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Permeable Interlocking Concrete Pavement

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PREFACE

Permeable pavements typically consist of pervious concrete, porous asphalt, or interlocking concrete paver units over an open-graded base or subbase layer(s). Permeable pavements are designed to infiltrate stormwater, reduce peak flows, improve stormwater quality, and promote groundwater recharge. They have become an integral part of low-impact development, sustainable design, green infrastructure, and best management practices for stormwater management. In order to be effective within municipal road networks, permeable pavements must be designed to provide sufficient structural capacity to accommodate the anticipated vehicle loadings while managing stormwater flows into and out of the permeable pavement.

Although there have been many well designed and constructed permeable pavements, this is a relatively new technology compared to conventional pavements, and there have been some performance concerns. These concerns include pavement surface rutting caused by loads exceeding the pavement structural design, settlement caused by improper base and/or subbase gradations, and insufficient compaction of the base or subbase. A common concern is clogging of the pavement surface from sediments tracked onto the pavement or transported by water run-on from adjacent surfaces.

This standard was written to address these concerns and more. It provides design, construction, and maintenance guidance for permeable interlocking concrete pavement to achieve stormwater management goals while providing a structurally adequate pavement section to accommodate the anticipated vehicular loading in a cost-efficient manner.

Introduction

Permeable interlocking concrete pavement (PICP) can provide a durable and effective pavement and stormwater management system. As with any pavement and stormwater management practice, proper design, construction, and maintenance procedures are required. To better address these needs, this standard was prepared by the ASCE Permeable Interlocking Concrete Pavement Committee. This publication establishes guidelines for developing appropriate pavement structures for various stormwater drainage, traffic, and subgrade conditions as well as providing guidance on construction and maintenance.

This standard is written with the intent of being adopted in whole or in part for use by national, provincial, state, and local stormwater and road agencies for the consistent and effective design, construction, and maintenance of permeable interlocking concrete pavement systems. The overall goal is assisting design professionals, civil engineers, the industry, public stormwater and transportation agencies, and the wider public by establishing design standards for permeable interlocking concrete pavements. The document provides

- Definitions of terms common to permeable pavements;
- Methods for structural design to accommodate incidental and frequent vehicular use;
- Methods for hydrologic design to accommodate water infiltration and flow into, within, and out of the pavement system;
- Construction and inspection procedures;
- Guide construction specifications; and
- Maintenance procedures for the permeable pavement system.

PICP may help achieve compliance with many national, provincial, state, and local regulations, as well as transportation agency design requirements for the control of stormwater runoff. Requirements may include the following:

- Compliance with federal, provincial, state, and local transportation design standards;
- Compliance with pavement structural design and construction requirements;
- Compliance with vehicular and pedestrian safety and access requirements;
- Transportation asset management compliance, including lifecycle cost analysis and lifecycle assessment of environmental impacts;
- Stormwater runoff controls and regulatory compliance;
- Compliance with groundwater protection requirements;
- Postconstruction runoff volume and pollutant control for new development and redevelopment;
- Reductions in impervious cover (i.e., roofs and pavements) and resulting runoff;
- Runoff volume storage and/or infiltration to reduce overflows, especially combined sewer overflows, as well as reduction of flooding for a more resilient infrastructure;
- Compliance with total maximum daily load (TMDL) requirements for receiving waters;
- Management of water quality and/or quantity storm events; and
- Compliance with local building code requirements.

Permeable interlocking concrete pavements may assist in achieving regulatory program and policy compliance. Examples include the Great Lakes Protection Act, Species at Risk Act, National Pollutant Discharge Elimination System (NPDES), Canadian Federal Fisheries Act, U.S. Clean Water Act, U.S. Environmental Protection Agency (US EPA) Stormwater Assessment Program, Source Water Protection Plans, CALGreen in California, the International Green Construction Code, ASHRAE Standard 189.1, and stormwater utility fee credits or other codes that require compliance with Leadership in Energy and Environmental Design (LEED) or similar sustainable design and construction rating systems.

