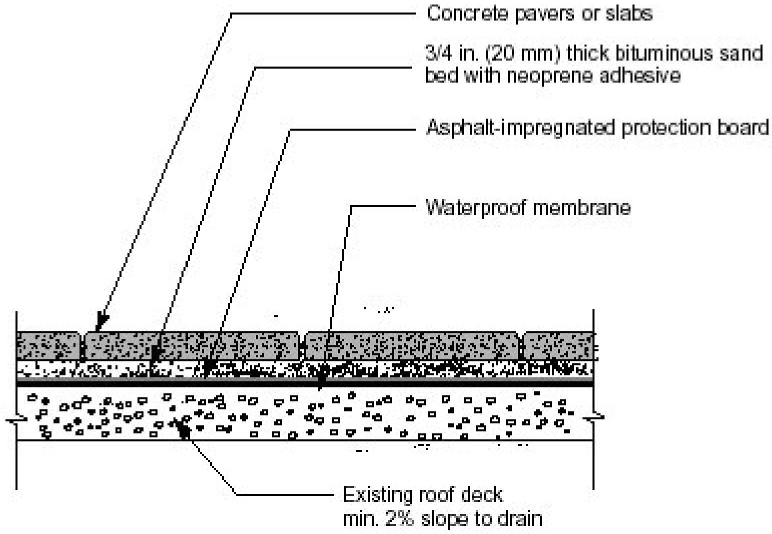

Figure 8. Neoprene adhesive on an asphalt-stabilized sand setting bed

Grading Requirements for ASTM No. 9 and ASTM No. 89 Bedding Materials		
Sieve Size	ASTM No. 9 Percent Passing	ASTM No. 89 Percent Passing
1/2 in. (12.5 mm)	–	100
3/8 (9.5 mm)	100	90 to 100
No. 4 (4.75 mm	85 to 100	20 to 55
No. 8 (2.36 mm)	10 to 40	5 to 30
No. 16 (1.18 mm)	0 to 10	0 to10
No. 50 (0.300 mm)	0 to 5	0 to 5

Table 2. ASTM No. 9 or 89 materials for the bedding material may be an advantageous alternative to some sands for vehicular and pedestrian applications

With any segmental paving system, the final, installed result should provide a smooth, stable, and even surface. For pedestrian plaza deck applications, lipping tolerances among adjacent paving units should be no greater than 1/8 in. (3 mm). Surface tolerances of the finished elevations should be no greater than ±1/8 in. (±3 mm).

Bedding and Joint Materials for Vehicular Applications--As with pedestrian plaza or terrace applications, bedding materials for vehicular applica tions need to freely drain water so that they do not become saturated. Again, an essential roof structure requirement is a 2% minimum slope. Parking decks with saturated bedding sand subjected to constant wheel loads will pump sand laterally or upward and out of the paving assembly. Joint sand is carried out as well, and loss of interlock follows. An unstable surface results where loose pavers receive damage (chipping and cracking) from continued wheel loads. Loss and lateral movement of bedding sand can result in dam age to and leaks in the waterproof membrane from loose paving units. In a few older, vehicular roof deck applications, there have been instances of bedding sand becoming clogged with fines over several years. The source of fines is likely from a combination of a lack of adequate slope, dirt deposited from vehicles and sometimes from degradation and wearing of the sand into finer material under constant traffic. The fines eventually accumulate in the bedding sand and slow drainage. To help prevent the bedding layer from becoming saturated or becoming clogged, bedding material with a coarser gradation than that shown in Table 1 may be advantageous for vehicular or pedestrian applications. An example is material conforming to the gradation of ASTM No. 9 or No. 89 aggregate (9). See Table 2. The void space in this aggregate can allow for movement and removal of fines. Joint sand should have sufficient coarseness such that it is does not vacate the joints by working its way down and into the bedding material. The bedding material gradation should overlap with that of ASTM C 33 or CSA A23.1 joint sand to help prevent it from working into the bedding sand.

Joint Sand Stabilization--Joint stabilization materials are recommended in sand-set roof appli cations for pedestrian and vehicular use. They are applied as a liquid or mixed dry with the joint sand and activated by moistening the joints with water. These materials reduce infiltration of water and ingress of fines brought to the surface by vehicles, and they achieve early stabilization of joint sand. Stabilization can help prevent the joint sand from being washed out by rainfall or blown out by winds. ICPI Tech Spec 5 Cleaning, Sealing and Joint Sand Stabilization of Interlocking Concrete Pavements offers further guidance on the types of joint stabilizers and their applications.

Neoprene adhesive with bitumen-sand bed-- This setting method typically involves applying an asphalt primer to the substrate and then placing a 3 / 4 in. (20 mm) (1 in. or 25 mm maximum) thick asphalt stabilized sand layer over it, followed by a neoprene adhesive. The sand asphalt mix is applied hot and compacted. The units are set into the adhesive after a dry skin forms and the joints are then filled with sand. Figure 8 provides a schematic cross-section. The waterproof membrane manufacturer should confirm compatibility of the primer, asphalt setting bed and adhesive with the membrane. Joint sand stabilizer can provide early stabilization of the joint sand. Cement mixed with sand to stabilize it in joints is not recom mended since the cement can stain the surface of the paving units. Drainage should be provided at roof drains as with sand-set assemblies. This includes holes in the sides of roof drains to remove water that collects below the paving units. Details on drains are discussed later.

Mortar--While it is not a common setting mate rial, a mortar bed (approximately 3:1 sand to cement) may be used to level and secure pavers or slabs. This setting method is not used over drainage mats. See Figure 9. Like a bitumen setting bed, mortar is costly to remove and replace should there be a need for roof maintenance. In addition, mortar deteriorates in freeze thaw climates, and especially when exposed to deicing salts. In ASTM C 270, Standard Specification for Mortar for Unit Masonry, the Appendices include a table on the Guide for the Selection of Masonry Mortars. While Type S is recommended, the guide states caution in selecting mortar for horizontal appli cations. While they are not foolproof, latex or epoxy modified mortars can reduce the onset of deteriora tion from freeze-thaw and salts making them accept able for some pedestrian applications. However, loading and environmental factors preclude the use of mortar-set paving units for vehicular applications, and this setting method is better suited for nonfreezing areas.

Geotextiles, Protection Board, Insulation and Drainage Mats
Geotextiles--With sand or aggregate bedding mate rials, geotextile will be needed to contain them and keep them from migrating into deck drains or through wall drains such as scuppers. In addition, sand or aggregate requires geotextile under it to pre vent loss into the protection board and insulation (if used). Geotextile manufacturers should be consulted on geotextile selection. The fabric should be turned up against drains, vents and other protrusions in the roof and along parapets and walls. To contain sand and aggregate bedding materials, the geotextile should extend up the side. Figure 10 shows this detail which will help prevent loss of bed ding materials from a deluge of rainfall that causes temporary ponding around the drains. A separate piece of geotextile is wrapped around the roof drain to prevent loss of bedding sand or aggregate.

Protection board--Most waterproofing systems require a protection board over them to prevent dam age to the waterproofing from paving units and to reduce thermal stresses from temperature changes. This can be an asphaltic protection board or other materials. The manufacturers of waterproofing sys tems can provide guidance on the use of protection layers and they can recommend specific materials when this option is required. Protection board is generally not used in vehicular applications.

Insulation--If a pedestrian plaza deck covers an inhabited space, insulation may be required. Insulation typically consists of foam or fiber boards placed over the waterproofing. Sometimes they are adhered direct ly to the waterproofing. Insulation may be tapered to roof drains to facilitate movement of water into the drains. Insulation board in contact with the waterproof membrane should have drainage channels to facilitate drainage of water under it. Insulation under pavers in vehicular applications requires careful design and execution. As with other engineered pavements, con sult an experienced designer familiar with these appli cations. A secure location for insulation is sandwiched in place inside the concrete deck.

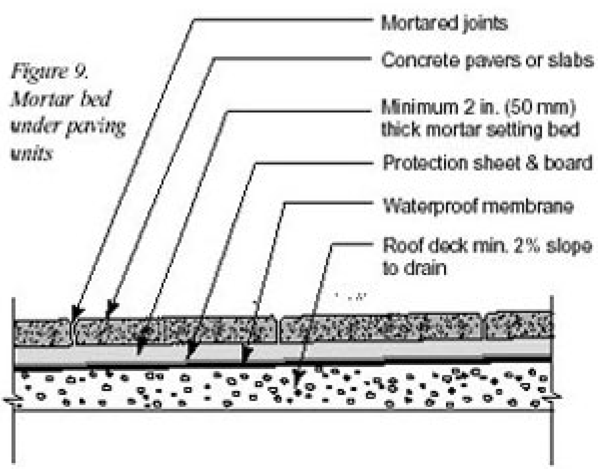

Figure 9. Mortar bed under paving units

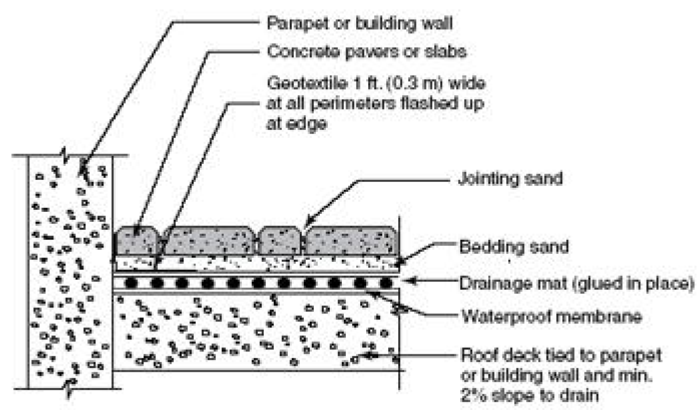

Figure 10. Detail showing geotextile at all edges of sand and aggregate bedding courses for a pedestrian application.

Drainage mats--Drainage mats are generally placed under bedding sand and over waterproof mem branes to accelerate drainage of water from the sand. Drainage mats are typically 1 / 4 to 3 / 8 in. (6 to 10 mm) thick. They consist of a plastic structure covered by geotextile. The structure and geotextile support and contain the bedding sand under the paving units while allowing water to move into it and laterally to roof drains. They are recommended in pedestrian applica tions under a sand setting bed. They should be placed at a minimum of 2% slope. Installation of drainage mats for pedestrian applica tions should start at the lowest slope on the roof with the work proceeding upslope. Flaps on each should go under the next (in a manner similar to placing roof shingles) so that the water drains from one section to the next. This helps prevent water from leaking under the mats. While mats reduce the amount of water reaching the waterproof membrane, they are not a substitute for deck waterproofing. The paving installa tion contractor should install mats. Drainage mats are typically supplied in rolls making them difficult to flatten, and they often don't remain flat during installation. An adhesive between the mat and waterproof membrane will likely be required to maintain flat drainage mats during their installation. Drainage mats can be used under foam or plastic pedestal systems. While drainage mats may be tested according to the compressive strength test method in ASTM D 1621 (10), they may require additional test ing by pre-loading to ensure that they will not crush under loads from the pedestals. Drainage mats should not be used under vehicles. Mats deflect under wheel loads, eventually fatiguing, compressing and deforming. Repeated deflection tends to shift the pavers, bedding and joint sand, making interlock difficult to maintain. The deflection causes the joint sand to work its way into the bed ding and the bedding sand shifts under loads, espe cially when saturated. The loss of joint and bedding sand, with possible eventual crushing of the mat, retains water and this can saturate the bedding sand.

Waterproof Membranes
The choice of waterproofing is influenced by the application, the project budget, the deck materials under it and the type of structure supporting the roof. There are three broad types of waterproofing materi als used under concrete paving units. They are sin gle-ply, liquid membranes, built-up or modified bitumen roofing. A brief description of these materi als follows with their compatibility to segmental paving (11,12).

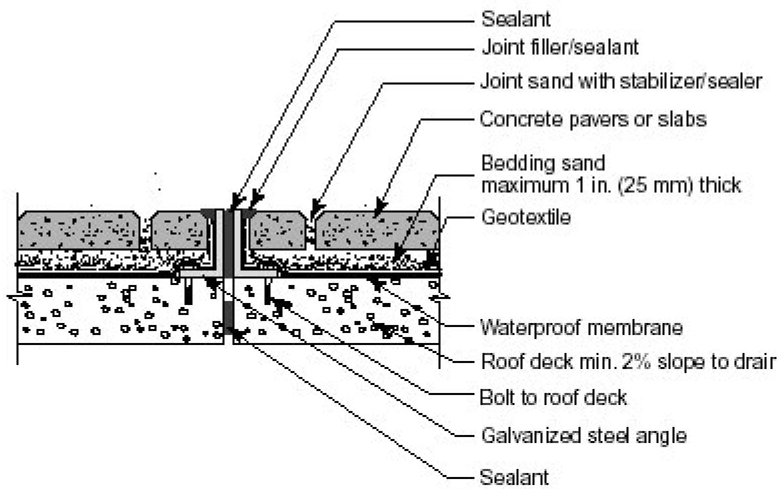

Figure 11. Edge restraint detail at a roof construction joint for pedestrian roof applications (14)

Single-ply roofing is strictly for pedestrian appli cations and it is the most widely used waterproofing. It is typically made from vulcanized (cured) elasto mers such as ethylene propylene diene monomer (EPDM), neoprene, or butyl. These flexible sheets have excellent weathering properties, high elongation and puncture resistance. When assembled on a roof, the sheets are spliced together at the job site with an adhesive. The entire assembly of sheets can be loose laid and ballast provided by paving units. They also can be partially or fully adhered, or mechanically fastened to the roof deck. Another type of single-ply membranes includes non-vulcanized elastomers such as polyisobutylene (PIB), chlorinated polyethylene (CPE), chlorosulfan ated polyethylene (CSPE). These materials are usually reinforced with a polyester mat laminated between two plies. Thermoplastics such as polyvinyl chloride (PVC) sheets are heat welded in the field. Like the elastomers, PVC is loose-laid with ballast paving units, partially or fully adhered, or mechanically fastened to the deck material. Rubberized asphalt membranes and polyethylene laminates have been used extensively to waterproof pedestrian plaza decks. Prefabricated sheets are made in small sheets and are spliced together in field. They generally are fully adhered to the concrete deck, so their longevity is highly dependent on the quality of the workmanship in splicing and on the smoothness and quality of the concrete. Manufacturers of single-ply membranes should be contacted about the extent of warranties on the field splices under paving units. Additional measures may be necessary to protect the splices from the paving. This can include installation of a second, sacrificial membrane layer directly under the paving units. Liquid applied membranes are installed either hot or cold depending on the materials. Rubberized asphalt membranes are hot applied to the concrete deck to form a continuous coating with no seams. These are for pedestrian plaza decks only. Cold applied liquid resins and elastomers such as polyure thane are generally suitable as waterproofing on con crete decks subject to vehicular use. Sprayed-in-place polyurethane foam acts as an insulator and as water proofing. The material is soft and is not recommended for use with concrete paving units. Built-up roofing is made from paper, woven fabric or glass fiber mats, polyester mats or fabrics adhered together in alternating layers with bitumen or coal tar. The exterior surface of the layers is covered with bitu men or coal tar. Built-up roofs use concrete pavers or slabs as a walking surface to prevent wear and punc ture of the membrane, especially around mechanical equipment. The use of pedestal systems should be avoided in built-up roofing due to the likelihood of indentations in the layered waterproofing materials. Modified bitumen consists of plastic or rubber additives pressed into asphalt sheets. They are installed by heating the sheets with a torch and applying them to the deck substrate, or by mopping bitumen and securing them to the substrate with it. Some systems use cold cement or mastics to adhere the sheets to the substrate. Some modified bitumen waterproofings create overlap "bumps" every yard (meter) or so. There can be an additional construction cost to avoid these when using a pedestal system. These systems do not require segmental paving ballast unless insula tion needs to be secured in place. While these sys tems are generally compatible with concrete paving units in pedestrian applications, manufacturers should be contacted for verification of use with paving units under vehicular traffic. Each of these waterproofing systems has advan tages and disadvantages on speed of installation, costs, durability and manufacturer warranties. Many water proof membrane manufacturers require the use of roofing contractors that have been certified to install a particular manufacturer's roofing system. The subject of roof waterproofing is large and outside the scope of this publication. There are many references on roofing and waterproofing systems. An overview is provided in Roofing--Design Criteria, Options, Selection (12). Other resources are publications by the National Roofing Contractors Association at http://www.nrca.net and the Roof Consultants Institute at http://www.rci-online.org.

Deck Structure Systems
Concrete--There are four types of concrete deck structural systems (11). They are reinforced concrete slabs, post-tensioned slabs, pre-stressed precast ele ments such as "T" beams with a concrete topping, and concrete poured onto and formed by steel decks. Each type responds to waterproofing differently. For example, volumetric changes in reinforced concrete slabs can cause reflective cracking in liquid-applied membranes and some fully adhered bituminous sys tems. Post-tensioned slabs are generally suited for liquid applied membranes because the slabs have a low amount of deflection and cracking. Loose-laid waterproofing systems are suited for over precast ele ments because they can accommodate the many joints in the deck, whereas liquid-applied and fully adhered membranes are prone to reflective cracking and splitting at joints. In lighter, less expensive roofs, the concrete deck is poured onto and formed by a corrugated steel deck. In some cases the concrete is lightweight, i.e., weighing less per cubic foot or cubic meter than ordinary ready mixed concrete. The weight of lightweight concrete is reduced

by using lighter aggregates and by air-entrain ing the concrete mix. Lightweight concrete reduces loads on the columns and beams, thereby reducing their size and expense. (See Reference 13 for further information on lightweight concrete.) Steel decks topped with concrete should be vented so that moisture can escape if waterproofed with liquid-applied or fully adhered materials. Some waterproofing manufacturers do not recommend use of their materials over light weight concrete.

Steel--Corrugated steel decks are generally cov ered with insulation and loose-laid single-ply membranes. This inexpensive assembly often uses ballast made with lightweight concrete paving units. These assemblies typi cally do not use heavier precast concrete pavers or paving slabs.

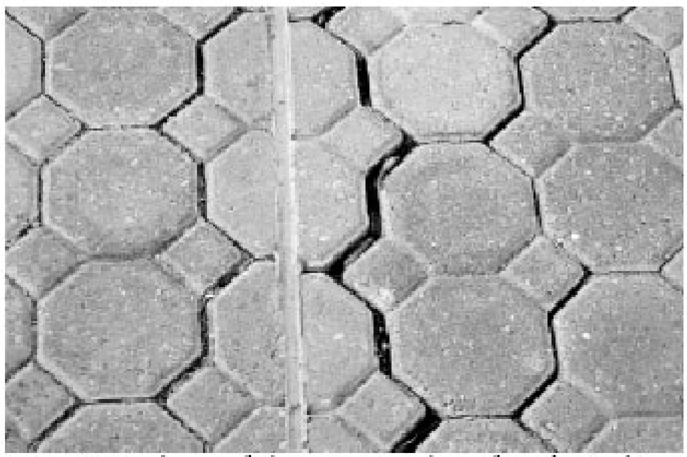

Figure 12. An absence of edge restraints and use of a sealant in this construction joint caused the pavers to shift and open their joints on both sides of the sealant.

Design Considerations

Detailing for movement for pedestrian applications--Roof joints should be located when there is a change in roof direction, dimension, height, material, or when there are extreme differ ences in humidity or temperature within a building. Most roof structures have joints that allow each part of the structure to move independently due to settlement, seismic activity and thermal expansion/contraction. There is usually a flexible sealant in the joint to prevent water from entering and leaking into the space below. The sealant can be a compression seal squeezed into the joint, or a more expensive and durable strip seal. A strip seal is a length of flexible material fastened to metal clips secured to the concrete deck. The strip seal flexes with the movement of the adjacent structures. Figure 11 illustrates a joint in a concrete struc ture and with sand-set paving units over it. Expansion joints should be treated as pavement edges. As with all segmental pavement construc tion, an edge restraint is required to hold the units together. Figure 11 shows steel angle restraint on both sides of the joint and secured to the concrete deck. There should be a compression seal at the top against the steel edge restraints, as well as one between the concrete decks. This detail is recom mended at roof expansion joints for pedestrian applications. This detail shows the paving pattern stopping at a joint in the deck and resuming on the opposite side. The sealant is joined to the edge restraint and not to the sides of the paving units. The use of a sailor or soldier course of pavers on both sides of the joint will present a clean visual break in the pattern. Figure 12 shows the consequences of not stopping the pattern with an edge restraint at an expansion joint. The pav ers separated and exposed the bedding sand and waterproof membrane. Parapets or building walls can typically serve as edge restraints. For sand-set paving assemblies, expan sion material should be placed between the outside edge of the pavers and vertical walls of buildings when functioning as separate structures from the deck on which the paving units rest. Figure 13 shows this detail with expansion material. It should not adhere to the paving units or the wall, but should independently expand and contract with their movement. Expansion materials at the perimeter of the pavers are not neces sary to place against walls or parapets when the pavers are resting on the same structure as the walls. Figure 10 illustrates this condition.

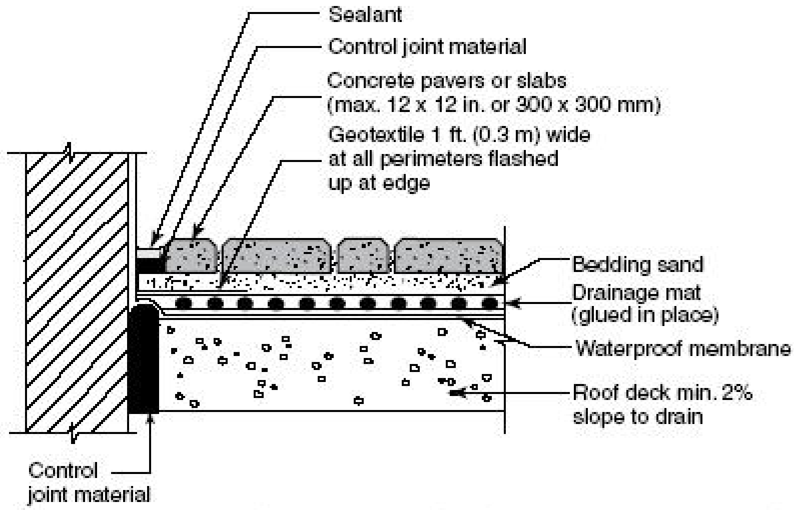

Figure 13. Detail at building wall not joined to decking using paving units and bedding sand with a drainage mat for pedestrian applications only

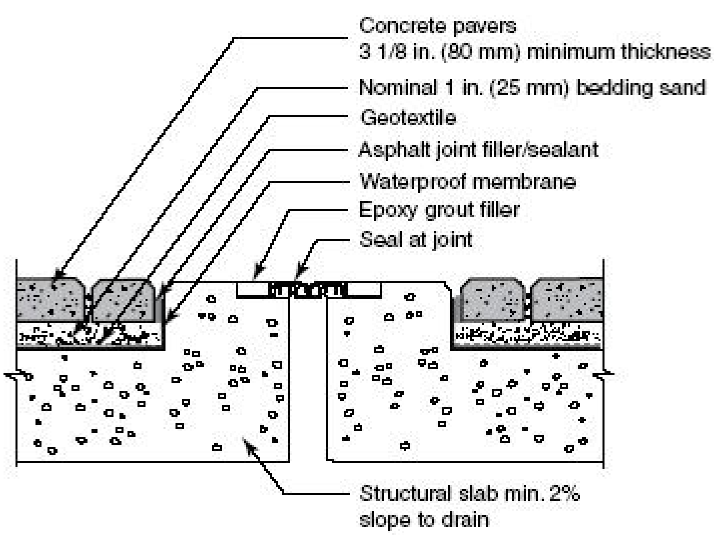

Figure 14. Edge restraint detail at a roof expansion joint for vehicular applications

Figure 15. An absence of holes in the sides of this roof drain led to ponding.

Detailing for movement for vehicular applications--Figure 14 details an expansion joint in a roof application subject to vehicles such as a parking struc ture. Although compression seals can be used, this assembly uses a strip seal for bridging the joint. The ends of the concrete deck are formed as edge restraints to hold the concrete pavers in place.

2 3 / 8 in. (60 mm) vs. 3 1 / 8 in. (80 mm) thick pavers for vehicular applications--Most vehicular applications with pavers are supported by a concrete structure. The support from such a structure is often is used as rationale for using pavers that are less than 3 1 / 2 in. (80 mm) thick.

Thicker units render greater vertical and rotational interlock. Using concrete pavers less than 3 1 / 2 in. (80 mm) thick in vehicular of applications increases the risk of reduced surface stability by reduc ing horizontal and rotational interlock under turning and braking vehicles.

Weight--Concrete pavers, slabs and bedding materials exert substantial weight on roof structures. The structure supporting these materials should with stand dead and live loads. The advice of a structural engineer should be sought to assess the capacity of the roof and tolerable deflections from paving-related loads especially when units are added to an existing roof deck structure. The weight of paving units can be obtained from manufacturers for the purposes of cal culating loads. Bedding sand (1 in. or 25 mm thick) weighs approximately 10 lbs. per sf (49 kg/m *2*).

Resistance to wind uplift--The designer should consult Loss Prevention Data for Roofing Contrac tors Data Sheets published by Factory Mutual (FM) Engineering Corporation (15). Data Sheets 1-28 and 1-29 provide design data including the minimum pounds per square foot (or kg/m *2*) of paving unit weight required for resistance to wind uplift. The FM charts consider wind velocity pressure on roofs at various heights in different geographic locations. Design pressures are then compared to the type of roof construction, parapet height and the whether the pav ing units have tongue-and-groove, beveled joints, or are strapped together. Some high wind regions may have local building codes with additional weight requirements for paving units, especially on high-rise buildings.

Slope for drainage--A flat or "dead level" roof, i.e., one with no pitch, should never be designed. A dead level roof does not drain, creating a high risk of leaks in the waterproofing, as well a potential satura tion of bedding sand (when used). The membrane will be exposed to continual standing water and ice that accelerates its deterioration and increases the potential for leaks. Likewise, paving units and bedding materi als in constantly standing water subject to many freeze and thaw cycles will experience a decrease in their useful life. Regardless of the deck substrate, it should be built with a minimum 2% slope to drain. This may be dif ficult to achieve with certain decks sloping toward area drains and some decks are built flat and then a topping applied to achieve slopes. The designers should take every opportunity to use deck systems that enable construction of a minimum 2% slope as some toppings are not waterproof and flat roofs will eventually leak.

Slopes for pedestrians and vehicles --The maximum slope is constrained by the need for a com fortable walking surface and the maximum percentage is typically 8% (4.5°). For driving surfaces, the maxi mum recommended slope should not exceed 20% (11°) and ideally should not exceed 8% as such sur faces often will often see pedestrian use. For slopes exceeding 4% with exposure to vehicles, consideration should be given to using bituminous-set rather than sand set systems.

Roof drains--Depending on the design, roofs are drained at their edges and/or from the interior with roof drains. When roofs decks are loaded with dead and live loads, they will deflect. Continual deflection over time results in deformation of the roof. This movement can make drain inlets or scuppers adjacent to columns or on frame lines at the perimeter the highest points of the roof. Therefore, sufficient pitch to the roof that accounts for such deflections is essential to continual drainage. In addition, the surface of the paving should be a minimum of 3 / 16 in. (5 mm) above the inlet of roof drains. When sand or aggregate is used for bedding or fill, it is essential that holes be in the sides of drains to allow water to escape the bedding sand. The bottom of the holes should be at the same elevation as the top of the waterproof membrane. As previously noted, drains should be wrapped in geotextile to prevent loss of bed ding material through the drain holes. Figure 15 illustrates ponding around a parking deck roof drain that didn't have drain holes in its sides to drain subsurface water. Figures 16 and 17 illustrate a possible drain solution with holes for a pedestrian roof and parking deck. For paving slabs with pedestals, the slabs generally are located over roof drains, or are cut to fit around drains (see Figure 5). Bitumen-set assem blies require holes in the sides of the drains to remove water that may collect below the paving units. Bitumen and neoprene must not be allowed to clog roof drains or holes on their sides during installation.

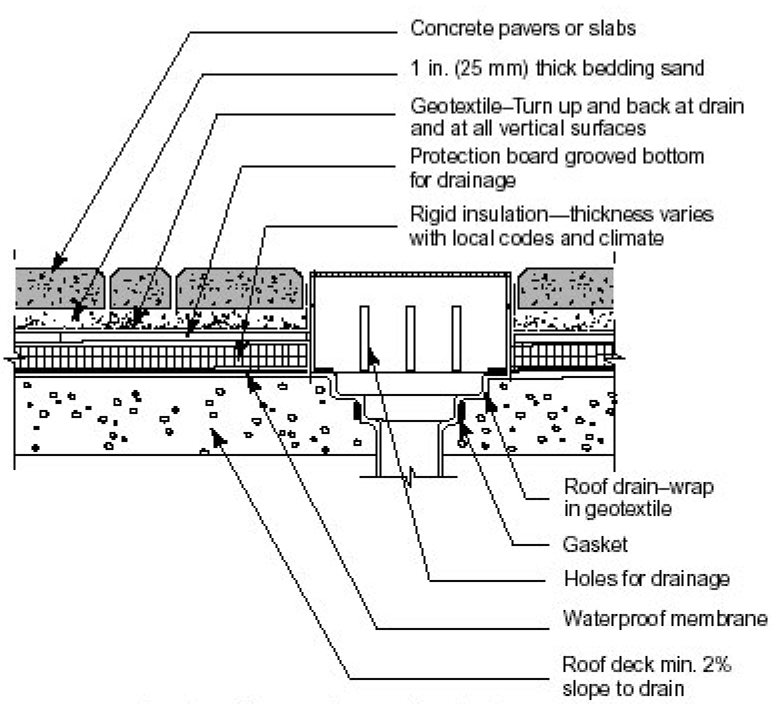

Figure 16. A drain detail for a pedestrian plaza deck over habitable space.

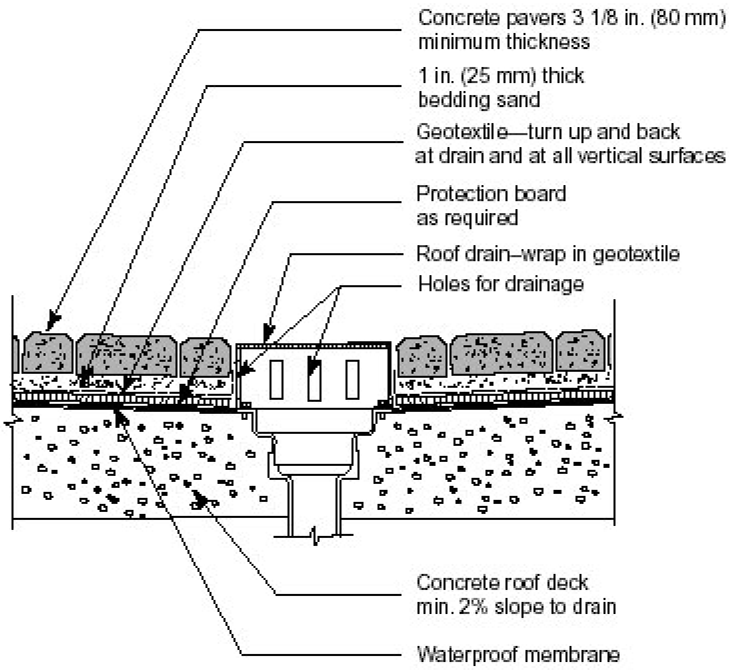

Figure 17. A drain detail on a vehicular roof application.

Raising elevations--New and rehabilitated roofs may require fill material for raising the paved surface so it conforms to adjacent elevations. The deck surface receiving the fill material should slope a minimum of 2%. Fill materials are typically concrete, asphalt, or open-graded base. The structure should be evaluated first by a structural engineer for its capability in taking the additional load. Lightweight concrete may be con sidered if there are load limitations. These fill materials are often placed over a water-proof membrane. Consideration should be given to using insulation and protection board over the waterproof membrane. Attention in detailing and during construction should be given to how the fill materials will meet vents, skylights and other protrusions in the roof without damage to them, their flashing, or to their water proofing. Open-graded bases will require geotextile under them to contain them. The fabric should cover all sides of the base. Dense-graded aggregate base fill materials are not recommended since water can collect at the bottom of the base and soften it. Over time, this condition can increase the potential for deformation of the base under repeated vehicular wheel loads. In addition, aggregate base materials can shed fine particles that, over time, can clog geotextiles and drains. Concrete, asphalt, or open-graded bases are preferred as fill materials since they do not deform when continually exposed to water. In addition, they seldom shed parti cles into the roof drains so they present a much lower risk of clogged geotextile and drains. Due to its high temperature at application, asphalt may not be compatible with some waterproof mem branes, insulation, or protection board. All fill materi als should be reviewed with the manufacturer for compatability with these components. Other important considerations are the minimum thickness to which the fill materials can be applied without cracking and deterioration from freeze-thaw cycles and salts. The design and selection of fill materials should address movement from temperature changes, vibration (if exposed to vehicles) and seismic activity.

Figure 18. A mechanical screed used to level bedding sand on a roof parking deck project.

Figure 19. Mechanical equipment used to install concrete pavers on a roof deck.

Construction Considerations
Low slope roofs and waterproofing systems are gen erally installed by a specialty roofing subcontractor. A second subcontractor specializing in the installa tion of segmental paving supplies and installs bed ding materials, pedestals, pavers or slabs after the waterproofing is placed by the roofing contractor. Installation of protection board and/or drainage mat may be by the paving contractor or roofing contrac tor depending on the project specifications. Testing of the waterproofing for leaks and any repairs should be completed prior to starting the paving.

Job Planning--Roof jobs are typically built in a very limited space. There will be an additional expense of moving the paving units from the ground to the roof. Most roofs may not have space to store cubes of pavers and stockpiled sand, and if they did, they most likely do not have the structural capacity to withstand their concentrated weight. The advice of a structural engineer should be should be sought on assessing the maximum load capacity of the roof to safely support the weight, packaging and distribution of all materials deliv ered to the roof, or a crane used to lift them from the exterior. Forecasting delivery time for moving pavers to the roof, as well as sand, ped estals, saw(s), tools, geotextile and crew to the roof is a critical to accurately esti mating roof projects. Labor functions and costs must be tracked on each proj ect for use in future bids. For example, additional time and expense may arise from the need for the paving contractor to place temporary protection on the waterproof membrane to prevent damage during construction. A one-story parking garage may allow all materials to be driven onto and delivered quickly to the roof. A multi-story parking garage with pavers on the top floor may have a 6 ft - 6 in. (2 m) ceiling height that will not allow delivery of pavers and sand in large trucks. Trucks with a low clearance will be needed to move materials through the structure and to the roof, or craned to the roof. The packaging of most concrete pavers and slabs allows their transport to the roof via elevator or crane during construction. Roof access, construction scheduling, the capacity of the roof to withstand loads from packaged materials, and reduction of labor costs will dictate the economics of using a crane to transport materials to the roof. The roofing contractor often handles this. In some cases, an elevator may be the only means of transport. An example of using only an elevator to move crews, tools and materials was to the observation deck on the 86th floor of the Empire State Building in New York City (Figure 1) where the deck was rehabilitated with concrete pavers. The layout of paving slabs can be more demanding than the layout of interlocking concrete pavers. Some designers prefer joint lines to be located in particular places such as centered at columns or staircases. Careful planning of the layout will spare wasted cuts and adjusting the pattern on site to conform to the drawings and design intent. Sometimes railing posts along the perimeter of a roof may require coring holes in paving slabs to fit around them. In addition, paving units may need to be cut to fit against moldings and other protrusions from parapets. The location of the pattern and cutting should be anticipated in advance of the construction.

Figure 20. Vacuum assisted mechanical equipment for installing paving slabs.

Installation of bedding sand--After placing the geotextile, the bedding sand is screeded using screed bars and a strike board to 1 in. (25 mm) thickness. Mechanical screeders may be used on large deck jobs as shown in Figure 18. This shows 40,000 sf (3,715 m 2) of pavers on a concrete parking deck next to a condominium housing project. Once the bedding sand is screeded, the pavers are compacted into the bedding sand. Sand is spread, swept and vibrated into the joints with at least two passes of a plate compactor. Excess sand is removed upon completion of compacting. For larger than 12 in. x 12 in. (300 mm x 300 mm) slabs, bitumen or pedestals are recommended as the preferred setting methods rather than a sand bed. If placed on bedding sand, larger slabs tend to tip and tilt when loads are placed on their corners. Pedestals and bitumen are more stable assemblies for pedestrian applications. When compacting paving slabs with a plate compactor, using "add-on" rollers on this equipment should be considered to help eliminate risk of damage. Some jobs may require slabs to completely cover the roof right up to the parapets and protruding vents. If full slabs do not fit next to vents and parapets, the slabs are saw cut and placed on pedestals next to them.

Mechanical installation--Roof decks can be built by mechanically placing the paving units. Figure 19 shows a parking deck being installed with mechan ical equipment. Slabs can be installed with vacuum equipment that relies on suction to grab and place each unit. See Figure 20. For most jobs, these kinds of equipment can not run directly on the waterproofing. They must run over installed concrete pavers. Therefore, a starting area of pavers may need to be placed by hand and the equipment placed on it to continue the paving. Further information on mechanical installation is found in ICPI Tech Spec 11--Mechanical Installation of Interlocking Concrete Pavements. Regardless of the installation method, all federal, provincial, state and local worker safety rules should be followed for fall protection of crews working on roofs.

Figure 21. The plaza area around Scope Center in Norfolk, Virginia, (left) and one side of the Alamo Dome (right) in San Antonio, Texas, include roof plaza decks surfaced with concrete pavers.

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A Guide for The Construction of Mechanically Installed Interlocking Concrete Pavements

This Tech Spec does not include material or installation guidelines for permeable interlocking concrete pavement (PICP) installations. See the ICPI manual Permeable Interlocking Concrete Pavements, available at ICPI.org.

Introduction

This guide is intended to assist design professionals in developing a construction specification for the mechanical installation of interlocking concrete pavement. The core is the Quality Control Plan that requires a high level of planning and detail for executing large-scale projects. When refined into a project specification, it should be a tool to obtain a commitment to its requirements by the General Contractor (GC), paver installation subcontractor, manufacturer, and facilitate coordination among them. The ultimate outcome is increased assurance for owners of large paved facilities. The set of contractual relationships among the owner, Engineer, GC, subcontractors, and manufacturers (suppliers) will vary with each project. This guide assumes that an Engineer works for the owner who hires a GC to build the project. The GC subcontracts to a company specializing in interlocking concrete paving. The GC or subcontractor purchases pavers from a paver manufacturer. The Engineer or other employees working for the owner inspect and accept the paving. Construction specifications in North America follow various formats. A common one is set forth by the Construction Specifications Institute (CSI) called MasterFormat (2004) and this guide is written to fit this format. Specifications using the CSI format sections have three parts; General, Products, and Execution. This guide is divided into these three parts to assist in writing each.

1.0 PART 1--GENERAL This specification guide includes the installation of interlocking concrete pavers with mechanical equipment, bedding and joint sand and optional joint sand stabilization materials. ICPI Tech Spec 11Mechanical Installation of Interlocking Concrete Pavements (ICPI 1998) should be consulted for additional information on design and construction with this paving method. Other references will include American Society for Testing and Materials and the Canadian Standards Association for the concrete pavers, sands, and joint stabilization materials, if specified. Other subcontractors or the GC provides the base, drainage, and earthwork.

Figure 1. Mechanical installation of interlocking concrete pavements (left) and permeable units (right) is seeing increased use in industrial, port, and commercial paving projects to increase efficiency and safety.

1.1 Definitions
This guide sets forth definitions so all project participants use the same terms within the specification: Figure 1. Mechanical installation of interlocking concrete pavements (left) and permeable units (right) is seeing increased use in industrial, port, and commercial paving projects to increase efficiency and safety.

Base: Layer(s) of material under the wearing course and bedding course.

Bedding course: A screeded sand layer on which the pavers are bedded.
Bundle: Paver clusters stacked vertically, bound with plastic wrap and/or strapping, and tagged for shipment to and installation at the site. Bundles of pavers are also called cubes of pavers. Concrete paver bundles supplied without pallets are strapped together for shipment then delivered and transported around the site with clamps attached to various wheeled equipment. The Subcontractor may provide some wooden pallets at the site to facilitate movement of bundles. See Figure 2.
Chamfer: A 45 o beveled edge around the top of a paver unit nominally 2 to 6 mm wide.
Cluster: A group of pavers forming a single layer that is grabbed, held and placed by a paver-laying machine on a screeded sand bedding course.
Interlock: Frictional forces between pavers which prevent them from rotating, or moving horizontally or vertically in relation to each other.
Joint: The space between concrete pavers typically filled with sand.
Joint filling sand: Sand used to fill spaces between concrete pavers.
Joint sand stabilizer: Liquid applied materials penetrate the in-place joint sand or an additive is mixed dry with sand prior to filling the joints. Joint sand stabilization materials are optional and may be of value in certain applications.
Laying face: Working edge of the pavement where the laying of pavers occurs.
Wearing course: Surfacing consisting of interlocking concrete pavers and joint sand on a sand bedding layer.
Wearing surface: The top surface that contacts traf- fic whose edges are typically chamfered.

Figure 2. Bundles of ready-to-install pavers for setting by mechanical equipment. Bundles are often called cubes of pavers.

Figure 3. A cluster of pavers (or layer) is grabbed for placement by mechanical installation equipment. The pavers within the cluster are arranged in the final laying pattern as shown under the equipment.

Development and implementation of the Quality Control Plan is a joint effort by the project engineer, the GC, the paver installation subcontractor, material suppliers and testing laboratories.

1.2 Submittals
The following is submitted by the GC to the Engineer for review and approval:

1. 14 pavers with the date of manufacture marked on each. These can be made available for testing.
2. Manufacturer's catalog cut sheets and production mold drawings.
3. The pattern for joining clusters when the pavers are placed on the bedding sand.
4. 6 lbs. (3 kg) bedding sand.
5. 6 lbs. (3 kg) joint filling sand.
6. Manufacturer's catalog cut sheets of joint stabilization material (if specified).
7. 1 quart (liter) joint sand stabilizer or joint sand additive (if specified), or 2 lbs. (1 kg) joint sand stabilizer additive.
8. Quality Control Plan.

1.3 Quality Control Plan

The GC provides the Engineer, paver installation subcontractor, and manufacturer with a Quality Control Plan describing methods and procedures that assure all materials and completed construction submitted for acceptance conform to contract requirements. The Plan applies to specified materials procured by the GC, or procured from subcontractors or manufacturers. The GC meets the requirements in the Plan with personnel, equipment, supplies and facilities necessary to obtain samples, perform and document tests, and to construct the pavement. The GC performs quality control sampling, testing, and inspection during all phases of the work, or delegates same, at a rate sufficient to ensure that the work conforms to the GC requirements. The Plan is implemented wholly or in part by the GC, a subcontractor, manufacturer, or by an independent organization approved by the Engineer. Regardless of implementation of parts of Plan by others, its administration, including compliance and modification, remains the responsibility of the GC. The Plan should be submitted to the Engineer at least 30 days prior to the start of paving. The GC, paving Subcontractor, and Manufacturer then meet with the Engineer prior to start of paving to decide quality control responsibilities for items in the Plan. The Plan includes:

1. Quality Control organization chart with the names, qualifications, and contact information of responsible personnel, and each individual's area of responsibility and authority.
2. A listing of outside testing laboratories employed by the GC and a description of the services provided and the tests performed by GC personnel.
3. Preparation and maintenance of a Testing Plan containing a listing of all tests to be performed by the GC and the frequency of testing.
4. Procedures for ensuring that tests are conducted according with the Plan including documentation and steps for taking corrective actions if materials do not meet criteria for meeting the standards.
5. The paver installation Subcontractor's method statement.

1.3.1 Quality Control Plan Elements

Testing--Independent testing laboratories typically are involved in testing sand and concrete pavers. They should have in-house facilities for testing bedding and joint sands. The laboratory should provide a letter certifying calibration of the testing equipment to be used for the specified tests. Upon approval of the Engineer, the laboratory performs testing of sand and paver samples prior to commencement of paving to demonstrate their ability to meet the specified requirements. Paver Manufacturer--The paver manufacturer provides evidence of capability to manufacture interlocking concrete pavers. Information may include a history of supplying projects of similar application and size, with project references and contact information in writing for verification. Personnel and qualifications may be part of the submission. The project history and references should demonstrate ability to perform the paver installation and related work indicated in the plans and specifications to the satisfaction of the Engineer. The submission should include a description of the manufacturer's ability to make, cure, package, store and deliver the concrete pavers in sufficient quantities and rates without delay to the project. Evidence can include diagrams and photos showing the number and stacked height of pavers on pallets, or in bundles without pallets, banding of the pavers, use and placement of plastic wrap, pallet dimensions and construction, and overall loaded pallet or bundle dimensions. Transportation planning for timely delivery of materials is a key element of large interlocking concrete pavement projects. Therefore, the manufacturer should include a storage and retrieval plan at the factory and designate transportation routes to the site. In addition, there is a description of the transportation method(s) of pavers to the site that incurs no shifting or damage in transit that may result interference with and delay of their installation. The manufacturer's portion of the quality control plan includes typical daily production and delivery rates to the site for determining on-site testing frequencies. A key component is the plan is a method statement by the manufacturer that demonstrates control of paver dimensional tolerances. This includes a plan for managing dimensional tolerances of the pavers and clusters so as to not interfere with their placement by paving machine(s) during mechanical installation. The contents of this plan include, but are not limited to the following:

1. Drawings of the manufacturer's mold assembly including overall dimensions, pattern, dimensions of all cavities including radii, spacer bars, and the top portion of the mold known as a head or shoe.
2. If a job is large enough to require more than one mold, the actual, measured dimensions of all mold cavities need to be recorded prior to manufacture of concrete pavers for this project. This is needed because the new or used production molds may vary in overall cluster size. Mixing pavers from a larger mold with a smaller mold may cause installation problems.
3. Molds will wear during manufacture of pavers. Production mold wear is a function of the concrete mix, mold steel, and production machine settings. A manufacturer can control by rotating the molds through the production machine(s) on an appropriate schedule so that all molds experience approximately the same amount of wear on the inside of the mold cavities. The manufacturer can also hold a larger mold out of the rotation until the smaller (newer) molds wear sufficiently to match its size. An initial, baseline measurement of all mold cavities provides starting point for documenting and planning for mold cavity growth.
4. The manufacturer should state the number of molds and a mold rotation plan with a statement of how often mold cavities will be measured during production, as well as the method of recording and reporting, and the criteria for mold rotation. While mold cavity wear will vary depending on a number of factors, approximately 0.1 mm wear of the mold cavities can typically be expected for every 10,000 cycles. Production records for each bundle should show the date of manufacture, a mix design designation, mold number, mold cycles and sequential bundle numbers.