Nonregulatory drivers that influence PICP use include the following: economics that often make PICP a lower-cost alternative to conventional drainage and stormwater management system designs, and project owner preference for conformance to sustainable rating systems for roads and transportation infrastructure. Examples include the Green Business Certification, Inc.'s Sustainable SITES Initiative, the Institute for Sustainable Infrastructure's Envision evaluation system, Greenroads, GreenPave, and the Federal Highway Administration's Infrastructure Voluntary Evaluation Sustainability Tool (INVEST).

Finally, other nonregulatory drivers include product, system, or project lifecycle analysis (LCA) of environmental impacts in the manufacture, construction, use, and end-of-life phase. Product Category Rules (PCRs) for segmental concrete paving products used in PICP are available from ASTM. These rules provide a useful framework for conducting a LCA, as well as for providing environmental product declarations for paving products.

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Permeable Interlocking Concrete Pavement Standards Committee
David K. Hein, P.Eng., M.ASCE, *Chair*
David R. Smith, M.ASCE, *Vice Chair*
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Greg Hoffmann, P.E.
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Christopher King, P.E., F.ASCE
Kathlie S. Jeng-Bulloch, P.E., D.WRE, M.ASCE
Keith H. Lichten, P.E., M.ASCE
Glenn Herold, P.Eng., M.ASCE
Ken MacKenzie, P.E., M.ASCE
Glenn MacMillan
Lincoln Paiva, P.Eng.
Donald Rissmeyer, P.E., CFM, M.ASCE
Robert M. Roseen, Ph.D., P.E., D.WRE, M.ASCE
Mark Smallridge, P.E., M.ASCE
Mary Vancura, Ph.D., P.E.
Harald von Langsdorff
Neil Weinstein, P.E., M.ASCE

Associate Members
Robert Bowers, P.Eng., M.ASCE
John Folts, P.E., M.ASCE
John T. Kevern, Ph.D., P.E., M.ASCE

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CHAPTER 1
GENERAL

1.1 SCOPE

This standard establishes hydrologic and structural design methods for permeable interlocking concrete pavement (PICP). Permeable pavement design is typically site specific and requires careful consideration of structural and hydrologic conditions, and of the impact on the surrounding environment.

This document provides information for professionals to use in the design of permeable pavement systems. This information includes applicable standards, definitions, best practices, structural and hydrologic design, key design elements, guide specifications, construction guidelines, and long-term maintenance. This standard is recommended for roadways with design speeds no greater than 50 kph (35 mph) receiving less than 1 million equivalent single axle loads (ESALs).

The pavement structural design recommendations in this standard are based on mechanistic-empirical design research. The process described herein is based on data from a full-scale accelerated PICP load testing program. Design considerations herein require a working knowledge of stormwater drainage, soil mechanics, traffic loading, and pavement materials. Pavement design and stormwater specialists should be consulted for the application of this standard.

This book consists of six chapters plus appendixes and references:

- Chapter 1 outlines the general scope of the standard;
- Chapter 2 provides definitions of key terms, as well as a list of consensus standards and other referenced documents used in this standard;
- Chapter 3 provides preliminary information required to design permeable pavements and also provides fundamental information on typical designs for common site conditions;
- Chapter 4 provides detailed procedures and rationale for structural and hydrologic design;
- Chapter 5 covers construction and inspection guidelines; and
- Chapter 6 includes pavement maintenance guidelines.

The appendixes are the following:

- Appendix A: Design Examples,
- Appendix B: Guide Construction Specifications,
- Appendix C: Examples of Orifice and Common Weir Equations,
- Appendix D: PICP Structural Design Using AASHTO 1993, *Guide for Design of Pavement Structures*, and
- Appendix E: Approximate Correlation between Permeability and Unified Soil Classification.

This standard applies to the design of new and retrofit pavement systems surfaced with PICP. It also includes hydrologic and structural design guidelines using open-graded aggregate bases. This standard does not address the specific biological, chemical, and physical processes as related to water quality improvement. Other references should be consulted for the water quality benefits available to project-specific pavement systems.

This standard does not address site-specific constraints and/or local conditions that may require more detailed analysis, specifications, construction, and maintenance practices critical to successful pavement performance.

1.2 REFERENCED STANDARDS

In addition to provincial, state, and local government jurisdiction over stormwater drainage and pavement structural design procedures, the provisions of applicable ASTM, CSA, or AASHTO standards listed herein are provided in full in the list of consensus standards and are part of this standard. Many ASTM standards and test methods have equivalent standards and test methods in AASHTO *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*. Equivalent standards published by both organizations are used throughout this standard.

1.3 VARIATIONS FROM THIS STANDARD

Use of proprietary, new and/or improved permeable interlocking concrete pavers, aggregate materials, evaluation techniques, and installation methods are not specifically excluded, as long as the design and installation of the pavement are shown to comply with or exceed this standard.

1.4 ENGINEER REQUIRED

Work covered by this standard should be carried out under the guidance of a professional engineer with a background in the design of pavement and stormwater systems. The professional engineer is hereinafter referred to as the engineer. This standard does not dictate the means and methods to be used by the engineer. Means and methods must be appropriate to each project.

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CHAPTER 2
DEFINITIONS

2.1 GENERAL

This chapter defines specific terms common to permeable interlocking concrete pavements (PICPs) used in this standard. *ICPI Tech Spec 1: Glossary of Terms for Segmental Concrete Pavement* (1995, 2017) can be referenced for defining additional terms used by the interlocking concrete pavement industry.

Terms not defined in this standard should use their ordinarily accepted meaning within the context in which they are written. *Webster's New International Dictionary of the English Language, Unabridged,* latest edition, https://www.merriam-webster.com, should be considered as providing ordinarily accepted meanings.

2.2 TERMS

AASHTO: American Association of State Highway and Transportation Officials.

Adsorption: The adhesion of pollutants commonly found in stormwater runoff to the PICP materials and soil subgrade to improve water quality.

Aggregate: Crushed stone used for jointing, bedding, base, and subbase materials.

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

Aquifer: A porous, water-bearing geologic formation that yields water for human and environmental use.

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

ASTM: American Society for Testing and Materials International.

ASTM No. 2 Stone: As defined by ASTM D448, the CSA A23.1 approximation would be Group II 80-40.

ASTM No. 8 Stone: As defined by ASTM D448, the CSA A23.1 approximation would be Group II 5-2.5.

ASTM No. 57 Stone: As defined by ASTM D448, the CSA A23.1 approximation would be Group II 28-14.

Base or Base Course: A material of a designed thickness placed under the surface wearing course of paving units and its bedding course. It is placed over a subbase or a subgrade to support the surface course and bedding materials. A base course can be compacted aggregate, cement or asphalt stabilized aggregate, asphalt, or concrete. This material generally conforms to the grading requirements of ASTM No. 57 stone and is generally 100 mm (4 in.) thick. Sometimes called a choker course. All layers within a permeable pavement are open graded.

Bedding Course: A layer of coarse crushed and washed stone screeded smooth as bedding for the pavers. This material generally conforms to the grading requirements of ASTM No. 8 stone. A screeded layer is generally 50 mm (2 in.) thick.

Best Management Practice (BMP): A structural (or nonstructural) measure designed to infiltrate, temporarily store, or treat stormwater runoff in order to reduce pollution and/or flooding. Also called a stormwater control measure or SCM.

Bioretention: A stormwater management practice that uses soils and vegetation to treat pollutants in urban runoff and to encourage infiltration of stormwater into the ground.

Bundle: Several layers (or clusters) of unit pavers stacked vertically, packaged, and tagged for shipment. Also sometimes called a cube.

California Bearing Ratio (CBR): A test method and result that renders an approximation (expressed as a percent) of the bearing strength of soil compared to that of a high-quality, compacted aggregate base. The test defines the ratio of (1) the force per unit area required to penetrate a soil mass with a 19 cm^2 (3 $in.^2$) circular piston (of approximately 51 mm (2 in.) diameter) at the rate of 1.3 mm/min (0.05 in./min), to (2) that force required for corresponding penetration of a standard material. The ratio is usually determined at 2.5 mm (0.1 in.) penetration, although other penetrations are sometimes used. *See* ASTM D1883 or AASHTO T-193 for more details.