A large variation in cluster size can reduce mechanized paving productivity, thereby increasing costs and lengthening production schedules. Extreme variations in cluster size can make mechanical installation impossible. Following certain procedures during manufacture will reduce the risk of areas of cluster sizes that will not fit easily against already placed clusters. Such procedures include (1) consistent monitoring of mold cavity dimensions and mold rotation during manufacture, (2) consistent filling of the mold cavities, (3) using a water/cement ratio that does not cause the units to slump or produce "bellies" on their sides after the pavers are released from the mold, and (4) moderating the speed of production equipment such that pavers are not contorted or damaged. All of these factors are monitored by regular measurement of the cluster sizes by the manufacturer and the subcontractor. It is essential that at least two identical jigs be used to check cluster dimensions, one in the paver production plant and the second on the job site. The manufacturer should provide these two jigs. The jigs should check the overall length and width of assembled, ready-to-place clusters. The sampling frequency should provide at least a 95% confidence level and the frequency should be agreed upon in writing by the owner, GC, subcontractor and manufacturer. In no case should the "stack test" be used as a means for determining dimensional consistency. This test consists of stacking 8 to 10 pavers on their sides to indicate square sides from a stable column of pavers, or leaning and instability due to bulging sides or "bellies." It is a test for checking for bellied pavers, thereby providing a quick field determination of the possibility of pavers that may not be capable of being installed with mechanical equipment. It is an early warning test to indicate the possibility of installation problems from bellied pavers (Probst 1998). The stack test is not reliable and should not be substituted for actually measuring the pavers to see if they meet specified tolerances. The mold pattern, the mold rotation plan and the anticipated mold wear information should be reviewed and submitted by both the manufacturer and the paver installation subcontractor. This is necessary to insure that they have a common understanding and expecta- tions. The subcontractor's quality control procedures include, but are not limited to the following:

1. Demonstrate past use of mechanical installation by key staff on single projects having a similar application and loads.
2. Provide mechanical installation project history including references in writing with contact information for verification. The history and references should demonstrate ability to perform the paver installation and related work indicated in the plans and specifications to the satisfaction of the Engineer.
3. List the experience and certification of field personnel and management who will execute the work.
4. Provide personnel operating mechanical installation and screeding equipment on job site with prior experience on a job of similar size.
5. Report methods for checking slope and surface tolerances for smoothness and elevations.
6. Show a means for recording actual daily paving production, including identifying the site location and recording the number of bundles installed each day.
7. Show diagrams of proposed areas for storing bundles on the site, on-site staging of storage and use, and the starting point(s) of paving the proposed direction of installation progress for each week of paving. These should be made in consultation with the GC as site conditions that effect the flow of materials can change throughout the project.
8. Provide the number of paver installation machines to be present on the site, and anticipated average daily installation rate in square feet (m^2).
9. Provide a diagram, including dimensions, of the typical cluster or layer to be used.
10. Provide a diagram of the laying pattern used to join clusters including a statement about or illustration of the disposition of half-pavers, if any.
12. The subcontractor and manufacturer are encouraged to hold memberships in the Interlocking Concrete Pavement Institute.

1.4 Mock-Up

A requirement for a test area or mock-up may or may not be included in the project specification documents. If required in the specifications, the mock-up shall serve as an example of compliance with the construction documents. The mock-up may be constructed prior to the start of construction or may be part of the first days work. The mock-up:

1. Install a minimum of 10 ft x 10 ft (3 x 3 m) paver area.
2. Use this area to determine the surcharge of the bedding sand layer, joint sizes, lines, laying pattern(s), color(s) and texture of the job.
3. Evaluate the need for protective pads when compacting paving units with architectural finishes.
4. This area will be used as the standard by which the work will be judged.
5. Subject to acceptance by owner, mock-up may be retained as part of finished work.
6. If mock-up is not retained, remove and properly dispose of mock-up.

Although a mock-up can be a valuable tool, it does not guarantee workmanship or quality. A collaborative effort between the contractor, specifier and owner is the best way to assure a successful project. A site visit and inspection of the installation during the first day of paving is often a much better solution to a mock-up from financial and expediency perspectives. In either case, the owner's representative shall provide the contractor with a written statement of approval.

1.5 Delivery, Storage And Handling

All required testing for products or materials should be completed and the results submitted in writing for approval by the Engineer prior to delivery of that product or material to the site. Materials should arrive at the site with no damage from hauling or unloading, and be placed on the site according the Quality Control Plan. Each bundle of pavers should be marked with a weatherproof tag that includes the manufacturer, the date of manufacture, the mold number, the project (or project phase), for which the pavers were manufactured, and the sequential bundle number. The sequential number should be applied to the bundle based on the manufacturing run for the job, not on the order of delivery. Any breaks in numbering should be reported immediately by the manufacturer to the subcontractor, GC and engineer in writing. Bedding and joint sand delivered to the site should be covered and protected from wind and rain. Saturated bedding cannot be installed because it will not compact. Environmental conditions precluding installation are heavy rain or snowfall, frozen granular base, frozen sand, installation of pavers on frozen sand, and conditions where joint sand may become damp so as to not readily flow into the joints.

2.0 PART 2--PRODUCTS

2.1 Concrete Pavers

In North America, concrete pavers should meet ASTM C 936 (ASTM 2006) in the United States or CSA A231.2 (CSA 2006) in Canada. Besides supplier information, the color(s), plus the exact length, width, and height dimensions of the units should be stated. Spacer bars are required for mechanical installation and are not included in the overall dimensions. Spacer bars should protrude from the side of the paver a distance equal to the minimum allowable joint width. See Figure 4. ASTM C 936 includes the following require- ments:

1. Absorption: 5% average with no individual unit greater than 7% per ASTM C 140 (ASTM 2001).
2. Abrasion resistance: No greater volume loss than 0.92 $in.^3$ (15 cm^3) per 7.75 $in.^2$ (50 cm^2) and average thickness loss shall

not exceed 0.118 in. (3 mm) when tested in accordance with Test Method ASTM C 418 (ASTM 2005).
3. Compressive strength: Average 8,000 psi (55 MPa), with no individual unit below 7,200 psi (50MPa) when tested according to ASTM C 140. If whole pavers are tested, an adjustment factor should be multiplied by the tested compressive strength per the table below to compensate for the height of the unit (BS 6717 1993):

Nominal Thickness	Multiply Tested Compressive Strength by
3 1/8 in. (80 mm)	1.18
4 in. (100 mm)	1.24
4 3/4 in. (120 mm)	1.33

If cut, cube-shaped coupons are tested, use the 55 MPa and 50 MPa values regardless of the initial dimensions of the paver from which the coupon was cut. CSA A231.2 includes the following requirements:

1. Compressive strength: Average 7,200 psi (50 MPa) at 28 days with no individual unit less than 6,500 psi (45 MPa) . The CSA test method for compressive strength tests a cube-shaped specimen. This method eliminates differences in compressive strength resulting from various thicknesses of pavers.
2. Freeze-thaw deicing salt durability: average weight loss not exceeding 225 g/m 2 of surface area after 28 cycles or 500 g/m 2 after 49 cycles. This requirement can be omitted for projects not subject to deicing salts. However, the test method and criteria should be applied to all projects in North America subject to deicing salts, and not just those in Canada. (The freeze-thaw test and requirements in ASTM C 936 do not include deicing salt durability. Therefore, it is not a requirement in this guide specification.)

Figure 4. Spacer bars are small nibs on the sides of the pavers that provide a minimum joint spacing into which joint sand can enter.

The CSA freeze-thaw deicing salt test for freezethaw durability requires several months to conduct. Often the time between manufacture and time of delivery to the site is a matter of weeks or even days. In such cases, the Engineer may consider reviewing freeze-thaw deicing salt test results from pavers made for other projects with the same mix design. These test results can be used to demonstrate that the manufacturer can meet the freeze-thaw durability requirements in CSA A231.2. Once this requirement is met, the Engineer should consider obtaining freeze-thaw deicing salt durability test results on a less frequent basis than stated here. Sometimes the project schedule requires that pavers be delivered to a job site prior to 28 days. If that is the case, the manufacturer can develop strength-age curves to demonstrate the relationship of compressive strength at 3, 7, or 14 days with respect to what the strength will be at 28 days. This should be submitted to the Engineer before the start of the project. Under no conditions should the pavers be opened to container handling equipment prior to achieving their 28-day compressive strength. A key aspect of this guide specification is dimensional tolerances of concrete pavers. For length and width tolerances, ASTM C 936 allows ± 1 / 16 in. (±1.6 mm) and CSA A231.2 allows ±2 mm. These are intended for manual installation and should be reduced to ±1.0 mm (i.e., ±0.5 mm for each side of the paver) for mechanically installed projects, excluding spacer bars. Height should not exceed ± 1 / 8 in. (±3 mm) from specified dimensions. Dimensions should be checked with calipers.

Table 1

Grading Requirements for Bedding Sand			
ASTM C 33		CSA A23.1-FA1	
Sieve Size	Percent Passing	Sieve Size	Percent Passing
3/8 in.(9.5 mm)	100	10 mm	100
No. 4 (4.75 mm)	95 to 100	5 mm	95 to 100
No. 8 (2.36 mm)	85 to 100	2.5 mm	80 to 100
No. 16 (1.18 mm)	50 to 85	1.25 mm	50 to 90
No. 30 (0.600 mm)	25 to 60	0.630 mm	25 to 65
No. 50 (0.300 mm)	10 to 30	0.315 mm	10 to 35
No. 100 (1.150 mm)	2 to 10	0.160 mm	2 to 10
No. 200 (0.075 mm)	0 to 1	0.075 mm	0 to 1

Note: ASTM C33 does not specify the percent passing the No. 200 (0.075 mm) sieve. CSA A23.1 allows up to 3% passing the No. 200 (0.075 mm) sieve. The above grading requirement for this sieve are modifications of these standards.

Table 2

Grading Requirements for Joint Filling Sand			
ASTM C 144		CSA A179	
Sieve Size	Percent Passing	Sieve Size	Percent Passing
No. 4 (4.75 mm)	100	5 mm	100
No. 8 (2.36 mm)	95 to 100	2.5 mm	90 to 100
No. 16 (1.18 mm)	70 to 100	1.25 mm	85 to 100
No. 30 (0.600 mm)	40 to 75	0.630 mm	65 to 95
No. 50 (0.300 mm)	10 to 35	0.315 mm	15 to 80
No. 100 (0.150 mm)	2 to 15	0.160 mm	0 to 35
No. 200 (0.075 mm)	0 to 10	0.075 mm	0 to 10

Note: The allowable maximum percent passing the No. 200 (0.075 mm) sieve may need to be decreased to allow for penetration of joint sand stabilizer. Test penetration depths on the site mock up area of paving.

2.1.1 Quality Assurance Testing

An independent testing laboratory typically conducts tests on the pavers and sands. The General Conditions of the Contract (typically found in Division 01 of the project manual) may specify who pays for testing. It is recommended that the GC be responsible for all testing. All test results should be provided to the Engineer, GC, subcontractor, and manufacturer, and within one working day of completion of the tests. All should be notified immediately if any test results do not meet those specified. The independent testing is intended for project quality assurance. It does not replace any testing required for quality control during production. For the initial testing frequency, randomly select 14 full-size pavers from initial lots of 25,000 sf (2,500 m 2) manufactured for the project, or when any change occurs in the manufacturing process, mix design, cement, aggregate or other materials. 25,000 sf (2,500 m 2) approximates an 8-hour day's production by one paver manufacturing machine. This can vary with the machine and production facilities. This quantity and the sample size should be adjusted according to the daily production or delivery from the paver supplier. Consult the paver supplier for a more precise estimate of daily production output. Initial sampling and testing of pavers should be from each day's production at the outset of the project to demonstrate consistency among aggregates and concrete mixes. Testing includes five pavers for dimensional variations, three pavers for density and absorption and three pavers for compressive strength (and three pavers for freeze-thaw durability if required). If all tested pavers pass all requirements for a sequence of 125,000 sf (12,500 m 2) of pavers, then reduce the testing frequency for each test to three full-sized paver from each 25,000 sf (2,500 m 2) manufactured. If any pavers fail any of these tests, then revert to the initial testing frequency. 125,000 sf (12,500 m 2) approximates five days of production by one paver manufacturing machine. This can vary with the machine and production facilities. This quantity and the sample size should be adjusted according to the daily production or delivery from the paver supplier. Consult the manufacturer for a more accurate estimate of the five-day production output. The entire bundle of pavers from which the tested paver(s) were sampled should be rejected when any of the individual test results fails to meet the specified requirements. Additional testing from bundles manufactured both before and after the rejected test sample should be performed to determine, to the satisfaction of the Engineer, the sequence of the paver production run that should be rejected. Any additional testing should be performed at no cost to the owner. The extent of nonconforming test results may necessitate rejection of entire bundles of pavers or larger quantities. The Engineer may need to exercise additional sampling and testing to determine the extent of non-conforming clusters and/or bundles of pavers, and base rejection of clusters of entire bundles on those findings.

2.2 Bedding Sand

Bedding sand gradation should conform to ASTM C 33 (ASTM 2001) or CSA A23.1 (CSA 2006) as appropriate with modifications as noted in Table 1. Supply washed, natural or manufactured, angular sand. At the start of the project, conduct gradation tests per ASTM C 136 (ASTM 2001) or CSA A23.2A (CSA 2000) for every 25,000 sf (2,500 m 2) of wearing course or part thereof. Testing intervals may be increased upon written approval by the Engineer when sand supplier demonstrates delivery of consistently graded materials. The Micro-Deval test is recommended as the test method for evaluating durability of aggregates in North America. Defined by CSA A23.2-23A, The Resistance of Fine Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus (CSA 2004), the test method involves subjecting aggregates to abrasive action from steel balls in a laboratory rolling jar mill. In the CSA test method a 1.1 lb (500 g) representative sample is obtained after washing to remove the No. 200 (0.080 mm) material. The sample is saturated for 24 hours and placed in the Micro-Deval stainless steel jar with 2.75 lb (1250 g) of steel balls and 750 mL of tap water (See Figure 1). The jar is rotated at 100 rotations per minute for 15 minutes. The sand is separated from the steel balls over a sieve and the sample of sand is then washed over an 80 micron (No. 200) sieve. The material retained on the 80 micron sieve is oven dried. The Micro-Deval loss is then calculated as the total loss of original sample mass expressed as a percentage. ASTM and the American Association of State Highway Transportation Officials have both adopted the coarse aggregate version of the Micro-Deval test, ASTM D 6928 (2006) and AASHTO TP 58. Both are also considering a version for fine aggregates. Since the test apparatus uses the same size drum and rotates at the same rpm, no modifications to the apparatus are required to perform the fine aggregate test in laboratories currently equipped to perform the coarse aggregate test procedure. Table 3 lists the primary and secondary material properties that should be considered when selecting bedding sands for vehicular applications. Other material properties listed such as soundness, petrography and angularity testing are at the discretion of the specifier and may offer additional insight into bedding sand performance. Repeat the Micro-Deval test for every 250,000 sf (25,000 m 2) of bedding sand or when there is a change in sand source. Test intervals for other material properties should be at every 200,000 sf (25,000 m 2) of bedding sand or higher as determined by the engineer. ICPI Tech Spec 17--Bedding Sand Selection for Interlocking Concrete Pavements in Vehicular Applications provides additional background to these test methods and criteria.

Table 3
Recommended Laboratory Material Properties for Bedding and Joint Sands in Vehicular Applications [1,2]

Material Properties	Test Method	Recommended Maximum or Minimum
Primary Properties		
Gradation	ASTM C 33 CSA A23.1 (FA1)	Maximum 1 % passing No. 200 (0.075 or 0.080 mm) sieve
Micro-Deval Degradation	CSA A23.2-23A	Maximum 8%
Constant Head Permeability	ASTM D 2434	Minimum 2×10^{-3} cm/second (2.83 in/hr)
Secondary Properties		
Soundness – Sodium Sulfate or Magnesium Sulfate	ASTM C 88	Maximum 7%
Silica (Quartz and Quartzite)/ Carbonate Ratio	MTO LS-616 ASTM C 295	Minimum 80/20 ratio
Angularity and Particle Shape	ASTM D 2488	Minimum 60% combined sub- angular and sub- rounded

Note 1: See "Recommended Material Properties" on page 4 of ICPI Tech Spec 17
Note 2: Bedding sand may also be selected based on field performance. Field performance is selected when the specifier or contractor assumes responsibility for the selection and performance of bedding sand not conforming to the properties in Table 4. Field performance as a selection criteria is suggested when the available local materials do not meet the primary material properties suggested in Table 4, but the specifier or contractor can demonstrate to the satisfaction of the owner (or owner's representative), successful historical field performance. In this case the owner should specify the class of vehicular traffic, and the contractor should verify past field performance of the bedding sand under similar vehicular traffic.

2.3 Joint Filling Sand

Joint sand gradation should conform to ASTM C 144 (ASTM 2002) or CSA A179 (CSA 2000) with modifications as noted in Table 2. Supply washed, manufactured, angular sand. At the start of the project, conduct gradation test per for every 25,000 sf (2,500 m 2) of concrete paver wearing course. Testing intervals may be increased upon written approval by the Engineer when the sand supplier demonstrates delivery of consistently graded materials.

2.4 Joint Sand Stabilizer
Stabilization materials for joint filling sand are optional and there are two categories of materials. These are liquid penetrating and dry mix formulas including materials mixed with joint sand and activated with water. Both categories of materials achieve early stabilization of joint sand. Liquid penetrating materials should have 24-hour cure time and be capable of penetrating the joint sand to a minimum depth of 1 in. (25 mm) prior to curing. Dry mix organic or polymer additives combine with joint sand prior to placing it in the joints. These materials typically cure in a few hours after activation with water. If the need for joint sand stabilization is determined, the application rate and method should be established on the mock-up area of paving.

Figure 7. Maintaining an angular laying face that resembles a saw-tooth pattern facilitates installation of paver clusters.

3.0 PART 3 EXECUTION
3.1 Examination
The elevations and surface tolerance of the base determine the final surface elevations of concrete pavers. The paver installation subcontractor cannot correct deficiencies in the base surface with additional bedding sand or by other means. Therefore, the surface elevations of the base should be checked and accepted by the GC or designated party, with written certification to the paving subcontractor, prior to placing bedding sand and concrete pavers. The GC should inspect, accept and certify in writing to the subcontractor that site conditions meet specifications for the following items prior to installation of interlocking concrete pavers:

1. Subgrade preparation, compacted density and elevations conform to specified requirements.
2. Geotextiles or geogrids, if applicable, placed according to drawings and specifications.
3. Aggregate, cement-treated, asphalt-treated, concrete, or asphalt base materials, thicknesses, compacted density, plus surface tolerances and elevations that conform to specified finished sur- face requirements.

Heavy-duty paving will often have high strength base material such as cement stabilized base, concrete slabs or asphalt. Even though these materials are used as a base layer, the construction specification must require installation of the top layer of these materials to typical surface finish tolerances. Asphalt crews, for example, may use different elevation control methods for base lifts than they do for top lifts. The base lift methods often are not as tightly controlled for grade as variations can be made up by the top lift of asphalt. If a base lift is directly under the bedding sand, a top lift may not be present, nor close surface tolerances normally expected from a top lift. Compensation for variations in base lift elevations must not be from adding more bedding sand. Special care should also be taken at edge contacts to ensure that asphalt, or other materials are installed deeply enough to allow a complete paver and sand section above. Edge restraints should be in place before pavers are installed. Some projects can have completed edge restraints with paving activity near them while the construction schedule dictates that the opposite side of the area may see ongoing construction of edge restraints. In such cases, the GC should propose an edge restraint installation schedule in writing for approval by the Engineer. All bollards, lamp posts, utility covers, fire hydrants and like obstructions in the paved area should have a square or rectangular concrete collar. The location, type, and elevations of edge restraints, and any collars around utility structures, and drainage inlets should be verified with the drawings. Likewise, verification of a clean surface of the base surface is required, including no standing water or obstructions prior to placing the bedding sand and concrete pavers. There will be a need to provide drainage during installation of the wearing course and joint sand by means of weep holes or other effective method per the drawings, temporary drains into slot drains, dikes, ditches, etc. to prevent standing water on the base and in the bedding sand. These may be indicated on the drawings. If not, they should be a bid item provided by the GC from the paver installation subcontractor. All locations of paver contact with other elements of the work should be inspected, including weep holes, drain inlets, edge restraints, concrete collars, utility boxes, manholes and foundations. Verify that all contact surfaces with concrete pavers are vertical. Areas where clearances are not in compliance, or where the design or contact faces at adjacent pavements, edges, or structures are not vertical should be brought to the attention of the GC and Engineer in writing with location information. The GC should propose remediation method(s) for approval by the Engineer. All such areas shall be repaired prior to commencing paver installation. Alternately, the GC may propose a repair schedule in writing for approval by the Engineer.

Figure 8. Edge pavers are saw cut to fit against a drainage inlet.

Figure 9. Initial compaction sets the concrete pavers into the bedding sand.

Figure 10. During initial compaction, cracked pavers are removed and immediately replaced with whole units.

3.2 Installation

There are a variety of ways to install interlocking concrete pavements. The following methods are recommended by ICPI as best practices. Other methods vary mainly in the techniques used for compaction of the pavers and joint sand installation. ICPI recommends using a vibrating plate compactor on concrete pavers for consolidation of bedding and joint sands. Other methods that have been used under specific project conditions including vibrating steel rollers and applying water to move sand into the joints. The bedding sand installation begins by screeding a uniform layer to a maximum 1 in. (25 mm) thickness. Maintain a uniform thickness within a tolerance of ± 1 / 4 in. (±6 mm). Allow for surcharge due to compaction of the pavers, typically 3 / 16 in. (5 mm), and an additional 3 / 16 in. (5mm) for paver surfaces above curbs and utility structures. For example, if the pavers are 3 1 / 8 in. (80 mm) thick, the elevations of the base surface should be 3 3 / 4 in. (95 ± 5 mm) below the finish elevation of the pavement. The exact amount of surcharge will vary depending on local sands and this is determined in the mock-up. Do not fill depressions in the surface of the base with bedding sand, as they may reflect to the paver surface in a few months. Variations in the surface of the base must be repaired prior to installation of the bedding sand. The screeded bedding course should not be exposed to foot or vehicular traffic. Fill voids created by removal of screed rails or other equipment with sand as the bedding proceeds. The screeded bedding sand course should not be damaged prior to installation of the pavers. Types of damage can include saturation, displacement, segregation or consolidation. The sand may require replacement should these types of damage occur. Installation of the concrete pavers starts with securing string lines, laser lines or snapping chalk lines on the bedding course. These or other methods are acceptable to maintain dimensional control in the direction of paving. These lines are typically set at 50 ft. (15 m) intervals for establishing and maintaining joint lines at maximum allowable width of clusters. The installation subcontractor will determine exact intervals for lines. A starting area may need to be placed by hand against an existing curb. This will establish coursing, squareness of the pattern, and offset of the mechanical installed layers. Interlocking patterns such as herringbone patterns are recommended for port pavements. The orientation of the pattern is typically governed by the site operational layout and orientation should be included in the drawings. An angular laying face (or faces) should be maintained with the laid clusters creating a saw tooth pattern. This will facilitate rapid installation and adjustment of clusters as laying proceeds. Figure 7 illustrates this pattern for the laying face. Bundles of pavers are positioned by the laying face and machines pick from them as laying proceeds. Straight joint lines are maintained by adjusting clusters and pavers with rubber hammers and alignment bars. If the cluster pattern is shipped to the site with halfsized paver units, adjust their locations, or remove them and fill openings with full-sized pavers so that each cluster is stitched and interlocked with adjacent clusters into the designated laying pattern. There may be paver layers that do not require the removal of half pavers if the layers are installed in a staggered fashion. The resulting final pattern should be illustrated in the method statement in the Quality Control Plan. As paving proceeds, hand install a string course of pavers around all obstructions such as concrete collars, catch basins/drains, utility boxes, foundations and slabs. Pavers are typically cut with powered saws. Cutting pavers with mechanical (non-powered) splitters for industrial pavement is an acceptable method as long as the resulting paver meets project tolerances for squareness and surface variations, as well as specified joint widths. Do not allow concrete materials emitted from cutting operations to collect or drain on the bedding sand, joint sand or in unfinished joints. Figure 8 shows a cutting with a dust collection system to prevent contamination of surfaces. If such contact occurs, remove and replace the affected materials. Whenever possible cut pavers exposed to tire traffic should be no smaller than one-third of a full paver and all cut pavers should be placed in the laying pattern to provide a full and complete paver placement prior to initial compaction. Coursing can be modified along the edges to accommodate cut pavers. Joint lines are straightened and brought into conformance with this specification as laying proceeds and prior to initial compaction. Sometimes the pattern may need to be changed to ensure that this can be achieved. However, specifiers should note that some patterns cannot be changed because of the paver shape and some paver cuts will need to be less than one-third. Remove debris from surface prior to initial compaction and then compact the pavers using a vibrating plate compactor with a plate area not less than 2 sf (0.2 m^2) that transmits a force of not less than 15 psi (0.1 MPa) at 75 to 100 Hz (see Figure 9). After initial compaction, remove cracked or broken pavers, and replace with whole units. Figure 10 shows removal of a paver with an extraction tool. Initial compaction should occur within 6 ft. (2 m) of all unrestrained edges at the end of each day. After initial compaction of the pavers, sweep and vibrate dry joint sand into the joints until all are completely filled with consolidated joint sand (see Figures 11 and 12). The number of passes and effort required to produce completely filled joints will vary based on many factors. Some of these include sand moisture, gradation and angularity, weather, plus the size, condition and adjustment of the vibrat- ing plate, the thickness of the pavers, the configuration of the pavers and the skill of the vibrating plate operator. Joint sand should be spread on the surface of the pavers in a dry state. If is damp, it can be allowed to dry before sweeping and vibration so it can enter the joints readily. Vibration and filling joints with sand in completed to within 6 ft. (2 m) of any unconfined edge at the end of each day. The various activities of the crews should be scheduled so that the paver surface is completed each day. This is the best practice. The surface should be placed to specified tolerances, all cut pavers in place before initial compaction, and the joints completely filled after the final compaction. This provides the maximum protection from weather and vehicles. Moreover, once an area is completed, inspected and accepted, it can be put to immediate use by the owner. Coordination and Inspection--Large areas of paving are placed each day and often require inspection by the Engineer or other owner's representative prior to initial and final compaction. Inspection should keep up with the paving so as to not delay its progress. There may be the occasional case where there inspection is not administered on a timely basis. In such unlikely cases, the Engineer should decide the total allowable uncompacted area. It should be based on the daily production of the subcontractor, inspection schedules, and weather. Therefore, the Engineer may establish a maximum distance from the laying face for uncompacted pavers that relates to the timing of inspection. For work in rainy weather, the 6 ft. (2 m) distance should be maintained, regardless of the timing of inspection. Rainfall will saturate the bedding sand under uncompacted pavers with no sand in the joints. This condition makes the bedding course impossible to compact.

Figure 11. Sweeping jointing sand across the pavers is done after the initial compaction of the concrete pavers.

Figure 12. Final compaction should consolidate the sand in the joints of the concrete pavers.

3.2.1 Joint Sand Consolidation

After the final compaction of the joints in the sand, filling and consolidation of the joint sand should be checked by visually inspecting them. Consolidation is important to achieving interlock among the units. Consolidation also reduces infiltration of water into the sand and base. This can be done by dividing the project into areas of about 5,000 sf to 10,000 sf (500 to 1,000 m^2). Visually and physically inspect each area by taking at least 30 measurements of joint sand depth and consolidation. Take measurements by inserting a thin, rigid putty knife into the joint and pressing down. See Figure 13. It should not penetrate more than 1 / 4 in. (6 mm) when pressed firmly into the joint. If areas are found deficient in consolidation and/or joint sand, make additional passes of a plate compac- tor. It should have a minimum compaction of 6,000 lbf (26 kN). Higher force compactors will be required on pavers thicker than 3 1 / 8 in. (80 mm). Inspect the joints again after refilling and compaction. Fill and compact until the joint sand has consolidated so that a putty knife moves less than 1 / 4 in. (6 mm) into the joint.

3.3 Tolerances on Completion
The minimum joint width is determined by the size of the spacer bar used for the project. This is typically 1 / 16 in. (2 mm). The maximum joint width depends on the paver shape and thickness. Generally, thicker pavers with more than four sides (dentated) will require slightly larger joints, often as much as 1 / 4 in. (6 mm). Recommended tolerances are as follows:

1. Joint widths: This depends on the paver thickness. For 3 1 / 8 and 4 in. (80 and 100 mm) thick pavers, 1 / 16 to 3 / 16 in. (2 to 5 mm) is acceptable. No more than 10% of the joints should exceed 5 mm for the purposes of maintaining straight joint lines. For 4 3 / 4 in. (120 mm) thick dentated pavers, the maximum joint spacing can be increased to 1 / 4 in. (6 mm) with no more than 10% of the joints exceeding 6 mm for the purposes of maintaining straight joint lines.
2. Bond or joint lines: ± 1 / 2 in. (±15 mm) from a 50 ft. (15 m) string line.
3. Surface tolerances: ± 3 / 8 in. over a 10 ft. (±10 mm over a 3 m) straightedge. This may need to be smaller if the longitudinal and cross slopes of the pavement are 1%. Surface elevations should conform to drawings. The top surface of the pavers may be 1 / 8 to 1 / 4 in. (3 to 6 mm) above the final elevations after the second compaction. This helps compensate for possible minor settling normal to pavements. The surface elevation of pavers should be 1 / 8 to 1 / 4 in. (3 to 6 mm) above adjacent drainage inlets, concrete collars or channels. Surface tolerances on flat slopes should be measured with a rigid straightedge. Tolerances on complex contoured slopes should be measured with a flexible straightedge capable of conforming to the complex curves in the pavement.

3.4 Protection and Clean Up
The GC should insure that no vehicles other than those from subcontractor's work are permitted on any pavers until completion of paving. This requires close coordination of vehicular traffic with other contractors working in the area. After the paver installation subcontractor moves to another area of a large site, or completes the job and leaves, he has no control over protection of the pavement. Therefore the GC should assume responsibility for protecting the completed work from damage, fuel or chemical spills. If there is damage, it should be repaired to its original condition, or as directed by the Engineer. When the job is completed, all equipment, debris and other materials are removed from the pavement.

Figure 13. A simple test with a putty knife checks consolidation of the joint sand.

Figure 14. The Port of Oakland, California, is the largest mechanically installed project in the western hemisphere at 4.7 million sf (470,000 m^2).

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Achieving LEED ® Credits with Segmental Concrete Pavement

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Background
Rapidly rising energy and material costs have accelerated energy and natural resource conservation in design and construction. Sustainable development has evolved as a response and ethos to encourage conservation. It is also a framework for creating environments that enhance human existence and natural processes. Broadly defined, sustainable development meets the needs of the present without compromising the ability of future generations to meet their needs. Within the North American design and construction community, a means for addressing sustainability or `green building' is through LEED ® or Leadership in Energy and Environmental Design. Developed by the U.S. Green Building Council (USGBC) in 1998, LEED ® provides voluntary guidelines for reducing energy and wasted resources from building and site design. The Canadian Green Building Council (CaGBC) formed in 2003 published similar LEED ® guidelines tailored to Canadian climates. U.S. and Canadian guidelines were developed by a range of representatives from the building industry and environmental science. LEED ® establishes a consensus-based means for measuring building and site performance. It promotes designs that integrate energy and resource conservation. LEED ® is being applied to many publicly funded projects and a growing number of private ones. A primary objective of LEED ® is to help facility owners reduce maintenance and life-cycle costs. This is accomplished by including all players in an integrated development process during the design stages of a project.

Purpose
LEED ® rating systems have been developed or are under development for:

· New Commercial Construction and Major Renovation projects
· Existing Building Operations and Maintenance
· Commercial Interior projects
· Core and Shell Development projects
· Homes
· Neighborhood Development
· Guidelines for Multiple Buildings and On-Campus Building Projects
· LEED ® for Schools

This publication provides guidance on applying the rating system for New Commercial Construction and Major Renovation projects or LEED-NC to the family of segmental concrete pavement products. This family includes interlocking concrete pavements, permeable interlocking concrete pavements, concrete grid pavements and precast concrete paving slabs. The products can also be used to satisfy the requirements in the other rating systems listed above. LEED-NC version 2.2 is promulgated by the USGBC and version 1.0 by the CaGBC. Excerpts from each version that relate to segmental concrete pavement are presented in this technical bulletin with application guidance. Each version has similar evaluation criteria for sustainable design and some minor differences. USGBC LEED-NC version 2.2 likely will be adopted by CaGBC in 2007, thereby making each organization's version identical or very similar. Readers should check with www.usgbc.org and www.cagbc. org for the most current versions.

Figure 1. Sustainability for buildings extends to the site with sustainable paving that promotes infiltration and reflects sunlight.

The LEED ® Process

The decision to apply for LEED ® certification must occur early in the design process. The project owner and designers evaluate categories and associated criteria explained in the rating categories below for compatibility with the project, architectural program, budget and resulting environmental impact. This enables energy and cost-saving synergies for site and building design decisions. To start the LEED ® certification process, the project is registered on the USGBC or CaGBC web site with payment of a fee based on the total area of the project plus a registration fee. The web site specifies materials to be submitted such as project plans and documentation. The person seeking LEED ® certification is sent a project checklist to evaluate aspects of the project might be eligible for LEED ® credits. A letter template is also provided to help standardize documentation of credits. The registration fee enables access to the member-only parts of the web site and to access to the history of credit interpretations. LEED ® documentation can come from all involved on the project team including product manufacturers, contractors, cost estimators, specification writers and designers. Responsibility for managing this process will vary with each project. However, this effort is often coordinated by a LEED ® Accredited Professional, one who has taken a course sponsored by USGBC or CaGBC and an exam on the credits and their requirements. Once documentation is submitted with the LEED ® application, they are reviewed for acceptance for LEED ® credits. Additional documentation can be requested from the USGBC (or CaGBC) as needed and the project team has a specified amount of time to provide this. Final certification is granted within 30 days of receipt of all necessary documentation. LEED ® certificates and a plaque are issued to the project design team.

LEED ® Credits

For new commercial construction or LEED ® -NC, the US and Canadian Green Building Councils grant certification based on the same number of points earned from each rating system. The minimum number of required points is 26. Higher ratings are shown in Table 1. New projects and major renovations earn points from six broad rating categories with specific subcategories. The major categories include:

· Sustainable Sites
· Water Use Efficiency (for building)
· Energy and Atmospheric Pollutants
· Materials and Resources
· Indoor Air Quality
· Innovative Ideas and Designs

The two primary categories that pertain to segmental concrete paving are Sustainable Sites and Materials and Resources. Within these categories, there are several subcategories for rating various aspects of the building and site for LEED ® points.

Table 1. LEED®-NC Points

Level	Points
Certification	26-32
Silver	33-38
Gold	39-51
Platinum	52 or more

LEED ® in Specifications and Project Management

Upon registering a project for LEED ® certification, a project checklist is provided by the USGBC or CaGBC that lists all of the LEED ® credits in a table. The project is compared to the applicable LEED ® credits thereby identifying which credits will require the appropriate documentation or tests. This evaluation helps scope the level of certification to be attained by the project. Generally, the higher the certification, the more effort is placed into documentation and into building and site systems that comply with LEED ® requirements. The LEED ® project checklist can also be used to identify responsibility among the architect, contractor or owner for complying with applicable credits. Besides identifying which parts of the building or site could comply with LEED ®

requirements, the project checklist identifies which sections of the specification will need to be written to include LEED ® requirements, and into Part 1, 2 or 3 of each Section in the project specifications. Division 01, General Conditions should include the owner's goals for achieving LEED ® credits, substitution procedures for green building products that contribute to LEED ® points, submittal procedures (which may be covered in greater detail for each product in the relevant specifications sections), and a waste management plan. Submittals should occur before construction begins and substitutions should be conducted at the bid stage rather than during construction. The latest specification formats include sections for specifying sustainable building products. Specific requirements and procedures for compliance to LEED ® credits for segmental concrete paving products for sustainable sites and materials and resources should be included in the specifications. Examples include a letter from the manufacturer stating the recycled content of the paving units could be a required submittal, waste management goals, or drainage calculations showing the required reduction of stormwater runoff contributed by permeable interlocking concrete pavement or grid pavements. If segmental paving is indoors and sealed, or the joint sand stabilized with a liquid, such materials should comply with indoor air quality construction requirements in LEED ® . Many projects have a pre-bid conference where the scope of the project is presented with details on the bid documents. The person running the conference should be familiar with LEED ® goals for the project and also review submittal requirements and substitution request procedures with prospective bidders. During construction, the owner's representative or contractor should appoint someone responsible for enforcing the contract provisions pertaining to achieving LEED ® requirements and documentation. The importance and role of this person should be presented at the pre-bid conference. This person could be responsible fulfilling contractor related items on the project checklist. The additional project cost for compliance to LEED ® certification is small and segmental concrete paving products used in the normal course of project design (roads, plazas, sidewalks, roof decks, etc.) can earn LEED ® credits. Higher levels of certification (Silver, Gold, etc.) will likely increase project costs. However, the initial investment in sustainable design and construction should be returned to the owner in lower maintenance costs during the life of the building and site. When properly designed and installed, segmental concrete pavement has very low maintenance.

Life Cycle Assessment

Groundwork is being prepared for incorporation of life cycle analysis or LCA into LEED ® . Integration of LCA in LEED ® will likely occur within the next three to five years. According to Trusty and Horst (Trusty), "LCA is a methodology for assessing the environmental performance of a service, process, or product, including a building, over its entire life cycle. Although the technique is still maturing, especially the aspects dealing with ultimate impacts on human and ecosystem health, it has become the recognized international approach to assessing the comparative environmental merits of products or processes." LCA includes goal and scope definition, inventory analysis, impact assessment, and interpretation of social, environment and economic impacts of a project. The method is described in detail in the ISO 14000 series of standards (see ISO references). LCA has been used by major corporations to reduce costs for products through creating efficiencies that generate less impact on human and natural systems. LCA consists of analyzing environmental impacts of a product or system. Impacts are weighted and their weightings are justified as part of the analysis. The impacts include:

· Global warming (from greenhouse gases)
· Acidification (typically from acid rain)
· Eutrophication (aging of water bodies through excess nutrient intake)
· Fossil fuel depletion
· Indoor air quality
· Habitat alternation
· Water intake
· Criteria air pollutants
· Smog
· Ecological toxicity
· Ozone depletion
· Human health

LCA is incorporated into British and European green building guides. The British Green Guide to Specification (BREAM 2002) is an LCA based methodology for assessing the human and environmental impacts of many building systems. Consideration is given to impacts from "cradle to grave" or from the energy used to extract natural resources to make the products, as well as manufacturing and recycling impacts. The Green Guide uses an A, B, C rating system where an A rating notes a low environmental impact, B is moderate and C is high. Table 2 illustrates the evaluation criteria and ratings of various pavement types with segmental concrete products receiving favorable ratings.

Table 2. British Green Guide *Life Cycle Assessment Rating of Various Pavement Materials*

Paving Type	Summary Rating	Climate Change	Fossil Fuel Depletion	Ozone Depletion	Human Toxicity to air & water	Waste Disposal	Water Extraction	Acid Deposition	Ecotoxicity	Eutrophication	Summer Smog	Minerals Extraction	Typical Replacement Interval, yrs	Recycled Content	Recyclability	Recycled Currently	Energy Saved by Recycling	Initial Cost
Asphalt	C	C	C	A	C	C	A	C	C	C	C	A	20	C	B	B	A	Low
Clay pavers	B	B	B	A	A	B	A	A	A	A	C	A	40	C	A	A	A	Medium
Concrete pavers/ PICP	A	A	A	A	A	B	A	A	A	A	B	A	40	A	A	A	A	Medium
Concrete Paving slabs	A	A	A	A	A	B	A	A	A	A	A	A	40	C	A	A	A	Medium
Concrete grid pavers	A	A	A	A	A	B	C	A	A	B	C	A	30	C	A	A	A	Medium
Cast-in-place concrete	C	C	A	A	B	C	B	B	A	C	B	C	60	C	A	A	A	Low
Granite pavers	B	A	A	A	A	B	A	A	A	A	A	B	60	C	A	A	A	High
Stone slabs	A	A	A	C	A	A	A	A	A	A	A	A	60	C	A	A	A	High
Gravel	B	A	A	A	A	C	B	A	A	A	A	C	10	C	B	B	C	Low

Other Evaluation Systems
Besides LEED ® , there are other environmental assessment programs such as Green Globes (www.greenglobes.com). According to their web site Green Globes has an on-line auditing tool that enables designers, property owners and managers to assess and rate existing buildings against best practices and standards for sustainable design. Evaluations are done by those using their web site and third party assessments are at the user's option.

USGBC

USGBC LEED ® -NC Version 2.2 Credits

Sustainable Sites
Credits applicable to segmental concrete paving products for sustainable sites include the following:
SS Credit 6.1 Stormwater Design: Quantity Control
SS Credit 6.2 Stormwater Design: Quality Control
SS Credit 7.1 Heat Island Effect: Non-roof
SS Credit 7.2 Heat Island Effect: Roof

USGBC LEED® SS Credit 6.1 Stormwater Design: Quantity Control
1 Point

Intent
Limit disruption of natural water hydrology by reducing impervious cover, increasing on-site infiltration, reducing or eliminating pollution from stormwater runoff, and eliminating contaminants.

Requirements
CASE 1 — EXISTING IMPERVIOUSNESS IS LESS THAN OR EQUAL TO 50%
Implement a stormwater management plan that prevents the post-development peak discharge rate and quantity from exceeding the pre-development peak discharge rate and quantity for the one- and two-year 24- hour design storms.
OR
Implement a stormwater management plan that protects receiving stream channels from excessive erosion by implementing a stream channel protection strategy and quantity control strategies.
OR
CASE 2 — EXISTING IMPERVIOUSNESS IS GREATER THAN 50%
Implement a stormwater management plan that results in a 25% decrease in the volume of stormwater runoff from the two-year 24-hour design storm.

Potential.Technologies.&.Strategies

Design the project site to maintain natural stormwater flows by promoting infiltration. Specify garden roofs and pervious paving to minimize impervious surfaces. Reuse stormwater volumes generated for non-potable uses such as landscape irrigation, toilet and urinal flushing and custodial uses.

Application of Credit SS 6.1

Permeable interlocking concrete pavement (PICP) is a type of pervious paving that can help earn this LEED ® credit. Figure 2 illustrates examples of PICP for runoff reduction. A typical design consists of paving units with openings filled with small, open-graded crushed stone. The units are bedded on a 2 in. (50 mm) thick layer of the same filling material. The bedding layer is compacted into the base consisting of open-graded aggregate base and sub-base. They have sufficient space between stones to store water and allow it to infiltrate into the soil. The water storage capacity is typically 30% to 40% of the total volume of the base and sub-base. This water is allowed to infiltrate into the soil usually within 24 to 36 hours. Water that does not infiltrate can be filtered through the base and drained through perforated pipes at the bottom of the sub-base. PICP benefits:

· Meet national/provincial/state stormwater regulations: part of best management practice (BMP) mix
· Conserves space: pavement built on detention facility
· Reduce retention requirements
· Filter and reduce nutrients, metals
· Groundwater recharge
· Lower peak flows/volume that helps preserve drainage system capacity while reducing downstream erosion
· Reduce runoff temperatures
· Potentially fewer drainage appurtenances
· Reinstatement of surface after repairs
· Filters oil drippings
· Resists frost heave and can be snowplowed
· Visually more attractive than alternatives

An in-depth presentation of design, specification, construction and maintenance is found in the ICPI publication, Permeable Interlocking Concrete Pavements (ICPI 2000). Most PICP will infiltrate runoff falling directly on it from 80% to 90% of all storms. The infiltration rate of the soil, base thickness (reservoir capacity) and any runoff from contributing areas will determine if PICP qualifies for reducing the peak discharge to the pre-development one and two year, 24 hour peak discharge rate. In most cases PICP will meet this requirement. Pavement infiltration rates are a function of several factors including permeability of the fill material for the surface openings and for the base materials. No. 8 stone typically used in the openings has an infiltration rate exceeding 500 in./hr (12.7 m/hr). Infiltration rates of Nos. 57 and 2 stone used for the base and sub-base exceed 1,000 in./hr (25 m/hr). Over time, the voids in these materials can become clogged, especially around the stone in the surface openings. Nearby sources of sediment can typically run onto the pavement. Periodic maintenance with vacuum sweeping will help maintain high surface infiltration rates. Research has shown that high infiltration rates can be maintained by removing the sediment in the first inch (25 mm) of the openings (Gerrits 2002).

Figure 2. Examples of permeable interlocking concrete pavements for earning LEED® points. The photo on the left shows a hotel entrance in southern California. The photo on the right shows the driveway and parking lot for a fire station in Toronto.

Peak discharge rate, Q, can be calculated using the Rational Method where Q = CIA where C = the coefficient of runoff from the catchment, I = intensity of rainfall in in./hour, and A = area of the catchment. The Rational Method is a simple, first order method to estimate peak flows from a site with varying degrees of perviousness. According to Ferguson (2005), the runoff coefficient, C, will vary with each storm. For small storms permeable pavements will infiltrate all of the rainfall rendering a low runoff coefficient. In intense storms, and when the soil is saturated from antecedent storms, the runoff coefficient will be higher. Since most sites are exposed to a range of storm intensities and durations, the overall runoff coefficient of 0.25 to 0.35 can be assumed for PICP. Concrete grid pavements (see Figure 3) are another type of permeable pavement. They are typically used for less intense vehicular applications than PICP such as overflow parking and emergency fire lanes. Unlike PICP, the base is typically dense-graded, compacted aggregate. The grids are bedded in sand and the openings are filled with aggregate or topsoil and grass. If they have grass in the openings, the surface will require lawn maintenance such as mowing, seeding and fertilizing. ICPI Tech Spec 8 Concrete Grid Pavements provides detailed information on applications, design, specifications, construction and maintenance.