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

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

Choker 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 choker course are generally smaller than those of the surface into which it is being pressed but are not too small to pass through the underlying layer.

Clay Soils: 1. (Agronomy) Soils with particles less than 0.002 mm in size. 2. A soil textural class. 3. (Engineering) A fine-grained soil with more than 50% passing through the 0.075 mm (No. 200) sieve with a high plasticity index in relation to its liquid limit, according to the Unified Soil Classification System.

Cluster: The group of pavers forming a single layer from a bundle of pavers that can be held by the clamp of a unit paver laying machine during mechanical installation.

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

Combined Sewer System Overflow, or CSO: Conveyance of storm and sanitary sewage in the same pipes that, as a result of rain events, overflow and discharge into receiving waters. CSOs generally occur in older, more urban areas. CSOs do significant damage to water quality, resulting in diminished economic and recreational activities for receiving waters.

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 exposed surface area, such as newtons per square millimeter (megapascals) or pounds per square inch.

Concrete Block Pavement (CBP): *See* Interlocking Concrete Pavement (ICP).

Concrete Pavers: Precast concrete paver units meeting the requirements of ASTM C936 or CSA A231.2. For the purpose of this standard, they have an aspect ratio (length divided by thickness) of 3 or less.

Contributing Drainage Area (CDA) Ratio: The area contributing runoff into the PICP divided by the area of the PICP receiving that runoff.

Course: A row of pavers.

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.

CSA: Canadian Standards Association.

CSA Group II 5-2.5 Stone: As defined by CSA 23.1. The ASTM D448 approximation is No. 8 Stone.

CSA Group II 28-14 Stone: As defined by CSA 23.1. The ASTM D448 approximation is No. 57 Stone.

CSA Group II 80-40 Stone: As defined by CSA 23.1. The ASTM D448 approximation is No. 2 Stone.

Cube: *See* Bundle.

Curve Number (CN): A numerical representation of a given area's hydrologic soil group, plant cover, impervious cover, interception, and surface storage. The U.S. Soil Conservation Service (SCS) originally developed the concept. A curve number is used to help convert rainfall depth into runoff volume.

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 38 mm (1 1/2 in.) or 19 mm (3/4 in.) down to fines passing the 0.075 mm (No. 200) sieve.

Density: Mass per unit volume.

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

Edge Restraint: A curb, edging, building, or other fixed object that surrounds the bedding course and pavers so that they do not spread and lose interlock under loading.

Equivalent Axle Loads (EALs): See Equivalent Single Axle Loads (ESALs).

Equivalent Single Axle Loads (ESALs): Summation of equivalent 80 kN (18,000 lb-force) 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 of soil by water, wind, ice, or gravity and the detachment and movement of soil particles by same.

Evapotranspiration: The return of moisture to the atmosphere by the evaporation of water from soil and transpiration from vegetation.

Fines: Silt and clay particles in a soil, generally those passing the 0.075 mm or No. 200 sieve.

First Flush: The initial portion of a rainstorm that can flush high concentrations of accumulated pollutants into a storm drainage system. High concentrations are usually caused by antecedent dry weather conditions, which create an accumulation of pollutants on pavements washed off by the rainstorm.

Flexible Pavement: A pavement structure that maintains intimate contact with and distributes loads to its subgrade by a combination of horizontal and vertical forces. The base course materials rely on aggregate interlock, particle friction, and cohesion for stability.

Flowable Fill: Cemented aggregate produced in a concrete plant [typical maximum compressive strength of 0.7 MPa (100 psi)]. May also be referred to as flowable concrete fill.

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

General Contractor: Party responsible to the owner for a construction contract.

Geogrids: Plastic reinforcement for pavement, including both biaxial and triaxial types, that distribute the load above by the use of tensile strength primarily to minimize deflection.