Concrete grid pavements can be used to earn this LEED ® credit for runoff reduction. For Rational Method calculations a C value of 0.4 can be assumed if the grids are over a dense-graded aggregate base (Day 1980). A more sophisticated runoff calculation method for calculating peak flow is the U.S. National Resource Conservation Service (NRCS) TR-55 method. TR-55 relies on development of a Curve Number or CN that characterizes the amount of runoff depth from various land uses within a catchment. The CN for PICP will vary with the infiltration rate of the underlying soil. For example, a typical CN for permeable pavements in sandy soils is in the 40s and for clay soils it might be in the 60s. Bean (2005) has characterized CNs for PICP and grid pavements. Some municipalities use computer models to characterize urban runoff and project impacts on drainage systems. Models are sometimes calibrated with field measurements of rainfall, runoff, flows and pollutant loads. The hydrological characteristics of PICP and grid pavements can be input into these models to simulate their benefits on urban hydrology. The U.S. EPA Stormwater Management Model (SWMM) has been incorporated into software for computing the infiltration capacity of PICP (James 2003). For the purposes of calculating site perviousness, PICP should be counted as almost 100% pervious. The rationale is that with an open-graded material in the openings and base, the long-term conservative pavement surface infiltration rate is approximately 3 in./hour (75 mm/hour). This well exceeds the the rainfall intensity of common rainfall events. If runoff from an impervious area is directed to PICP, then PICP will be handling additional water other than rain falling directly on it. In such cases, calculate the average coefficient of runoff, C from the contributing area and the PICP and use the average for both areas. The averages would be weighted by the area of each surface. In these cases, the coefficient of runoff, C for PICP will likely be 0.25 to 0.4. Low C values should be used in high-infiltration sandy soils and higher values for lower-infiltration silt and clay soils. Concrete grid pavements with topsoil and grass have lower, longterm surface infiltration rates, typically 1 to 2 in./hour (25 to 50 mm/hour) (Smith, 1984). Like all pervious surfaces, grid pavement will infiltrate runoff from commonly occurring storms and eventually yield 100% runoff when saturated from concentrated high-intensity storms. The advantage of grid and PICP systems is they will store runoff for a period of time and release it at saturation well after adjacent saturated soil and vegetated areas. This storage and delay in generating runoff should be considered in drainage calculations. A design example (Table 3) follows for calculating imperviousness with PICP and grid pavers for a 40,000 sf (3,716 m 2) site consisting of roofs and paving. This exemplifies the information required for LEED ® documentation (USGBC 2003). The site has sandy soils with high infiltration rates. The following equations apply:

Impervious Area = Surface area x Runoff coefficient
Site Imperviousness [%] = Total impervious area / Total site area

This example shows 52% site imperviousness reduced to 32% by using PICP and grid pavement. This represents a 38% reduction in impervious cover and a corresponding runoff quantity reduction. If the total site imperviousness for conventional design was less than 50% or less, the engineer must demonstrate that a design with sustainable pavements will have a peak discharge rate not exceeding that from a 2 year, 24 hour storm. In this case, the conventional site design imperviousness exceeded 50%. With a 38% reduction in site imperviousness, the designer demonstrated site design with PICP and grid pavement resulted in a minimum 25% reduction in the rate and quantity of runoff.

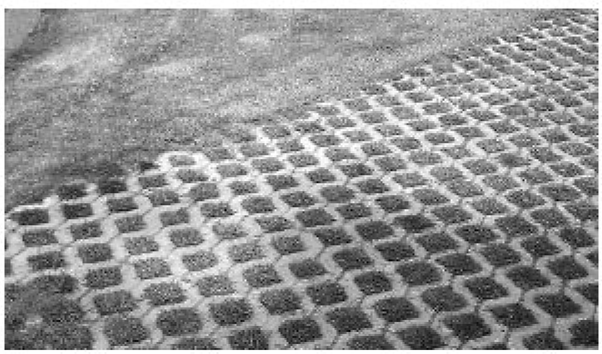

Figure 3. Concrete grid pavement substantially reduces runoff to levels approximating grass cover.

Table 3. Design Case for Calculating Impervious Area

Surface	Area (sf)	Runoff coefficient, C (imperviousness)	Conventional design Impervious area (sf)	LEED® design with PICP & grid pavement	Impervious area, PICP & grid pavement
Asphalt pavement	14,000	0.95	13,300	2,000 (entrance)	1,900
Conventional roof	8,000	0.95	7,600	7,600	7,600
PICP		0.25		12,000 (parking)	3,000
Grid pavement		0.40		400 (fire lane)	160
Total Paved Surface Area	22,000		20,900	22,000	12,660
Total Site Area	40,000		40,000		40,000
Site Imperviousness			52%		32%

USGBC LEED® SS Credit 6.2 Stormwater Design: Quality Control

1 Point

Intent
Limit disruption and pollution of natural water flows by managing stormwater runoff.

Requirements
Implement a stormwater management plan that reduces impervious cover, promotes infiltration, and captures and treats the stormwater runoff from 90% of the average annual rainfall1 using acceptable best management practices (BMPs). BMPs used to treat runoff must be capable of removing 80% of the average annual post development total suspended solids (TSS) load based on existing monitoring reports. BMPs are considered to meet these criteria if (1) they are designed in accordance with standards and specifications from a state or local program that has adopted these performance standards, or (2) there exists in-field performance monitoring data demonstrating compliance with the criteria. Data must conform to accepted protocol (e.g., Technology Acceptance Reciprocity Partnership [TARP], Washington State Department of Ecology) for BMP monitoring.

Potential.Technologies.&.Strategies
Use alternative surfaces (e.g., vegetated roofs, pervious pavement or grid pavers) and nonstructural techniques (e.g., rain gardens, vegetated swales, disconnection of imperviousness, rainwater recycling) to reduce imperviousness and promote infiltration thereby reducing pollutant loadings. Use sustainable design strategies (e.g., Low Impact Development, Environmentally Sensitive Design) to design integrated natural and mechanical treatment systems such as constructed wetlands, vegetated filters, and open channels to treat stormwater runoff.
1. In the United States, there are three distinct climates that influence the nature and amount of rainfall occurring on an annual basis. Humid watersheds are defined as those that receive at least 40 inches of rainfall each year, Semi-arid watersheds receive between 20 and 40 inches of rainfall per year, and Arid watersheds receive less than 20 inches of rainfall per year. For this credit, 90% of the average annual rainfall is equivalent to treating the runoff from:
(a) Humid Watersheds – 1 inch of rainfall;
(b) Semi-arid Watersheds – 0.75 inches of rainfall; and
(c) Arid Watersheds – 0.5 inches of rainfall.

Application of SS Credit 6.2
Roofs, sidewalks, driveways and streets (impervious cover) contribute additional runoff and pollution by denying infiltration of stormwater. These surfaces generate excessive amounts of runoff with sediment (total suspended solids or TSS) and water carrying nutrients (total phosphorous or TP and nitrogen forms) and metals. Other pollutants such as pesticides, detergent, fertilizer, oils, other chemicals and salts remain in suspension or solution in the flowing water which can damage wildlife and fish. Increased runoff flows and pollution are directed into waterways decreasing property values, fishing income and recreation opportunities. Some municipalities have older, combined sanitary and storm sewer systems. These discharge raw sewage into rivers when storm flows exceed the processing rate of the local waste treatment plant. Since PICP reduces runoff through infiltration, it has the ability to reduce TSS and TP. Several studies have demonstrated at least 80% reduction of TSS, a good indicator pollutant treatment. Studies include James (1997) and Rushton (2001). Studies that demonstrate at least 40% TP reduction include James (1997), Rushton (2001) and Bean (2005). All studies compared reductions of pollutants from PICP to that from impervious pavements. These studies provide evidence of the ability of PICP to reduce TSS and TP. In addition, the LEED ® Reference Guide (2005) suggests a 60%-80% removal efficiency for pervious pavement. Pre-treatment and filtering of runoff prior to entering PICP will assist in reducing TSS and TP emissions. Practices such as bioswales and sand filters can receive and filter runoff prior to entering adjacent PICP as well as receive outflows from PICP. The entire flow path design for runoff should be considered, especially when PICP is designed to receive runoff from impervious surfaces.

Integration with Other LEED ® Credits
In addition to earning LEED ® credits for reducing stormwater runoff and pollution, PICPs may earn points from Credit 7.1, Heat Island Effect, non-roof when the paving units have a minimum Solar Reflectance Index of 29. Another point can be earned from Credit 1.1, Water Efficiency under Water Efficient Landscaping when water captured in the PICP base is used for toilet grey water or for exterior irrigation.

USGBC LEED® SS Credit 7.1 Heat Island Effect: Non-Roof
1 Point

Requirements
OPTION.1
Provide any combination of the following strategies for 50% of the site hardscape (including roads, sidewalks, courtyards and parking lots):
• Shade (within 5 years of occupancy) • Paving materials with a Solar Reflectance Index (SRI)2 of at least 29
• Open grid pavement system
OR
OPTION.2
Place a minimum of 50% of parking spaces under cover (defined as under ground, under deck, under roof, or under a building). Any roof used to shade or cover parking must have an SRI of at least 29.

Potential.Technologies.&.Strategies
Shade constructed surfaces on the site with landscape features and utilize high-reflectance materials for hardscape. Consider replacing constructed surfaces (i.e. roof, roads, sidewalks, etc.) with vegetated surfaces such as vegetated roofs and open grid paving or specify highalbedo materials to reduce the heat absorption. 2The Solar Reflectance Index (SRI) is a measure of the

constructed surface's ability to reflect solar heat, as shown by a small temperature rise. It is defined so that a standard black (reflectance 0.05, emittance 0.90) is 0 and a standard white (reflectance 0.80, emittance 0.90) is 100. To calculate the SRI for a given material, obtain the reflectance value and emittance value for the material. SRI is calculated according to ASTM E 1980-01. Reflectance is measured according to ASTM E 903, ASTM E 1918, or ASTM C 1549. Emittance is measured according to ASTM E 408 or ASTM C 1371. Default values for some materials will be available in the LEED®-NC v2.2 Reference Guide.

Applications of SS Credit 7.1

All segmental concrete paving can meet three of the four above Submittals. While PICP doesn't provide shade, it can be used as paving around shade trees to allow air and water to reach roots. This indirect benefit ensures a longer tree life compared to impervious pavement that deprives air and water from reaching tree roots. An example of this application in a parking lot protecting an historic tree is found in the ICPI brochure, Project Profiles Permeable Interlocking Concrete Pavement (ICPI 2005). **Solar Reflectance Index (SRI) of Segmental Concrete Paving Products**-SRI consists of combined albedo and emittance measurements. Albedo is the ratio of outbound or reflected solar radiation divided by the inbound radiation. Lighter colored surfaces indicate a higher albedo than dark surfaces. The highest albedo of 1.0 means all solar energy reflects back from a surface with no absorbed energy. The test method for determining albedo is ASTM E 903, Standard Test Method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres (ASTM 2005). Reflectance is measured over a range of wavelengths and averaged to provide a single albedo value. According to the LEED ® Reference Guide (2003) new concrete made with grey cement has an albedo of 0.35 to 0.40 and weathered concrete 0.20 to 0.30. New concrete made with white cement generally has an albedo of 0.7 to 0.8 and 0.4 to 0.6 when weathered. White cement is about twice as expensive as grey cement. However, some normal cement can be light in color and be cost competitive. Cement and aggregate colors influence concrete color. For segmental concrete paving products, light colored aggregates and surface treatments with white cement can contribute to a higher albedo. Figure 4 shows an application with light colored paving slabs. By comparison, asphalt reflectance is 0.05 to 0.10 when new and 0.10 to 0.15 when weathered. Periodic surface cleaning may be required to maintain a minimum required SRI values. ICPI Tech Spec 5 Cleaning, Sealing and Joint Sand Stabilization of Interlocking Concrete Pavement provides additional guidance. When measured and documented in the LEED application process, existing interlocking concrete pavement surfaces can qualify for this credit. Samples taken from areas can be measured for their SRI and averaged to achieve this credit. A study by Lawrence Berkeley National Laboratories (Pomerantz, 2000) notes that new asphalt exhibited an albedo of 0.04 and five year-old pavements 0.12, substantially lower the 0.3 recommended in the LEED ® rating system. In their experiments, they found that an increase in albedo of about 0.1 produces a decrease in pavement temperature of about 4 o ±1 o C (-7 o ± 2 o F) when there is little wind. Increasing wind speed lowers the surface temperature and diminishes the influence of the change in albedo. Emittance measures a material's ability to release radiant heat (in watts/m 2) from a given wavelength spectrum. It is measured using ASTM E 408 Test Methods for Total Normal Emittance of Surfaces Using Inspection-Meter Techniques. Emittance and albedo measurements are combined to calculate SRI per ASTM E 1980 Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low-Sloped Opaque Surfaces. As noted earlier, surface color affects albedo and indirectly affects emittance. Since most manufacturers provide a range of colors, SRI measurements should be requested from manufacturers for specific product color or ranges, especially lighter colored products. Testing laboratories can provide requirements for specimen sizes cut from segmental concrete paving products. Specimen sizes are generally 2 x 2 in. (50 x 50 mm) by ½ in. (13 mm) thick. The overall all objective of Figure 4. Light colored paving units reflect light and help reduce mico-climatic temperatures. the SRI is to encourage light colored surfaces that reduce surface temperatures. High SRI surfaces can help reduce the urban heat island, the dome of warm air over a city that increases summer air conditioning costs and traps air pollutants.

Grid pavement - LEED ® defines open-grid pavement as one having less than 50% imperviousness. This includes concrete grid pavements with grass. Compared to asphalt, grassed grid pavements will reduce surface air temperatures by 2 o to 4 o F (1 o to 2 o C) and radiometric temperatures by 4 o to 6 o F (2 o to 4 o C) (Smith, 1981). Evapo-transpiration from the grass provides this cooling. Concrete grid pavers are recommended for overflow or intermittent parking areas and aren't intended where cars park regularly. Grids and grass will provide heat reducing benefits for these areas. Areas with regular parking should be paved with PICP.

Figure 4. Light colored paving units reflect light and help reduce mico-climatic temperatures.

USGBC SS Credit 7.2 Heat Island Effect: Roof

1 Point

Requirements

OPTION 1
Use roofing materials having a Solar Reflectance Index (SRI)[3] equal to or greater than the values in the table below for a minimum of 75% of the roof surface.
OR

OPTION 2
Install a vegetated roof for at least 50% of the roof area.
OR

OPTION 3
Install high albedo and vegetated roof surfaces that, in combination, meet the following criteria: (Area of SRI Roof / 0.75) + (Area of vegetated roof / 0.5) $\geq$Total Roof Area

Roof Type	Slope	SRI
Low-Sloped Roof	$\leq$2:12	78
Steep-Sloped Roof	>2:12	29

Potential Technologies & Strategies

Consider installing high-albedo and vegetated roofs to reduce heat absorption. SRI is calculated according to ASTM E 1980. Reflectance is measured according to ASTM E 903, ASTM E 1918, or ASTM C 1549. Emittance is measured according to ASTM E 408 or ASTM C 1371. Default values will be available in the LEED®-NC v2.2 Reference Guide. Product information is available from the Cool Roof Rating Council website, at www.coolroofs.org.

[3]The Solar Reflectance Index (SRI) is a measure of the constructed surface's ability to reflect solar heat, as shown by a small temperature rise. It is defined so that a standard black (reflectance 0.05, emittance 0.90) is 0 and a standard white (reflectance 0.80, emittance 0.90) is 100. To calculate the SRI for a given material, obtain the reflectance value and emittance value for the material. SRI is calculated according to ASTM E 1980. Reflectance is measured according to ASTM E 903, ASTM E 1918, or ASTM C 1549. Emittance is measured according to ASTM E 408 or ASTM C 1371.

Calculations
Simple formulas for calculating shade, pervious portion of the site and vegetated roof percentages are provided below (USGBC 2003):

Shade [%] = Shaded Impervious Area / Total Impervious Area
Pervious Portion [%] = Pervious Parking Area / Total Parking Area
Vegetated Roof [%] = Vegetated Roof Area / Total Roof Area

Some projects may combine a green roof with high reflectance roofing materials such concrete pavers or paving slabs. A sample calculation to meet the CaGBC credit calculates the minimum areas of green roof and reflective roof using the following formula: (1 .5 x Area green roof) + Area of reflective roof = 0 .75 x Total roof area For example, if the total roof area is 10,000 sf (1,000 m 2) and 4,000 sf (400 m 2) were designed as a green roof, the area of the reflective roof required to meet this credit is 1,500 sf or 150 m 2 , or:

(1 .5 x 4,000 sf) + X = 0 .75 x 10,000 sf
6000 + X = 7500
X = 1500

Figure 5. Light colored paving on low-slope roofs reflects light saving on air-conditioning costs while protecting the waterproofing.

Materials and Resources
USGBC LEED ® Credits applicable to segmental concrete paving products include the following:
Credit MR 2.1 Construction Waste Management: Divert 50% from Disposal
Credit MR 2.2 Construction Waste Management: Divert 75% From Disposal
Credit MR 3.1 Materials Reuse: 5%
Credit MR 3.2 Materials Reuse: 10%
Credit MR 4.1 Recycled Content: 10% (post-consumer + ½ post-industrial)
Credit MR 4.2 Recycled Content: 20% (post-consumer + ½ post-industrial)

Credit MR 5.1 Regional Materials: 10% Extracted, Processed and Manufactured Regionally
Credit MR 5.2 Regional Materials: 20% Extracted, Processed and Manufactured Regionally

USGBC LEED ® MR Credit 2.1 Construction Waste Management: Divert 50% from Disposal
1 Point

Intent
Divert construction, demolition and land clearing debris from landfill disposal. Redirect recyclable recovered resources back to the manufacturing process. Redirect reusable materials to appropriate sites.

Requirements
Recycle and/or salvage at least 50% of non-hazardous construction and demolition debris. Develop and implement a construction waste management plan that, at a minimum, identifies the materials to be diverted from disposal and whether the materials will be sorted on-site or comingled. Excavated soil and land-clearing debris do not contribute to this credit. Calculations can be done by weight or volume, but must be consistent throughout.

Potential.Technologies.&.Strategies
Establish goals for diversion from disposal in landfills and incinerators and adopt a construction waste management plan to achieve these goals. Consider recycling cardboard, metal, brick, acoustical tile, concrete, plastic, clean wood, glass, gypsum wallboard, carpet and insulation. Designate a specific area(s) on the construction site for segregated or comingled collection of recyclable materials, and track recycling efforts throughout the construction process. Identify construction haulers and recyclers to handle the designated materials. Note that diversion may include donation of materials to charitable organizations and salvage of materials on-site.

USGBC LEED ® MR Credit 2.2 Construction Waste Management: Divert 75% from Disposal
1 Point in addition to MR Credit 2.1

Intent
Divert construction and demolition debris from disposal in landfills and incinerators. Redirect recyclable recovered resources back to the manufacturing process. Redirect reusable materials to appropriate sites.

Requirements
Recycle and/or salvage an additional 25% beyond MR Credit 2.1 (75% total) of non-hazardous construction and demolition debris. Excavated soil and land-clearing debris do not contribute to this credit. Calculations can be done by weight or volume, but must be consistent throughout.

Potential.Technologies.&.Strategies
Establish goals for diversion from disposal in landfills and incinerators and adopt a construction waste management plan to achieve these goals. Consider recycling cardboard, metal, brick, acoustical tile, concrete, plastic, clean wood, glass, gypsum wallboard, carpet and insulation. Designate a specific area(s) on the construction site for segregated or commingled collection of recyclable materials, and track recycling efforts throughout the construction process. Identify construction haulers and recyclers to handle the designated materials. Note that diversion may include donation of materials to charitable organizations and salvage of materials on-site.

Application of Credits MR 2.1 and 2.2
High tipping fees at landfills and threat of soil pollution have forced recycling of construction and demolition waste. The US EPA estimates this type of waste accounts for 23% of municipal solid waste (USGBC 2003). Like most concrete, pavers can be crushed and recycled, or removed and reinstated elsewhere on the site. A key consideration is that waste material reused on-site or processed and shipped off-site cannot be used for other LEED ® credits such as those from Resource Reuse, Recycled Content or Regional Materials content credits. These three credits are based on costs. The intent of Credits MR 2.1 and 2.2 is to recycle construction waste on the site, or process and place it into the market for recycled materials. These actions do not involve a purchase transaction. The types of demolition waste from a site should be estimated (by weight or volume) and listed in a waste management plan. Their ultimate destination should also be identified as well as the percentage of waste that remains on the site. The crowded nature of construction in dense urban areas will almost always require collection of concrete in waste bins for shipment to off-site processing. Other projects may have sufficient space on the site to separate and process waste construction materials. In such cases, local regulations for processing should be followed. In contrast, concrete removed from the site, processed and sold back to the same job site, or recycled material purchased from elsewhere and brought to the site can qualify for Recycled Content and Regional Materials credits. Examples are shipping used concrete pavers to a recycler, crushing them and purchasing them back for re-use on the site as base material. Another example is purchasing recycled, crushed concrete for a base under interlocking concrete pavements. These two examples could earn Recycled Content and Regional Materials content credits.

Documentation
If the project involves renovating an existing site, concrete pavers at the site can be re-used or directed to other appropriate sites. Concrete pavers can also be crushed and re-used for road base materials. A list of the total construction waste is required, measured by weight or volume, specifying those that will be diverted from the landfill. This list is typically prepared by the company responsible for waste management on the site. Calculations can be in weight or volume, but they must be consistent. They do not include hazardous waste and excavated soil. Typically, waste containers are sized by volume and are weighed at the material recovery facility or landfill site. Typical factors for converting concrete paver volume to weight are 140 to 145 lbs/ft 3 (2240 to

2350 kg/ m 3) for stacked pavers and approximately 100 lb/ft 3 (1600 kg/m 3) for loose pavers in a bin. The following equation is used to calculate the percent recycled:

% Recycled = Recycled Waste / Recycled Waste + Garbage

Where Garbage is the land-filled material and the Recycled Waste is the recycled construction, demolition and land clearing wastes.

USGBC LEED ® MR Credit 3.1 Materials Reuse: 5%
1 Point

Requirements
Use salvaged, refurbished or reused materials such that the sum of these materials constitutes at least 5%, based on cost, of the total value of materials on the project. Mechanical, electrical and plumbing components and specialty items such as elevators and equipment shall not be included in this calculation. Only include materials permanently installed in the project. Furniture may be included, providing it is included consistently in MR Credits 37.

Potential.Technologies.&.Strategies
Identify opportunities to incorporate salvaged materials into building design and research potential material suppliers. Consider salvaged materials such as beams and posts, flooring, paneling, doors and frames, cabinetry and furniture, brick and decorative items.

USGBC LEED ® MR Credit 3.2 Materials Reuse: 10%
1 Point in addition to MR Credit 3.1

Intent
Reuse building materials and products in order to reduce demand for virgin materials and to reduce waste, thereby reducing impacts associated with the extraction and processing of virgin resources.

Requirements
Use salvaged, refurbished or reused materials, products and furnishings for at least 10% of building materials.