Geomembranes: Typically, EPDM (ethylene propylene diene monomer) rubber, PVC (polyvinyl chloride), or HDPE (high-density polyethylene) liners, which can prevent water from passing through them. Minimum thicknesses and methods for construction joints are critical to their successful installation with PICP systems.

Geotextiles: Woven or nonwoven fabrics made from plastic fibers used for separation, reinforcement, or drainage between pavement layers and the adjacent soils.

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 C136 (2014b) for more details.

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

Gravel: Rounded or semirounded particles of rock that pass through a 75 mm (3 in.) sieve and are retained on a 4.75 mm (No. 4) 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 that has particle sizes ranging from the 4.75 mm (No. 4) sieve size and larger.

H-20 and HS-20: Heavy vehicle loading designation used in the design of bridges and other suspended structures. This designation for vehicle loading should not be used for pavement design.

Herringbone Pattern: A pattern where joints are no longer than the length of 1 1/2 pavers. Herringbone patterns can be set at 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 runoff, usually because of a current or former land use.

Hydraulic Conductivity: The property of soils and rocks that describes the ease with which a fluid (usually water) can move through the spaces or fractures.

Hydrologic 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: Any surface in the built environment that prohibits percolation and infiltration of rainwater into the ground below; a term that commonly refers to pavements and roofs.

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

Infiltration Rate: The rate at which stormwater moves from the surface into the soil, typically measured in inches per hour, or millimeters, centimeters, or meters per second. It is critical to note that infiltration rate and hydraulic conductivity are two different concepts and that conversion from one parameter to another cannot be done through unit conversion (*see* Hydraulic Conductivity and Saturated Hydraulic Conductivity). Typically, saturated hydraulic conductivity is converted to an infiltration rate to be used as a design input based on approximate relationships, which may include an infiltration reduction factor (or safety factor).

Infiltration Reduction Factor: A safety factor applied to the infiltration capacity of the permeable pavement subgrade to account for future deposition of fine particles on top of the subgrade, which can reduce the ability or rate of infiltration into the subgrade.

Installer: Party responsible for the installation of the permeable pavement system. May be a subcontractor to the general contractor.

Interlock: Frictional forces between paving units that prevent them from rotating, or moving horizontally or vertically in relation to each other.

Interlocking Concrete Pavement: A system of paving consisting of segmental concrete paving units with either rectangular or indented shapes manufactured from concrete. Either type of shape is placed in an interlocking pattern, compacted into coarse bedding material, the joints filled with joint material, and compacted again to start interlock. The paving units and bedding material 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 for conventional interlocking concrete pavement or small, open-graded aggregate for permeable interlocking concrete pavement.

Jointing Aggregate: Small aggregates swept into the openings between the pavers. The aggregate size varies based on the joint width. Typical sizes are ASTM No. 8, 89, or 9 stone.

Karst Geology: Regions of the Earth underlain by carbonate rock typically with sinkholes and/or limestone caverns. Infiltration practices are strongly discouraged in these areas since they can cause sinkholes.

Laying Face: The open edge or face of a concrete paver laying pattern under construction not yet constrained by a curb, building, or other restraint.

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.

Life Cycle Analysis: Assessing the environmental impacts from all the stages of a product's life, including raw material extraction, materials processing, manufacture, distribution, construction, use, repair and maintenance, and disposal or recycling.

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.

Manufacturer: Party responsible for the fabrication and delivery of unit concrete pavers to the site.

Mechanical Installation: The use of machines to lift and place layers consisting of many pavers in their final laying pattern. The machines increase the rate of paving, as compared to manual placement of unit pavers (i.e., one at a time).

Mechanistic-Empirical Design: Analysis of the structural responses of applied loads through modeling stresses and strains in a pavement structure, and validation with full-scale load testing.

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.

Municipal Separate Storm Sewer Systems, or MS4s: A conveyance or system of conveyances owned by a state, city, town, village, or other public entity that discharges to waters of the United States and is designed or used to collect or convey stormwater. These systems include storm drains, pipes, ditches, streams, and lakes. MS4s do not include combined sanitary and storm sewers, nor do they include publicly owned treatment works (sewage treatment plants).

Observation Well: A perforated pipe inserted vertically into an open-graded base or subbase to monitor the water level and determine its infiltration rate.

One-Hundred-Year Storm: A 100-year recurrence interval (*see* Recurrence Interval and Return Period). A rainfall event that, on average, has a 1% probability of occurring in any given year.

One-Year Storm: A one-year recurrence interval (*see* Recurrence Interval and Return Period). A rainfall event that, on average, has a 100% probability of occurring in any given year.

Open-graded Aggregate: A crushed stone aggregate material with limited fine particles. The void spaces between the aggregates can store water and allow free drainage.

Outlet: The point at which water is discharged into a stream, lake, river, storm drain, or conveyance channel or location.

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

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

Performance Period: The period of time an initial pavement structure will last before requiring rehabilitation. The performance period is the time from initial serviceability as a new, reconstructed, or rehabilitated pavement structure to its terminal serviceability requiring rehabilitation.

Permeability: The rate a fluid (in this case, water) passes through a porous medium, usually expressed in calculations per specific ASTM or AASHTO tests, and typically expressed in inches per hour or meters per second.

Permeable Interlocking Concrete Pavement (PICP): A paving system consisting of segmental concrete paving units with rectangular or indented shapes manufactured from concrete. Either type of shape is placed in an interlocking pattern, compacted into a highly permeable bedding layer consisting of small aggregate, the joints filled with a highly permeable

aggregate compacted again to start interlock. The paving units and bedding material are placed over a highly permeable open-graded base typically 200 mm (4 in.) thick of aggregates ranging in size from 20 mm down to 3 mm. This layer is placed over an open-graded subbase consisting of large-sized aggregates, an unbound or occasionally a bound layer. Sand is not used within the PICP pavement structure.

Permeable Pavement: A surface with openings capable of passing water through it while supporting pedestrians and vehicles (e.g., permeable interlocking concrete pavement).

Pervious Pavement: A surface capable of accepting water and supporting pedestrian and vehicles (e.g., pervious concrete).

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

Porosity: Volume of voids in a base divided by the total volume of the base.

Porous Pavement: A surface full of pores supporting pedestrians and vehicles (e.g., porous asphalt).

Present Serviceability Index (PSI): Developed for the AASHO Road Test, a ride quality rating that required a panel of observers to ride in an automobile and provide an assessment of smoothness on a scale of 0 to 5.

Pretreatment: Best management practices (BMPs) that provide storage and filtering of pollutants before they enter another BMP for additional filtering, settling, and/or processing of stormwater pollutants.

R-Value: A value given to a saturated, compacted test specimen of soil when it exudes from the testing device under a 2-MPa (190-psi) load. *See* ASTM D2844 or AASHTO T-190 for more details.

Recurrence Interval: The recurrence interval is based on the probability that the given event will be equaled or exceeded in any given year (*see* Return Period). Rainfall recurrence intervals are based on the magnitude and the duration of a rainfall event.

Reservoir Layer: The portion of a permeable pavement designed hydrologically to detain or retain water, typically limited to the subbase and base layers.

Resilient Modulus: Testing that characterizes load (pressure or stress) to deformation (strain) and suggests soil (or base) resistance to rutting. Modulus is express in megapascals or pounds per square inch.

Retention Pond: A body of water that collects runoff and stays full permanently. Runoff flowing into the pond that exceeds its capacity is released into a storm drain, stream, lake, or river.

Return Period: An estimate of the likelihood of a storm event occurring, usually expressed in years. (*See* One-Hundred-Year Storm, One-Year Storm, and Recurrence Interval.)

Run-On: The portion of rainfall that drains onto a site.

Runoff: The portion of rainfall that drains away from a site.

Runoff Coefficient: Ratio of surface runoff to rainfall expressed as a number from 0 to 1.

Sailor Course: A paver course where lengths of rectangular pavers are laid parallel (lengthwise) to the edge restraint.