Requirements
Use salvaged, refurbished or reused materials for an additional 5% beyond MR Credit 3.1 (10% total, based on cost). Mechanical, electrical and plumbing components and specialty items such as elevators and equipment shall not be included in this calculation. Only include materials permanently installed in the project. Furniture may be included, providing it is included consistently in MR Credits 37.

Potential.Technologies.&.Strategies
Identify opportunities to incorporate salvaged materials into building design and research potential material suppliers. Consider salvaged materials such as beams and posts, flooring, paneling, doors and frames, cabinetry and furniture, brick and decorative items.

Application of Credits MR 3.1 and 3.2
A material salvaged during a building renovation can be applied to this credit only if it can no longer serve its original function and has been reprocessed and installed for a different use. An example would be crushing salvaged concrete pavers for reuse as pavement base material. However, on a project where an existing building is being demolished or deconstructed the material salvaged and installed on the new site can be used to comply to this credit.

Documentation
To calculate the percentage of salvaged material, list all of the salvaged materials and their costs. If the cost of the salvaged material is below market value, use the replacement cost. For example, salvaged concrete pavers may be purchased for $.50/ft 2 ($5.38/m 2) and new pavers would cost $2.50/ft 2 ($26.90/m 2). For this credit, use the new cost in the following salvage calculation:

% Salvage Rate = Market value of salvage materials if purchased new / Total project material costs

For example, total material costs on a project are $1,600,000 (excluding labor and equipment costs). Existing concrete pavers on the site are salvaged and reused for a 35,000 ft 2 (3,500 m 2) parking lot at a potential new cost of $2.50/ft 2 ($26.90/m 2). The market value of new replacement material is $87,500. Therefore, 5.4% of the materials costs are spared through salvaging and reuse. This qualifies for one point. An additional point is earned if other salvaged materials from the project are added to this to bring this calculation to over 10%.

USGBC LEED ® MR Credit 4.1 Recycled Content: 10% (post-consumer + 1/2 pre-consumer)
1 Point

Intent
Increase demand for building products that incorporate recycled content materials, therefore reducing impacts resulting from

extraction and processing of virgin materials.

Requirements
Use materials with recycled content such that the sum of post-consumer recycled content plus one-half of the pre-consumer content constitutes at least 10% (based on cost) of the total value of the materials in the project. The recycled content value of a material assembly shall be determined by weight. The recycled fraction of the assembly is then multiplied by the cost of assembly to determine the recycled content value. Mechanical, electrical and plumbing components and specialty items such as elevators shall not be included in this calculation. Only include materials permanently installed in the project. Furniture may be included, providing it is included consistently in MR Credits 37. Recycled content shall be defined in accordance with the International Organization of Standards document, ISO 14021-Environmental labels and declarations-Selfdeclared environmental claims (Type II environmental labeling). Post-consumer material is defined as waste material generated by households or by commercial, industrial and institutional facilities in their role as end-users of the product, which can no longer be used for its intended purpose. Pre-consumer material is defined as material diverted from the waste stream during the manufacturing process. Excluded is reutilization of materials such as rework, regrind or scrap generated in a process and capable of being reclaimed within the same process that generated it.

Potential.Technologies.&.Strategies
Establish a project goal for recycled content materials and identify material suppliers that can achieve this goal. During construction, ensure that the specified recycled content materials are installed. Consider a range of environmental, economic and performance attributes when selecting products and materials.

USGBC LEED ® MR Credit 4.2 Recycled Content: 20% (post-consumer + 1/2 pre-consumer)
1 Point in addition to MR Credit 4.1

Requirements
Use materials with recycled content such that the sum of post-consumer recycled content plus one-half of the preconsumer content constitutes an additional 10% beyond MR Credit 4.1 (total of 20%, based on cost) of the total value of the materials in the project. The recycled content value of a material assembly shall be determined by weight. The recycled fraction of the assembly is then multiplied by the cost of assembly to determine the recycled content value. Mechanical, electrical and plumbing components and specialty items such as elevators shall not be included in this calculation. Only include materials permanently installed in the project. Furniture may be included, providing it is included consistently in MR Credits 37. Recycled content shall be defined in accordance with the International Organization of Standards document, ISO 14021-Environmental labels and declarations-Selfdeclared environmental claims (Type II environmental labeling). Post-consumer material is defined as waste material generated by households or by commercial, industrial and institutional facilities in their role as end-users of the product, which can no longer be used for its intended purpose. Pre-consumer material is defined as material diverted from the waste stream during the manufacturing process. Excluded is reutilization of materials such as rework, regrind or scrap generated in a process and capable of being reclaimed within the same process that generated it.

Potential.Technologies.&.Strategies
Establish a project goal for recycled content materials and identify material suppliers that can achieve this goal. During construction, ensure that the specified recycled content materials are installed. Consider a range of environmental, economic and performance attributes when selecting products and materials.

Application of Credits MR 4.1 and 4.2
Segmental concrete paving products can be made with recycled materials and contribute to this credit. A portion of the cement can be replaced with flyash (coal combustion by-product), silica fume (by-product of silicon production), ground granulated blast furnace slag (from steel production), and recycled aggregate. They are called supplementary cementitious materials or SCMs. There is a growing amount of evidence that release of CO_2 from combustion and methane gasses contribute to global warming. For every ton of cement produced about a ton of CO_2 is released into the atmosphere. (Compare this to one gallon (3.8 l) of gasoline generates about 20 lbs (9 kgs) of CO_2 .) Cement production comprises approximately 6% of CO_2 generated throughout the world. Replacing a portion of cement with SCMs reduces CO_2 output. The potential for replacing cement will vary among paver manufacturers based on their location, which affects price and availability of recycled materials. Consult with an ICPI producer member to determine use of cement substitutes in paving products. Some cement suppliers to paver producers may provide cement with SCMs. Recycled content within cement does not count toward this credit unless the cement supplier provides a statement of recycled content for the cement.

Documentation
The percentage requirements in this LEED ® credit are based on cost. Post-consumer recycled content refers to recycled materials or products recovered and recycled after use by the consumer, e.g. a plastic bottle. For manufactured concrete pavers, this is typically not used in the calculation. Post industrial waste for concrete pavers means recycled materials or products recovered and traded such as flyash, slag or silica fume. These materials should meet the ASTM and CSA definitions for SCMs. Using a concrete mix without supplementary cementing materials is compared to the mix ingredients used with SCMs to calculate the Portland cement reduction. This is converted to a percent with a factor of 2 applied to account for the environmental merits of reducing Portland cement by substituting it with SCM's. An example follows: Basic mix: Concrete paver cement content: 16% Portland cement (by weight of total dry mix) SCM mix: Concrete paver with SCMs: 14% Portland cement + 2% flyash (by weight of total dry mix) Percentage of Portland cement reduction = [(Portland cement content of pavers without SCMs Portland cement content used with SCMs)/Portland cement content of pavers without SCMs] x 100 x 2

Reduction in Portland Cement = (16 -14)/16 x 100 x 2 = 25%

This is the post industrial recycled content contributed by the concrete pavers. It is used to calculate the recycled content value in the concrete pavers. For example, if the concrete pavers for a 30,000 ft² (3,000 m²) project were purchased for $75,000, the post industrial recycled value is $75,000 x 25% x ½ = $9,375. This result is added to post-consumer and other post industrial contributions from other materials used for the project. The total post-consumer and post industrial contribution are divided by the total material costs for the project to determine the percent of recycled content. All materials with recycled content are listed on a spreadsheet with their cost, percentage of post-consumer and one-half of the percentage of postindustrial recycled content and resulting dollar values of recycled content. Installation costs are excluded. If the percentage of the value recycled content is 10% or more one point is earned. Two points are earned if the percentage is 20% or more.

USGBC LEED ® MR Credit 5.1
Regional Materials: 10% Extracted, Processed & Manufactured Regionally
1 Point

Intent
Increase demand for building materials and products that are extracted and manufactured within the region, thereby supporting the regional economy and reducing the environmental impacts resulting from transportation.

Requirements
Use building materials or products that have been extracted, harvested or recovered, as well as manufactured, within 500 miles of the project site for a minimum of 10% (based on cost) of the total materials value. If only a fraction of a product or material is extracted/harvested/recovered and manufactured locally, then only that percentage (by weight) shall contribute to the regional value. Mechanical, electrical and plumbing components and specialty items such as elevators and equipment shall not be included in this calculation. Only include materials permanently installed in the project. Furniture may be included, providing it is included consistently in MR Credits 37.

Potential.Technologies.&.Strategies
Establish a project goal for locally sourced materials, and identify materials and material suppliers that can achieve this goal. During construction, ensure that the specified local materials are installed and quantify the total percentage of local materials installed. Consider a range of environmental, economic and performance attributes when selecting products and materials.

USGBC LEED ® MR Credit 5.2
Regional Materials: 20% Extracted, Processed & Manufactured Regionally
1 Point in addition to MR Credit 5.1

Intent
Increase demand for building materials and products that are extracted and manufactured within the region, thereby supporting the regional economy and reducing the environmental impacts resulting from transportation.

Requirements
Use building materials or products that have been extracted, harvested or recovered, as well as manufactured, within 500 miles of the project site for an additional 10% beyond MR Credit 5.1 (total of 20%, based on cost) of the total materials value. If only a fraction of the material is extracted/harvested/recovered and manufactured locally, then only that percentage (by weight) shall contribute to the regional value.

Potential.Technologies.&.Strategies
Establish a project goal for locally sourced materials and identify materials and material suppliers that can achieve this goal. During construction, ensure that the specified local materials are installed. Consider a range of environmental, economic and performance attributes when selecting products and materials.

Application of Credit MR 5.1 and MR 5.2
Segmental concrete paving products can earn these credits since most extraction of aggregate and sand from quarries and the manufacturing plant are often within 500 miles (800 km) of the project site.

Documentation
Credits 5.1 and 5.2 are met by the contractor providing costs to the designer for all materials that meet these requirements. The invoice cost is typically used but must exclude transportation costs. In addition, a letter from the manufacturer should indicate the location of the manufacturing facility and location of the source(s) of extracted materials. Material product sheets can be provided instead of a letter if the sheets clearly state the manufacturing location and resource extraction locations. A single letter from a manufacturer can certify compliance with more than one credit. For example, a single letter can be supplied for concrete pavers with a recycled content and production within 500 miles (800 km) of the project.

Other Sources of LEED ® Credits
Innovation and Design Processes-USGBC LEED ® Credits applicable to segmental concrete paving products include one to four points for Innovation in Design and an additional point for using a LEED ® Accredited Professional. Innovation in Design encourages new ideas in sustainability to gain recognition. The LEED ® Accredited Professional encourages designers to have a person with this credential on the design team. The USGBC and CaGBC LEED ® Credit 1 for Innovation in Design are almost identical. See below and page 23. Likewise, USGBC LEED ® Credit 2.1 and CaGBC LEED ® Credit 2 for Accredited Professional are almost identical. See below and page 23.

USGBC LEED ® ID Credit 1-1.4 Innovation in Design
1 to 4 Points

Intent
To provide design teams and projects the opportunity to be awarded points for exceptional performance above the requirements set by the LEED ® Green Building Rating System and/or innovative performance in Green Building categories not specifically addressed by the LEED ® Green Building Rating System.

Requirements
Credit 1.1 (1 point) In writing, identify the intent of the proposed innovation credit, the proposed requirement for compliance, the proposed submittals to demonstrate compliance, and the design approach (strategies) that might be used to meet the requirements.
Credit 1.2 (1 point) Same as Credit 1.1
Credit 1.3 (1 point) Same as Credit 1.1
Credit 1.4 (1 point) Same as Credit 1.1

Potential.Technologies.&.Strategies
Substantially exceed a LEED ® performance credit such as energy performance or water efficiency. Apply strategies or measures that demonstrate a comprehensive approach and quantifiable environment and/or health benefits.

Application of Credit 1
This credit category enables designers to incorporate innovative improvements in building materials and design into the LEED ® rating system. Besides original innovative design, credits may be awarded if a project achieves exceptional performance under an existing LEED ® credit for that project. Examples include exceeding or using water exfiltrated from PICP for landscape irrigation or grey water reuse in the building. As a general rule of thumb, ID credits for exceptional performance are awarded for doubling the credit requirements and/or achieving the next incremental percentage threshold.

USGBC LEED ® ID Credit 2.1 LEED ® Accredited Professional
1 Point

Intent
To support and encourage the design integration required by a LEED ® Green Building project and to streamline the application and certification process.

Requirements
At least one principal participant of the project team shall be a LEED ® Accredited Professional (AP).

Potential.Technologies.&.Strategies
Educate the project team members about green building design & construction and application of the LEED ® Rating System early in the life of the project. Consider assigning the LEED ® AP as a facilitator of an integrated design & construction process.

CaGBC

CaGBC LEED®-NC Version 1.0 Credits

Sustainable Sites
Credits applicable to segmental concrete paving products for sustainable sites include the following:
SS Credit 6.1 Stormwater Management, Rate and Quality
SS Credit 6.2 Stormwater Management, Treatment
SS Credit 7.1 Heat Island Effect, Non-roof
SS Credit 7.2 Heat Island Effect, Roof

CaGBC LEED ® SS Credit 6.1 Stormwater Management, Rate and Quantity
1 point

Intent
Limit disruption and pollution of natural water flows by managing stormwater runoff.

Requirements
If existing imperviousness is less than or equal to 50%, implement a stormwater management plan that prevents the post-development 1.5 year, 24 hour peak discharge rate and quantity from exceeding the pre-development 1.5 year, 24 hour peak discharge rate and quantity.
OR,
If existing imperviousness is greater than 50%, implement a stormwater management plan that results in a 25% decrease in the rate and quantity of stormwater runoff.

Submittals
Provide the LEED ® Letter Template, signed by the civil engineer or responsible party, declaring that the postdevelopment 1.5 year, 24 hour peak discharge rate and quantity does not exceed the pre-development 1.5 year 24 hour peak discharge rate and quantity. Include calculations demonstrating that existing site imperviousness is less then or equal to 50%.
OR,
Provide the LEED ® Letter Template, signed by the civil engineer or responsible party, declaring and demonstrating that the stormwater management strategies result in at least a 25% decrease in the rate and quantity of stormwater runoff. Include calculations demonstrating that existing site imperviousness exceeds 50%. If an audit of this Credit is requested during the certification process: For sites with less than 50% net imperviousness, provide pre-construction and post-construction site drawing. Include area calculations demonstrating no increase in net imperviousness of the site.
OR,
For sites with greater than 50% net imperviousness, provide a copy of the stormwater management plan. Include calculations describing how the measures of the plan decrease net imperviousness of the site by 25% over existing conditions.

Potential.Technologies.&.Strategies
Design the project site to maintain natural stormwater flows by promoting infiltration. Specify garden roofs and pervious paving to minimize impervious surfaces. Reuse stormwater volumes generated for non-potable uses such as landscape irrigation, toilet and urinal flushing and custodial uses.

CaGBC LEED ® SS Credit 6.2 Stormwater Management, Treatment
1 point

Intent
Limit disruption of natural water flows by elimination stormwater runoff, increasing on-site infiltration and eliminating contaminants.

Requirements
Construct site stormwater treatment systems designed to remove 80% of the average annual post-development total suspended solids (TSS) and 40% of the average annual post-development total phosphorous (TP) based on the average annual loadings from all storms less than or equal to the 2-year/24 hour storm. Do so by implementing the Best Management Practices (BMPs) outlined in Chapter 4, Part 2 (Urban Runoff), of the United States Environmental Protection Agency's (EPA's) Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters, January 1993 (Document No. EPA-840-B-92-002) or the local government's BMP document (which ever is more stringent).

Submittals
Provide the LEED ® Letter Template, signed by the civil engineer or responsible party, declaring that the design complies with or exceeds EPA or local government Best Management Practices (whichever set is more stringent) for removal of the total suspended solids and total phosphorous. If an audit of this Credit is requested during the certification process:

Provide drawings and specifications describing EPA Best Management Practices implemented for removal of TSS and TP. Provide calculations to demonstrate that the BMP's meet or exceed the minimum treatment requirements of the credit.

Potential.Technologies.&.Strategies
Design mechanical or natural treatment systems such as constructed wetlands, vegetated filter strips and bioswales to treat the site's stormwater.

CaGBC LEED ® SS Credit 7.1 Heat Island Effect: Non-Roof
1 Point

Intent
Reduce heat islands (thermal gradient differences between developed and undeveloped areas) to minimize impact on microclimate and human wildlife habitat.

Requirements
Provide shade (within 5 years) and/or use light-coloured / high-albedo materials (reflectance of at least 0.3) and/or open grid pavement for at least 30% of the site's non-roof impervious surfaces, including parking lots, walkways, plazas, etc.; OR, Place a minimum of 50% of parking spaces underground or covered by structured parking; OR, Use an open-grid pavement system (less than 50% impervious) for a minimum of 50% of the parking lot area.

Submittals
Provide the LEED ® Letter Template, signed by the civil engineer or responsible party, referencing the site plan to demonstrate areas of paving, landscaping (list species) and building footprint, and declaring that: A minimum of 30% of non-roof impervious surfaces areas are constructed with high-albedo materials and/or open grid pavement and/or will be shaded within five years OR, A minimum of 50% of parking spaces have been placed underground or are covered by structural parking OR, An open-grid pavement system (less than 50% impervious) has been used for a minimum of 50% of the parking lot area. If an audit of this Credit is requested during the certification process: Provide drawings highlighting all non-roof impervious surfaces and potions of these surfaces that will be shaded within five years. Including calculations demonstrating that a minimum of 30% of non-roof impervious surfaces areas will be shaded within five years. OR, Provide specifications and cut sheets for high-albedo materials applied to non-

roof impervious surfaces highlighting reflectance of the installed materials. OR, Provide drawings and cut sheets for a pervious paving system with a minimum perviousness of 50%. Including calculations demonstrating that the paving system covers a minimum of 50% of the total parking area.

Potential.Technologies.&.Strategies
Shade constructed surfaces on the site with landscape features and minimize the overall building footprint. Consider replacing constructed surfaces (i.e. roof, roads, sidewalks, etc.) with vegetated surfaces such as garden roofs and open grid paving or specify high-albedo materials to reduce the heat absorption. Provide drawings and specifications describing EPA Best Management Practices implemented for removal of TSS and TP.

CaGBC LEED ® SS Credit 7.2 Heat Island Effect: Roof
1 Point

Intent
Reduce heat islands (thermal gradient differences between developed and undeveloped areas) to minimize impact on microclimate and human and wildlife habitat.

Requirements
Use ENERGY STAR ® compliant (highly reflective) AND high emissivity roofing (emissivity of at least 0.9 when tested in accordance with ASTM 408) for a minimum of 75% of the roof surfaces; OR, Install a "green" (vegetated) roof for at least 50% of the roof area. Combinations of high albedo and vegetated roof can be used but they must collectively provide an effective area equal or greater than the 75% coverage that would be provided by a reflective roof alone but accounting for the relative weighted contributions.

Submittals
Provide the LEED ® Letter Template, signed by the civil engineer or responsible party, referencing the building plan and declaring that the roofing material comply with the ENERGY STAR ® Label requirements and have a minimum emissivity of 0.9. Demonstrate that high-albedo and vegetated roof areas combined constitute at least 50% of the total roof area. OR, Provide the LEED ® Letter Template, signed by the architect or responsible party, referencing the building plan and demonstrating that combined vegetated roof areas and high albedo surfaces are equivalent to at least 75% of the total roof area using a high albedo surface. If an audit of this Credit is requested during the certification process: Provide specifications and cut sheets highlighting roofing materials that are Energy Star labeled, with a minimum initial reflectance of 0.65, and a minimum three-yearaged reflectance of 0.5, and a minimum emissivity of 0.9. Include area calculations demonstrating that the roofing material covers a minimum of 75% of the total roof area. OR Provide specifications and cut sheets highlighting a green vegetated roof system. Include area calculations demonstrating that the roof system covers a minimum of 50% of the total roof area. OR Provide specifications and cut sheets highlighting reflective, low emittance roofing materials and green vegetated roof systems that collectively meet the credit requirement. Include area calculations demonstrating that the combined roof system provides an equivalent minimum area to the 75% coverage using a high albedo surface.

Potential.Technologies.&.Strategies
Visit the ENERGY STAR® Web site, www.energystar.gov, to look for compliant products. Consider installing highalbedo and vegetated roofs to reduce heat absorption.

Application of SS Credit 7.2
Emittance Emissivity or infrared emittance is a parameter between 0 and 1 which measures the ability of a warm or hot material to shed some of its heat in the form of infrared radiation (Cool Roofing). The wavelength range for this radiant energy is approximately 5 to 40 micrometers. Most building materials are opaque in this part of the spectrum and have an emittance of roughly 0.9. Concrete paving products have a minimum emissivity of 0.9 so they would conform to this requirement. ASTM E 408, Standard Test Methods for Total Normal Emittance of Surfaces Using Inspection-Meter Techniques is used to determine emittance of materials (ASTM 2005).
ENERGY STAR ® Rating ENERGY STAR ® is a U.S. government rating system to assess the ability of roof material to reflect solar radiation which reduces air conditioning loads. Lighter colored roof surfaces yield lower air conditioning costs. To qualify for ENERGY STAR ® , roof products such as concrete pavers and paving slabs must have warranties comparable to non-reflective roof products. They also must meet the criteria in Table 3 for albedo or solar reflectance. Practically all paving products used in roofs would be in lowslope applications. ASTM E 903 is used to determine solar reflectance or albedo. Specifiers should request reflectance data from suppliers. Albedo of paving products for non-roof applications applies to those used on roofs. The ENERGY STAR ® website <www.energystar.gov> lists compliant roofing products and also cross references with the reflectance and emissivity data listed in the Lawrence Berkeley National Laboratory's Cool Roofing Materials Database. This data does not include concrete unit paving. Specifiers may request reflectance and emissivity data from suppliers.

Table 3 . ENERGY STAR ® *reflectance requirements*

Roof Slope	Initial Solar Reflectance	3rd Year Solar Reflectance
Low-slope (≤ 2:12 inches)	> 0.65	> 0.50
Steep-slope (> 2:12 inches)	> 0.25	> 0.15

Materials and Resources
USGBC and CaGBC LEED ® Credits applicable to segmental concrete paving products include the following:
Credit MR 2.1 Construction Waste Management: Divert 50% from Landfill
Credit MR 2.2 Construction Waste Management: Divert 75% From Landfill
Credit MR 3.1 Resource Reuse: 5% Credit MR 3.2 Resource Reuse: 10%
Credit MR 4.1 Recycled Content: 7.5% (post-consumer + ½ post-industrial)
Credit MR 4.2 Recycled Content: 15% (post-consumer + ½ post-industrial)
Credit MR 5.1 Regional Materials: 10% Extracted and Manufactured Regionally
Credit MR 5.2 Regional Materials: 20% Extracted and Manufactured Regionally

CaGBC LEED ® MR Credit 2.1 Construction Waste Management: Divert 50% from Landfill
1 Point

Intent
Divert construction, demolition and land clearing debris from landfill disposal. Redirect recyclable recovered resources back to the manufacturing process. Redirect reusable materials to appropriate sites.

Requirements
Develop and implement a waste management plan, quantifying material diversion goals. Recycle and/or salvage at least 50% of construction demolition and land clearing waste. Calculations can be done by weight or volume,but must be consistent throughout.

Submittals
Provide the LEED ® Letter Template, signed by the architect, owner or responsible party, tabulating the total waste material, quantities diverted and the means by which diverted, and declaring that the Credit requirements have been met. If an audit is requested during the certification process: Provide a copy of the Waste Management Plan for the project highlighting recycling and salvage requirements. Include calculations demonstrating that 50% of the nonshell components were reused. Provide calculations on end-of-project recycling rates, salvage rates, and landfill rates demonstrating that 50% of construction wastes were recycled or salvaged.

Potential.Technologies.&.Strategies
Establish goals for landfill diversion and adopt a construction waste management plan to achieve these goals. Consider recycling land clearing debris, cardboard, metal, brick, concrete, plastic, clean wood, glass, gypsum wallboard, carpet and insulation. Designate a specific area on the construction site for recycling and track recycling efforts throughout the construction process. Identify construction haulers and recyclers to handle the designation of materials. Note that salvage may include donation of materials to charitable organizations such as Habitat for Humanity.

CaGBC LEED ® MR Credit 2.2 Construction Waste Management: Divert 75% from Landfill
1 Point

Intent
Divert construction, demolition and land clearing debris from landfill disposal. Redirect recyclable recovered resources back to the manufacturing process. Redirect reusable materials to appropriate sites.

Requirements
Develop and implement a waste management plan, quantifying material diversion goals. Recycle and/or salvage and additional 25% (75% of total) of construction, demolition and land clearing waste. Calculations can be done by weight or volume, but must be consistent throughout.

Submittals
Provide the LEED ® Letter Template, signed by the architect, owner or responsible party, tabulating the total waste material, quantities diverted and the means by which diverted, and declaring that the Credit requirements have been met. If an audit is requested during the certification process: Provide a copy of the Waste Management Plan for the project highlighting recycling and salvage requirements. Provide calculations on end-of-project recycling rates, salvage rates, and landfill rates demonstrating that 75% of construction wastes were recycled or salvaged.

Potential.Technologies.&.Strategies
Establish goals for landfill diversion and adopt a construction waste management plan to achieve these goals. Consider recycling land clearing debris, cardboard, metal, brick, concrete, plastic, clean wood, glass, gypsum wallboard, carpet and insulation. Designate a specific area on the construction site for recycling and track recycling efforts throughout the construction process. Identify construction haulers and recyclers to handle the designation of materials. Note that salvage may include donation of materials to charitable organizations such as Habitat for Humanity.

CaGBC LEED ® MR Credit 3.1 Resources Reuse: 5%
1 Point

Intent
Reuse building materials and products in order to reduce demand for virgin materials and to reduce waste, thereby reducing impacts

associated with the extraction and processing of virgin resources.

Requirements
Use salvaged, refurbished or reused materials, products and furnishings for at least 5% of the total cost of building materials.

Submittals
Provide the LEED ® Letter Template, signed by the architect, owner or responsible party, declaring that the credit requirements have been met and listing each material or products used to meet the credit. Include details demonstrating that the project incorporates the required percentage of reused materials and products and showing their costs and the total cost of materials for the project. The salvaged or refurbished status of each material must be validated by a statement from the provider of that material, in case this Credit is audited. If an audit is requested during the certification process: Provide specifications and contractor submittals highlighting salvaged and refurbished materials used on the project

Potential.Technologies.&.Strategies
Identify opportunities to incorporate salvaged materials into building design and research potential material suppliers. Consider salvaged materials such as beams and posts, flooring, paneling, doors and frames, cabinetry and furniture, brick and decorative items.

CaGBC LEED ® MR Credit 3.2 Resource Reuse: 10%
1 Point

Intent
Reuse building materials and products in order to reduce demand for virgin materials and to reduce waste, thereby reducing impacts associated with the extraction and processing of virgin resources.

Requirements
Use salvaged, refurbished or reused materials, products and furnishings for at least 10% of the total cost of building materials.

Submittals
Provide the LEED ® Letter Template, signed by the architect, owner or responsible party, declaring that the credit requirements have been met and listing each material or products used to meet the credit. Include details demonstrating that the project incorporates the required percentage of reused materials and products and showing their costs and the total cost of materials for the project. The salvaged or refurbished status of each material must be validated by a statement from the provider of that material, in case this Credit is audited. If an audit is requested during the certification process: Provide specifications and contractor submittals highlighting salvaged and refurbished materials used on the project

Potential.Technologies.&.Strategies
Identify opportunities to incorporate salvaged materials into building design and research potential material suppliers. Consider salvaged materials such as beams and posts, flooring, paneling, doors and frames, cabinetry and furniture, brick and decorative items.

CaGBC LEED ® MR Credit 4.1 Recycled Content: 7.5% (Post-Consumer + ½ Post-Industrial)
1 Point

Intent
Increase demand for building products that incorporate recycled content materials, therefore reducing impacts resulting from extraction and processing of new virgin materials and by-passing energy and green house gas intensive industrial and manufacturing processes.

Requirements
Use materials with recycled content such that the sum of the post-consumer recycled content plus one-half of the post-industrial content constitutes at least 7.5% of the total value of the materials in the project. The value of the recycled content portion of the materials or furnishing shall be determined by dividing the weight of the recycled content in the item by the total weight of all material in the item, then multiplying the resulting percentage by the total cost of the item. Mechanical and electrical components shall not be included in this calculation. Recycled content materials shall be defined in accordance with the Federal Trade Commission document, Guides for the Use of Environmental Marketing Claims, 16 CFR 260.7 (e), available at www.ftc.gov/bcp/grnrule/guides980427.htm.

Submittals
Provide the LEED ® Letter Template, signed by the architect, owner or responsible party, declaring that the credit requirements have been met and listing the recycled content products used. Include details demonstrating that the project incorporates the required percentage of recycled content materials and products and showing their cost and percentage(s) of post-consumer and/or post-industrial content, and the total cost of all materials for the project. If Supplementary Cementing Materials (SCMs) are used as part of the percentage recycled content, a letter signed by the concrete supplier/manufacturer or professional engineer must be submitted that certifies the reduction in Portland cement from Base Mix to Actual SCM Mix (as a percentage), where Base Mix is defined in LEED® reference guide calculations. This can be provided as a total reduction in Portland cement for all the concrete used on the project. If an audit is requested during the certification process: Provide specifications and contractor submittals

highlighting recycled content materials installed.

Potential.Technologies.&.Strategies
Establish a project goal for recycled content materials and identify material suppliers that can achieve this goal. During construction, ensure that the specified recycled content materials are installed and quantify the total percentage of recycled content materials installed.

CaGBC LEED ® MR Credit 4.2 Recycled Content: 15% (Post-Consumer + ½ Post-Industrial)
1 Point

Intent
Increase demand for building products that incorporate recycled content materials, therefore reducing impacts resulting from extraction and processing of new virgin materials and by-passing energy and green house gas intensive industrial and manufacturing processes.

Requirements
Use materials with recycled content such that the sum of the post-consumer recycled content plus one-half of the post-industrial content constitutes at least 15% of the total value of the materials in the project. The value of the recycled content portion of the materials or furnishing shall be determined by dividing the weight of the recycled content in the item by the total weight of all material in the item, then multiplying the resulting percentage by the total cost of the item. Mechanical and electrical components shall not be included in this calculation. Recycled content materials shall be defined in accordance with the Federal Trade Commission document, Guides for the Use of Environmental Marketing Claims, 16 CFR 260.7 (e), available at www.ftc.gov/bcp/grnrule/guides980427.htm.

Submittals
Provide the LEED ® Letter Template, signed by the architect, owner or responsible party, declaring that the credit requirements have been met and listing the recycled content products used. Include details demonstrating that the project incorporates the required percentage of recycled content materials and products and showing their cost and percentage(s) of post-consumer and/or post-industrial content, and the total cost of all materials for the project. If Supplementary Cementing Materials (SCMs) are used as part of the percentage recycled content, a letter signed by the concrete supplier/manufacturer or professional engineer must be submitted that certifies the reduction in Portland cement from Base Mix to Actual SCM Mix (as a percentage), where Base Mix is defined in LEED ® reference guide calculations. This can be provided as a total reduction in Portland cement for all the concrete used on the project. If an audit is requested during the certification process: Provide specifications and contractor submittals highlighting recycled content materials installed.

Potential.Technologies.&.Strategies
Establish a project goal for recycled content materials and identify material suppliers that can achieve this goal. During construction, ensure that the specified recycled content materials are installed and quantify the total percentage of recycled content materials installed.

CaGBC LEED ® MR Credit 5.1 Regional Materials: 10% Extracted and Manufactured Regionally
1 Point

Intent
Increase demand for building materials and products that are extracted and manufactured within the region, thereby supporting the use of indigenous resources and reducing the environmental impacts resulting from transportations.

Requirements
Use a minimum of 10% of building materials or products for which at least 80% of the mass is extracted, processed and manufactured within 800 km (500 miles) of the project site.OR, Use a minimum of 10% of building materials or products for which at least 80% of the mass is extracted, processed and manufactured within 2,400 km (1,500 miles) of the project site and shipped by rail or water. OR, Use a minimum of 10% of building materials or products that reflect a combination of the above extraction, processing, manufacturing and shipping criteria (e.g. 5% within 800 km (500 miles) and 5% shipped by rail within 2400 km (1,500 miles).

Submittals
Provide the LEED ® Letter Template, signed by the architect, or responsible party, declaring that the credit requirements have been met. Include evidence of transportation service by rail or water if applicable; and calculations demonstrating that the project incorporates required percentages of regional materials/products and showing their cost, distance from project to furthest site of extraction or manufacture, and the total cost of all materials for the project. If an audit is requested during the certification process: Provide product cut sheets, product literature, and letters from the manufacturers or other evidence showing the distance from the final point of manufacture to the site and mode of transportation, and the distance from the materials extraction to the site.

Potential.Technologies.&.Strategies
Establish a project goal for regionally sourced materials and identify materials and material suppliers that can achieve this goal. During construction, ensure that the specified regional materials are installed and quantify the total percentage of local materials installed.

CaGBC LEED ® MR Credit 5.2 Regional Materials: 20% Extracted and Manufactured Regionally
1 Point

Intent
Increase demand for building materials and products that are extracted and manufactured within the region, thereby supporting the use of indigenous resources and reducing the environmental impacts resulting from transportations.

Requirements
Use a minimum of 20% of building materials or products for which at least 80% of the mass is extracted, processed and manufactured within 800 km (500 miles) of the project site. OR, Use a minimum of 20% of building materials or products for which at least 80% of the mass is extracted, processed and manufactured within 2400 km (1,500 miles) of the project site and shipped by rail or water. OR, Use a minimum of 20% of building materials or products that reflect a combination of the above extraction, processing, manufacturing and shipping criteria (e.g. 5% within 800 km (500 miles) and 5% shipped by rail within 2400 km (1,500 miles).

Submittals
Provide the LEED ® Letter Template, signed by the architect, or responsible party, declaring that the credit requirements have been met. Include evidence of transportation service by rail or water if applicable; and calculations demonstrating that the project incorporates required percentages of regional materials/products and showing their cost, distance from project to furthest site of extraction or manufacture, and the total cost of all materials for the project.If an audit is requested during the certification process: Provide product cut sheets, product literature, and letters from the manufacturers or other evidence showing the distance from the final point of manufacture to the site and mode of transportation, and the distance from the materials extraction to the site.

Potential.Technologies.&.Strategies
Establish a project goal for regionally sourced materials and identify materials and material suppliers that can achieve this goal. During construction, ensure that the specified regional materials are installed and quantify the total percentage of local materials installed.

CaGBC LEED ® MR Credit 8 Durable Building
1 Point

Intent
Minimize materials use and construction waste over a building's life resulting from premature failure of the building and its constituent components and assemblies.

Requirements
Develop and implement a Building Durability Plan, in accordance with the principles in CSA S478-95 (R2001) Guideline on Durability in Buildings, for the components within the scope of the Guideline, for the construction and pre-occupancy phase of the building as follows:Design and construct the building to ensure that thepredicted service life exceeds the design service life established in Table 2 in CSA S478-95 (R2001) Guideline on Durability in Building.Where components and assembly design service lives are shorter than the design service life of the building, design and construct those components and assemblies so that they can be readily replaced, and use a design service life in accordance with Table 3 in CSA S478-95 (R2001) Guideline on Durability in Building, as follows:For components and assemblies whose categories ofFailure are 6, 7 or 8 in Table 3, use a design service life equal to the design service life of the building. For components and assemblies whose categories of Failure are 4 or 5 in Table 3, use a design service life equal to at least half of the design service life of the building.Demonstrate the predicted service life of chosen components or assemblies by documenting demonstrated effectiveness, modeling of the deterioration process or by testing in accordance with Clause 7.3. 7.4 or 7.5 and by completing Tables A1, A2 & A3 from CSA S478-95 (R2001) Guidelines on Durability in Buildings.Document the elements of quality assurance activities to be carried out to ensure the predicted service life is achieved, in the format contained in Table 1, Quality Assurance and the Building Process, of CSA S478-95 (R2001) Guidelines on Durability in Buildings.Develop and document the quality management program for the project that ensures the quality assurance activities are carried out, in accordance with the elements identified in Clause 5.3, Elements of Quality Management, CSA S478-95 (R2001) Guidelines on Durability in Buildings.

Submittals
Provide the LEED ® Letter Template signed by the professional responsible and the general contractor, declaring that a Building Durability Plan has been developed and implemented. Document the building science qualification certification or training qualifications of the processional(s) responsible for the building envelope design of the building.

Potential.Technologies.&.Strategies
Design strategies specifically included to minimize premature deterioration of the walls and roof and which are appropriate to the region, e.g., shading screens, eaves, overhangs, scuppers, etc., surface materials appropriate to exterior conditions, use of drained walls and continuous air-barrier systems of appropriate strength.

Other Sources of LEED ® Credits
Application of Credit MR 8-This credit requires development of a building durability plan according to CSA S478 Guideline on Durability for Buildings (CSA 2001). This guideline encourages use of readily replaced construction components and assemblies and design strategies that allow for ease of access for repairs, replacements and alterations of components and assemblies throughout the construction phase and service life of the building. The modular nature of all segmental paving products enables

easy access to underground utility repairs and reinstatement of the same paving units with no waste or damage to the surface. ICPI Tech Spec 6 Reinstatement of Interlocking Concrete Pavements provides technical guidance on this topic (ICPI 2005). In addition, roof applications with segmental concrete products and sand bedding or pedestals enable easy access to waterproofing and drains. These unique characteristics of segmental paving enable it to contribute to the building durability plan.

CaGBC LEED ® ID Credit 1-1.4: Innovation & Design Process
1 Point

Intent
To provide design teams and projects the opportunity to be awarded points for exceptional performance above the requirements set by the LEED ® Green Building Rating System and/or innovative performance in Green Building categories not specifically addressed by the LEED ® Green Building Rating System.

Requirements
Credit 1.1 (1 point) In writing, identify the intent of the proposed innovation credit, the proposed requirement for compliance, the proposed submittals to demonstrate compliance, and the design approach (strategies) that must be used to meet the requirements.
Credit 1.2 (1 point) Same as Credit 1.1
Credit 1.3 (1 point) Same as Credit 1.1
Credit 1.4 (1 point) Same as Credit 1.1

Submittals
Provide the proposal(s) within LEED ® Letter Template (including intent, requirement, submittals and possible strategies) and relevant evidence of performance achieved.

Potential.Technologies.&.Strategies
Substantially exceed a LEED ® performance credit such as energy performance or water efficiency. Apply strategies or measures that are not covered by LEED ® such as acoustic performance, education of occupants, community development or lifecycle analysis of material choices.

CaGBC LEED ® ID Credit 2: LEED ® Accredited Professional
1 Point

Intent
To support and encourage the design integration required by a LEED ® Green Building Project and to streamline the application and certification process.

Requirements
At least one principal participant of the project team that has successfully completed the LEED ® Accredited Professional exam.

Submittals
Provide the LEED ® Letter Template stating the LEED ® Accredited Professional's name, title, company, and contact information. Include a copy of this person's LEED ® Accredited Professional Certification.

Potential.Technologies.&.Strategies
Attending a LEED ® Accredited Professional Training Workshop is recommended but not required. Study the LEED ® Reference Guide. Successfully pass the LEED ® accreditation exam.

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ICPI TECH SPEC NUMBER · 17

Bedding Sand Selection for Interlocking Concrete Pavements in Vehicular Applications

Bedding sands are a critical component of all sand-set segmental concrete paving systems. Especially for vehicular applications, specifiers and contractors need to consider bedding sand selection. While gradation is an important consideration, other characteristics should be assessed in order to ensure long-term pavement performance. This technical bulletin examines these characteristics and provides guidance to specifiers and contractors.

Background

Bedding sand provides four main functions. It beds the pavers during installation; helps initialize interlock among the pavers; provides a structural component for the system (as described in ICPI Tech Spec 4 Structural Design of Interlocking Concrete Pavement for Roads and Parking Lots) and facilitates drainage of water that infiltrates through the joints. Typical specifications require bedding sands to conform to ASTM C 33 and CSA A 23.1 (FA1) gradation for concrete sands with additional limits on the allowable amount of material that passes the No. 200 (0.075 mm*) sieve (See Tables 1 and 2). In vehicular applications, experience and research have shown that other factors besides gradation contribute to the successful function of the bedding layer in vehicular applications. Knapton (1994) notes that since 1980 the amount of material passing the No. 200 (0.075 mm) sieve has been reduced in the British Standard BS 7533-1 (2001) Guide for the Structural Design of Heavy Duty Pavements Constructed of Clay or Concrete Pavers. He notes that fines have reduced from 10% in 1980, to 3% in 1991, to 1% for heavily trafficked pavements, further reducing to 0.1% for bus stations. North American standards currently limit the amount of allowable material passing these sieves to 1%. Other studies (Lilley and Dowson 1988) (Beaty 1996) have investigated failures of segmental concrete pavements subjected to channelized vehicular traffic. They have also concluded that more comprehensive specifications are required. Lilley and Dowson (1988) suggested that bedding sands in segmental concrete pavements designed to carry more than 1.5 million equivalent 18-kip (80 kN) axle loads should be subjected to grading and degradation tests. For the purposes of this Tech Spec, vehicular traffic is defined as roads exposed to a minimum of 1.5 million lifetime 18-kip (80 kN) equivalent single axle loads (ESALS), axle loads up to 24,250 lbs (11,000 kg) or has maximum vehicle loads of 50,000 lb (22,680 kg).

Table 1
ASTM C 33 requirements

Sieve Size	Percent Passing
3/8 in. (9.5 mm)	100
No. 4 (4.75 mm)	95 to 100
No. 8 (2.36 mm)	85 to 100
No. 16 (1.18 mm)	50 to 85
No. 30 (0.600 mm)	25 to 60
No. 50 (0.300 mm)	10 to 30
No. 100 (0.150 mm)	2 to 10
No. 200 (0.075 mm)	0 to 1

Table 2
CSA A23.1 (FA1) requirements

Sieve Size	Percent Passing
10mm	100
5 mm	95 to 100
2.5 mm	80 to 100
1.25 mm	50 to 90
0.630 mm	25 to 65
0.315 mm	10 to 35
0.160 mm	2 to 10
0.080 mm*	0 to 1

Table 1 and 2. Bedding sands should conform to ASTM and CSA gradations for concrete sand. ICPI also recommends additional limitations on the No. 200 (0.080 mm) sieve as shown above, where no other material property testing is available.

*Although the ASTM equivalent for the No. 200 sieve size is 75 micron (.075 mm), CSA standards use the German (DIN) and French (ANFOR) standard equivalent sieve size of 80 micron (0.080 mm)

Failure Mechanisms

Failure of the bedding sand layer occurs in channelized vehicular loads from two main actions; structural failure through degradation and saturation due to inadequate drainage. Since bedding sands are located high in the pavement structure, they are subjected to repeated applications of high stress from the passage of vehicles over the pavement (Beaty 1996). This repeated action, particularly from higher bus and truck axle loads that degrades the bedding sand and causes failure. For these applications sand should be selected based on their ability to withstand long-term degradation. Bedding sand permeability also is a significant factor in the selection process. Wherever difficulties have been experienced with laying course materials in heavily trafficked pavements, water has been a major factor (Knapton 1994). As they approach higher moisture levels in service, bedding sands may become unstable. Smaller particle sizes (fines) become suspended in water, forming slurry that lubricates the entire bedding layer. Choosing bedding sand with a gradation as shown in Tables 1 and 2 will help to reduce the risk of poor drainage and instability. However, these sands will be susceptible to drainage problems if they do not have the hardness to withstand long term degradation from vehicular wheel loads.

Figure 1. The Micro-Deval test apparatus. Photo courtesy of Geneq, Inc.

Selection and Performance Design Principles-Going beyond gradation

Selecting Durable Bedding Sands-Durability of aggregates has long been understood to be a major factor in pavement performance. ASTM C 88 Soundness of Aggregate by use of Sodium Sulfate or Magnesium Sulfate (ASTM 2005) is an example of a typical test method used by road agencies to assess aggregate durability. The test involves soaking an aggregate in a solution of magnesium or sulfate salts and oven drying. This is repeated for a number of cycles, with each cycle causing salt crystals to grow and degrade the aggregate. The test method takes a minimum of 6 days to complete. The percent loss is then calculated on individual size fractions. This test method, however, is considered highly variable. Jayawickrama, Hossain and Phillips (2006) note that when ASTM initially adopted this test method they recognized the lack of precision, saying, "it may not be suitable for outright rejection of aggregates without confirmation from other tests more closely related to the specific service intended." ICPI recommends using ASTM C 88 as a measure of aggregate durability as long as other material properties described in this bulletin are also considered. The Micro-Deval test is evolving as the test method of choice for evaluating durability of aggregates in North America. Defined by CSA A23.2-23A, The Resistance of Fine Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus (CSA 2004), the test method involves subjecting aggregates to abrasive action from steel balls in a laboratory rolling jar mill. In the CSA test method a 1.1 lb (500 g) representative sample is obtained after washing to remove the No. 200 (0.080 mm) material. The sample is saturated for 24 hours and placed in the Micro-Deval stainless steel jar with 2.75 lb (1250 g) of steel balls and 750 mL of tap water (See Figure 1). The jar is rotated at 100 rotations per minute for 15 minutes. The sand is separated from the steel balls over a sieve and the sample of sand is then washed over an 80 micron (No. 200) sieve. The material retained on the 80 micron sieve is oven dried. The Micro-Deval loss is then calculated as the total loss of original sample mass expressed as a percentage. ASTM and the American Association of State Highway Transportation Officials have both adopted the coarse aggregate version of the MicroDeval test, ASTM D 6928 (2006) and AASHTO TP 58. Both are also considering a version for fine aggregates. Since the test apparatus uses the same size drum and rotates at the same rpm, no modifications to the apparatus are required to perform the fine aggregate test in laboratories currently equipped to perform the coarse aggregate test procedure. A study conducted by the Interlocking Concrete Pavement Institute (ICPI 2004) investigated nine sands from across the United States reported by contractors to have "good to excellent" serviceability in vehicular applications. The results of this study indicated that eight of these sands had Micro-Deval degradation losses less than 8% when measured according to CSA A23.2-23A (CSA 2000). The same study subjected these sands to the ASTM C 88 soundness loss and found that no sample had greater than 6% loss. The Micro-Deval test is recommended as the primary means to characterize bedding sand durability (See Table 4) and the magnesium or sulfate soundness should be considered when the Micro-Deval test is not locally available. The variability of the soundness test method should always be a consideration unless measured in relation to other material properties. A test method similar in nature to Micro-Deval is the Lilley and Dowson test (Lilley Dowson 1998). This test method specifically developed for bedding sands is recognized internationally and is referenced in ICPI manuals Port and Industrial Pavement Design with Concrete Pavers (ICPI 1997) and Airfield Pavement Design with Concrete Pavers (ICPI 1995). This test method is performed on 3 lbs (1.4 kg) randomly selected, oven-dried sand samples with two 1 in. (25 mm) diameter steel balls together weighing 0.3 lb (135 g). Three sub-samples each weighing 0.5 lbs (0.2 kg) are derived from the main sample. Each sub-sample is sieved according to ASTM C 136 then re-mixed and placed in a nominal liter capacity porcelain jar with the two steel balls. The three jars are rotated at 50 rpm for six hours and sieved again. Sand durability is assessed from resulting increases in the percent passing the No. 50, 100 and 200 (0.300, 0.150, and 0.075 mm) sieves. Developed in the UK, the test is not readily available at laboratories in North America. The CSA Micro-Deval test may be more available. Beaty (1996) demonstrated a correlation between the two tests with a correlation coefficient greater than 0.99. The relationship between the two tests is:

$$L = 1.97 + 1.21\,M$$

Where:
M = CSA Micro-Deval Degradation Loss (%)
L = Lilley and Dowson Degradation Loss (%)

Beaty's correlation involved a modification to the test procedure by reconstituting the test aggregates into a standard gradation shown in Table 3 and performing the Micro-Deval and Lilley Dowson tests on the re-graded aggregate. In this modified version of the Lilley Dowson test procedure the loss (L) is measured as the total increase in percentage of fines passing the No. 200 (0.075 mm) sieve at the completion of the test. Using the correlation described above, an 8% Micro Deval degradation (See Table 4) would have a corresponding Lilley and Dowson degradation of 12%.

Assessing Drainage-Bedding layer drainage is important for early and long term performance of a pavement. One failure documented by Knapton (1993) describes a segmental pavement that was opened to bus traffic and within hours of construction subjected to continuous heavy rain. The bedding sand in this case had a high percentage of fines. As a result of the continuous rainfall, finer sieve fractions in the sand were transported into the drain holes of the underlying concrete slab. With the drainage compromised the bedding sand liquefied and was pumped through the joints of the pavement, resulting in immediate rutting and failure of the system. The pavement was subsequently reconstructed with bedding sand that had 0% material passing the No. 200 (0.075 mm) sieve and reported excellent performance. Although gradation is an important factor in drainage (since it affects permeability) eliminating all of the fines can sometimes be impractical. Therefore, ICPI recommends up to 1% passing the No. 200 (0.075 mm) sieve. Another important material property is permeability. Even specifications that allow up to 3% of fines can result in a five fold decrease in permeability from the lowest to highest percentage passing (Bullen 1998). In research conducted by the Interlocking Concrete Pavement Institute (ICPI 2004) the permeability of "very good to excellent" bedding sands was measured. Using the test method described by ASTM D2434-68 Standard Test Method for Permeability of Granular Soils (Constant Head) (ASTM 2006) the permeabilities ranged from 2.8 in./hr (2.1×10^{-3} cm/second) to 15.6 in./hr (1.1×10^{-2} cm/second). These values correspond to fines that range from 0 to 2.5% passing the No. 200 (0.075 mm) sieve but, more importantly they also are associated with Micro-Deval maximum degradation values of 8%. Table 4 indicates a minimum permeability of 2.8 in./hr (2.1×10^{-3} cm/second) that should also be considered at the same time as the other primary properties listed.

Table 3
Modified Gradation or Reconstituted Aggregates According to Beaty (1996)

Sieve Size	Percent Passing
4.75 mm	100
2.36 mm	90
1.18 mm	70
0.600 mm	47
0.300 mm	20
0.150 mm	7
0.075 mm	0

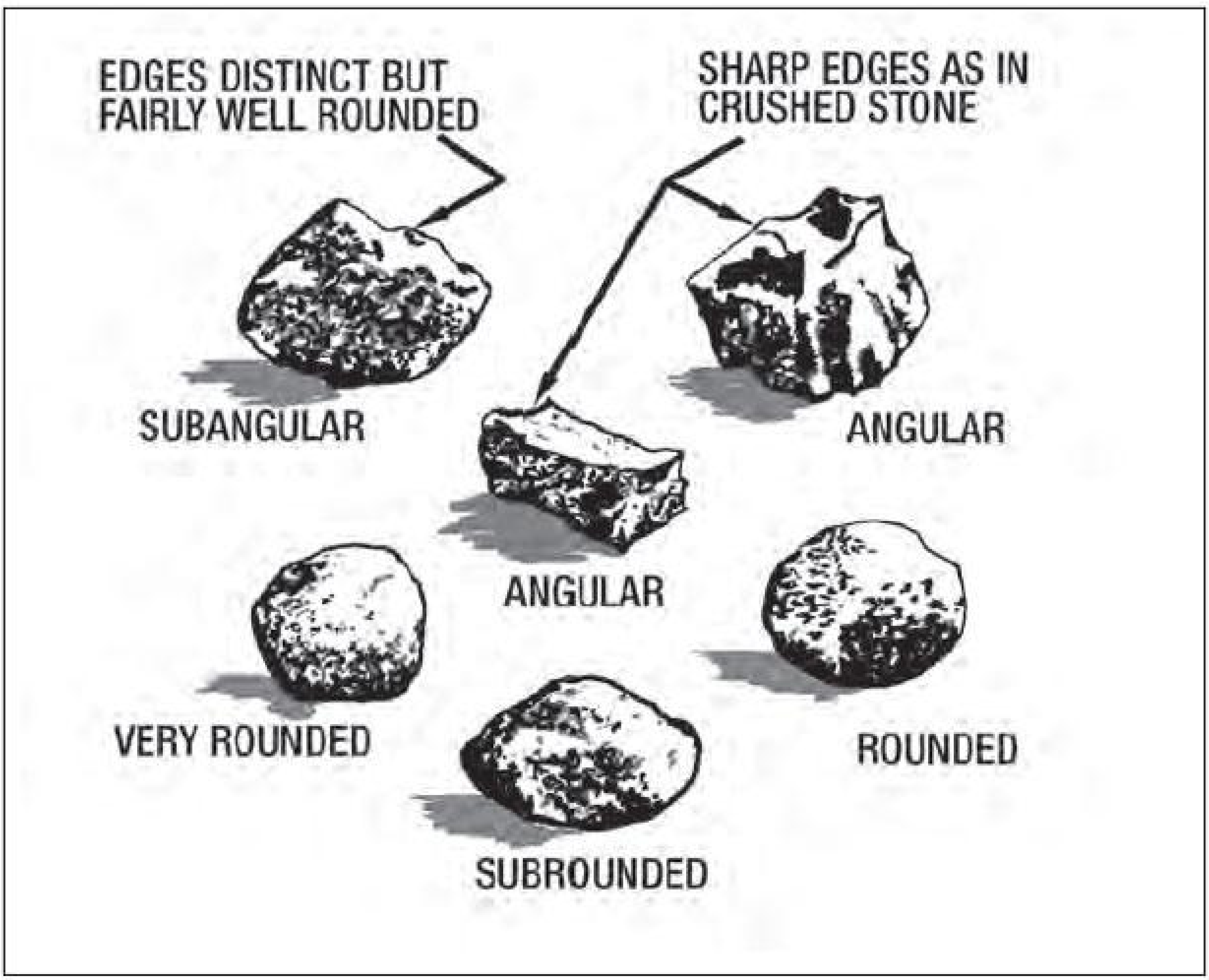

Figure 2. Typical description of coarse grains according to ASTM D 2488

Other Material Properties-Studies have indicated that bedding sand shape plays a role in bedding sand performance. (Knapton 1993) notes that rounded or cubic grains lead to stable sands, whereas more angular grains are frequently associated with sands that fail. The sands tested by ICPI (ICPI 2004) showed that eight of the nine "good to excellent" performing sands were characterized by having a predominance of sub-angular to sub-rounded particle shapes when tested according to ASTM D 2488 Description and Identification of Soils (Visual-Manual Procedure) (ASTM 2000). Specifiers and contractors should consider bedding sand angularity using Figure 2 as a guide. Figure 3 shows a photograph of one of the ICPI test sands at high magnification. Table 4 suggests that a combined percentage of sub-angular to sub-rounded particles should be a minimum of 60%.

Geology-Geology of bedding sands has been noted by a number of studies to play an important role in their performance. For example, bedding sand with quartz mineralogy is preferred over crushed sandstones (Knapton 1993). In the study by the Interlocking Concrete Pavement Institute (ICPI 2004), eight of the nine "good to excellent" performing sands were noted to consist predominately of silica minerals with over 80% of the material either quartz or quartzite. Table 4 recommends a minimum 80/20 ratio of silica/carbonate mineralogy. A tenth sample, included in the study (and noted as poor performing in the field) was characterized as having up to 50% carbonate content. Petrographic analysis was conducted according to the Ministry of Transportation of Ontario laboratory method MTO LS-616 Procedure for the Petrographic Analysis of Fine Aggregate (MTO 1996). ASTM C 295 Standard Guide for Petrographic Examination of Aggregates for Concrete (2003) offers an alternative test method. Limestone screenings and stone dust are not recommended for bedding sand. In addition to being unevenly graded and having excessive material passing the No. 200 (0.075 mm) sieve, screenings and stone dust will break down over time from wetting and abrasion due to vehicular loads. Unlike soft limestone screenings and stone dust, hard, durable concrete sand meeting the requirements in Table 4 will not break down easily. Limestone screenings also tend to break down during pavement construction under initial paver compaction. Depressions will eventually appear in the pavement surface with limestone screenings or stone dust.

Recommended Material Properties-Table 4 lists the primary and secondary material properties that should be considered when selecting bedding sands for vehicular applications. Bedding sands may exceed the gradation requirement for the maximum amount passing the No. 200 (0.075 mm) sieve as long as the sand meets degradation and permeability recommendations in Table 4. Micro-Deval degradation testing can be replaced with sodium sulfate or magnesium soundness testing as long as this test is accompanied by the other primary material property tests listed in Table 4. Other material properties listed, such as petrography and angularity testing are at the discretion of the specifier and may offer additional insight into bedding sand performance.

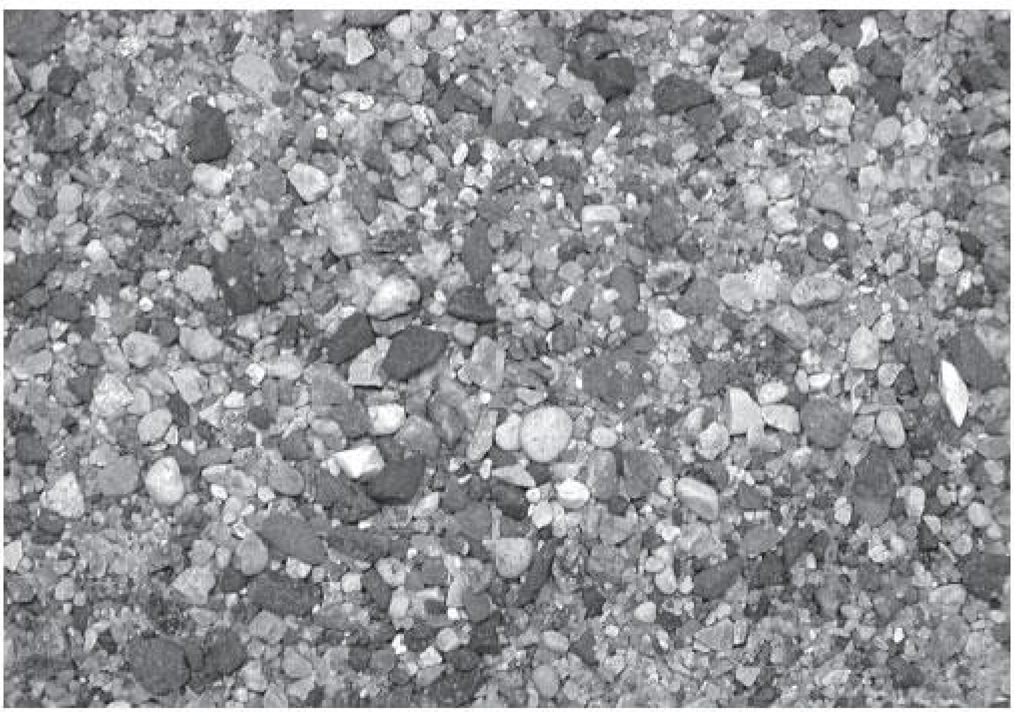

Figure 3. Example of sand from the ICPI bedding sand test program with a total combined percentage of sub-angular and sub-rounded particles equal to 65% according to ASTM D 2488

Figure 4. A two-man hand pulled screed

Figure 5. Mechanical screeding is the most efficient method of bedding sand installation

Role of Bedding Sand in Construction-Provided that the base was installed according to recommended construction practices and tolerances (See ICPI Tech Spec 2-Construction of Interlocking Concrete Pavements), the bedding sand ensures that the pavers have a uniform slope and meet surface tolerances without surface undulations or "waviness." Sand should be loosely screeded to a nominal thickness of 1 in. (25 mm) for vehicular applications. Screeds can either be pulled by hand or by machine (mechanical screed) as shown in Figures 4 and 5. Mechanical screeding provides the most efficient method. Pavers are placed on the loose uncompacted sand. Contractors should select sand that allows the pavers to be uniformly seated during their initial compaction with a minimum 4000 lb (18kN) force plate compactor. The sand should have sufficient moisture content to allow for adequate compaction. At no times should bedding sand be either "bone dry" or saturated. A moisture content range of 6% to 8 % has been shown to be optimal for most sands (Beaty 1992). Contractors can assess moisture content by squeezing a handful of sand in their hand. Sand at optimal moisture content will hold together when the hand is re-opened without shedding excess water. Although it can be difficult to control the exact moisture content on the job site, uniformity of moisture content can be maintained by covering stock piles with tarps. Digging into sand piles at mid-height to avoid saturated material that may be at the bottom of the pile is also recommended. While on the job site, a contractor should check the hardness of the bedding sand particles. Particles of sufficient hardness will not break under the pressure of a Swiss Army pocket knife. This field test, although not recommended for pre-selection of bedding sands, helps assess a material at the time of delivery. Table 5 lists the recommended bedding sand properties that need to be considered by a contractor during installation. Interlocking concrete pavements should also be designed and constructed such that the bedding sand should not be able to migrate into the base, or laterally through the edge restraints. Dense-graded base aggregates with 5% to 12% fines (the amount passing the No. 200 or 0.075 mm sieve), will ensure that the bedding sand does not migrate down into the base surface. For pavements built over asphalt or concrete bases, it is necessary to provide adequate drainage by providing 2 in. (50 mm) diameter weep holes at the low points in the pavement to drain excess water from the bedding layer. Holes should be filled with washed pea gravel and covered with geotextile to prevent the loss of bedding sand. Figure 6 on the next page shows a detail. Specifiers can visit the ICPI website to download similar details for use in specifications from <www.icpi.org>. To control lateral loss of bedding sand, Figure 7 shows geotextile installed at the interface of a concrete curb. To ensure that the sand cannot migrate through the joints in the curb woven geotextile is placed on top of the aggregated base, extending approximately 1 ft. (300 mm) into the pavement and wrapped up the sides of the curb to fully contain the bedding sand.

Table 4
Recommended Laboratory Material Properties for Bedding and Joint Sands in Vehicular Applications [1,2]

Material Properties	Test Method	Recommended Maximum or Minimum
Primary Properties		
Micro-Deval Degradation	CSA A23.2-23A	Maximum 8%
Constant Head Permeability	ASTM D 2434	Minimum 2×10^{-3} cm/second (2.83 in/hr)
Gradation	ASTM C 33 CSA A23.1 (FA1)	Maximum 1 % passing No. 200 (0.075 or 0.080 mm) sieve
Secondary Properties		
Soundness – Sodium Sulfate or Magnesium Sulfate	ASTM C 88	Maximum 7%
Silica (Quartz and Quartzite)/ Carbonate Ratio	MTO LS-616 ASTM C 295	Minimum 80/20 ratio
Angularity and Particle Shape	ASTM D 2488	Minimum 60% combined sub- angular and sub- rounded

Note 1: See "Recommended Material Properties" on page 4 of Tech Spec 17

Note 2: Bedding sand may also be selected based on field performance. Field performance is selected when the specifier or contractor assumes responsibility for the selection and performance of bedding sand not conforming to the properties in Table 4. Field performance as a selection criteria is suggested when the available local materials do not meet the primary material properties suggested in Table 4, but the specifier or contractor can demonstrate to the satisfaction of the owner (or owner's representative), successful historical field performance. In this case the owner should specify the class of vehicular traffic, and the contractor should verify past field performance of the bedding sand under similar vehicular traffic.

Table 5
Recommended Installation Properties for Bedding Sands in Vehicular Applications

Primary Properties	Test	Recommended Maximum or Minimum	Construction Tolerance	Frequency of Field Test
Gradation	ASTM C33 and CSA A23.1 (FA1)	See Tables 1 and 2	Not Applicable	Provided by aggregate supplier every 25,000 sf (2,500 m^2)
Bedding Layer Thickness	Check with ruler	Nominal 1 in. (25 mm)	± 3/8 in. (10 mm)	By contractor every 5,000 to 10,000 sf (500 to 1000 m^2)
Hardness	Test with Swiss army pocket knife blade	No broken particles	Not Applicable	By contractor every 25,000 sf (2,500 m^2)
Secondary Properties	**Test**	**Recommended Maximum or Minimum**	**Construction Tolerance**	**Frequency of Field Test**
Moisture content at time of installation	Hand test	Holds together without shedding water	Not applicable	While screeding

Role of Jointing Sand

Jointing sand provides two primary functions in a segmental concrete pavement; it creates interlock and helps seal the pavement. ICPI recommends that the same material properties listed in Table 4 also apply to jointing sand. Panda and Ghosh (2002) describe laboratory research on pavements using fine and coarse joint sands. Simulated loading consisted of 11-kip (51 kN) over 80 mm pavers with varying joint widths and joint sand gradations. Deflection of the pavement was then measured with coarser sand exhibiting lower deflections. The study concluded that "the coarser the sand, the better the performance." The coarser sands used in the study correspond to the gradations in Tables 1 and 2 and the study recommended joint widths up to 3 / 16 in. (5mm). ICPI recommends joint widths of 2 mm to 5 mm. Contractors can benefit from using one sand source. There are advantages to using the bedding material for the jointing sand during construction. Using one material allows the contractor to monitor and control one sand product on the job site. Over time the joints become filled with detritus, providing some degree of sealing. Regardless of the sand used, segmental concrete pavements will always allow some water penetration through the joints. Coarse bedding sand may require additional effort in sweeping into the joints by the contractor. In some cases, smaller joint widths may require the use of finer graded sand. In this case, the use of mortar sand is recommended. Mortar sand should conform to the gradations of either ASTM C 144 or CSA A179 but should also meet the material property requirements of Table 4. Although joint sand selection is an important factor, design and construction play a more important role. Considerations such as joint width, ensuring that the sand is swept in dry, degree of compaction, and ensuring the joints are completely filled, are just as critical to the long term success of pavement performance. Information on joint sand installation can be found in ICPI Tech Spec 2-Construction of Interlocking Concrete Pavements (ICPI 2004).

Figure 7. Woven geotextile used to contain bedding sand from migrating laterally. Visit <www.icpi.org> for detail drawings.

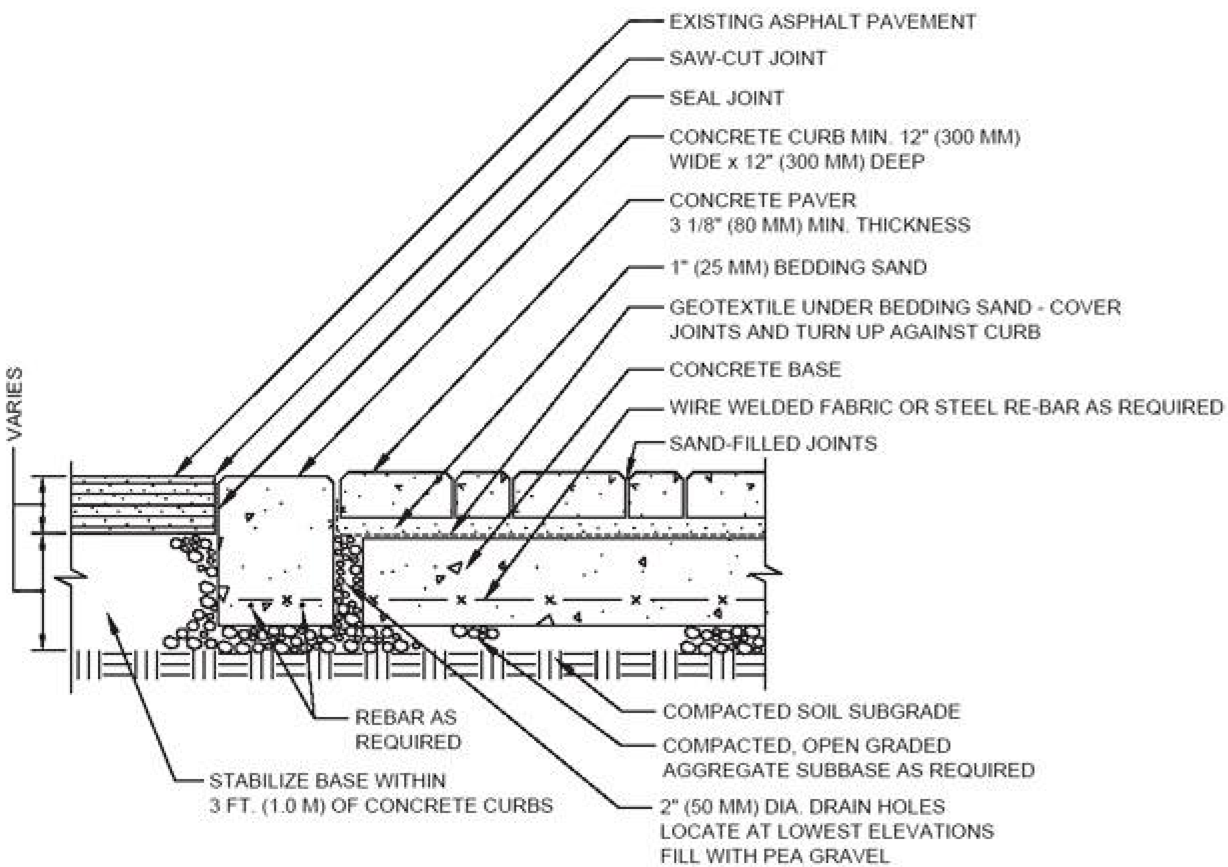

Figure 6. Recommended detail for sand set pavers over a concrete base. Drainage holes provide drainage for water that enters the bedding layer through the joints. The same detail applies for paver overlays on asphalt.

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