Sand: A soil larger than the 0.075 mm (No. 200) sieve and passing through the 4.75 mm (No. 4) sieve, according to the Unified Soil Classification System.

Saturated Hydraulic Conductivity: A quantitative measure of a saturated soil's ability to transmit water when subjected to a hydraulic gradient.

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

Serviceability: The ability of the pavement to serve the type of traffic (e.g., pedestrians, cars, trucks, buses, and other heavy vehicles) that uses the facility. The primary measure of serviceability is the present serviceability index (PSI), which ranges from 0 (very poor road) to 5 (perfect road).

Sheet Flow: The laminar movement of runoff across the surface of the landscape.

Silt: A soil with no more than 50% passing through the 0.075 mm (No. 200) sieve that has a low plasticity index in relation to the liquid limit, according to the Unified Soil Classification System.

Soldier Course: A paver course where lengths of rectangular pavers are laid perpendicular to the edge restraint.

Spacer Bars: The small protrusions on the sides of pavers keeping them uniformly spaced apart while compacting the pavement surface. They facilitate filling joints with aggregate and help minimize chipping and spalling during installation. Mechanically installed pavers should have spacer bars.

Stormwater Control Measure (SCM): Elements and best management practices that are designed and implemented to eliminate or reduce contact or exposure of pollutants to stormwater or remove pollutants from stormwater prior to discharge from the facility.

Structural Number (SN): A numerical value used by AASHTO to assess the structural capacity of a pavement to handle ESALs and soil subgrade strength.

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

Subgrade: The soil upon which the pavement structure is constructed.

Swale: A small, linear topographic depression that conveys runoff.

Time of Concentration: The time runoff takes to flow from a drainage area's most distant point to the point of discharge.

Total Maximum Daily Load (TMDL): A term in the U.S. Clean Water Act describing the maximum amount of a pollutant that a body of water can receive daily without significantly impairing the water quality or health of the existing aquatic ecosystem.

Treated Base: An aggregate base or subbase combined with cement, asphalt, or other material added to increase its stiffness and structural capacity.

Unified Soil Classification System: Method of describing the type and physical properties of soils.

Wearing Course: The top concrete paver surface of a permeable pavement system, which is subjected to traffic loads directly.

2.3 CONSENSUS STANDARDS AND OTHER REFERENCED DOCUMENTS

This section lists the standards and other documents that shall be considered part of this standard to the extent referenced in the chapters.

AASHTO GDPS-4. *Guide for Design of Pavement Structures*, 4th Ed., American Association for State Highway and Transportation Officials, 1993.

AASHTO T-307. *Standard Method for Testing Resilient Modulus*, American Association for State Highway and Transportation Officials, 1999.

AASHTO T-11. *Standard Test Method for Materials Finer than 75-μm (No. 200) Sieve in Mineral Aggregates by Washing*. American Association for State Highway and Transportation Officials, 2005.

AASHTO M-43. *Sizes of Aggregate for Road and Bridge Construction*, American Association for State Highway and Transportation Officials, 2013a.

AASHTO T-193. *Standard Method of Test for The California Bearing Ratio*, American Association for State Highway and Transportation Officials, 2013b.

AASHTO T-19M/T-19-15. *Standard Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate*, American Association for State Highway and Transportation Officials, 2014a.

AASHTO T-27. *Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates*, American Association for State Highway and Transportation Officials, 2014b.

AASHTO M-288-15. *Standard Specification for Geotextile for Highway Applications*, American Association for State Highway and Transportation Officials, 2015a.

AASHTO T-96. *Standard Test Method for Resistance to Degradation of Small-size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine*, American Association for State Highway and Transportation Officials, 2015b.

AASHTO HMAGGR-17. *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*. American Association for State Highway and Transportation Officials, 2017a.

AASHTO T-180. *Standard Method of Test for Moisture–density Relations of Soils Using a 4.54 kg (10 lb) Rammer and a 457 mm (18 in.) Drop*. American Association for State Highway and Transportation Officials, 2017b.

ABA. *Architectural Barriers Act – United States Access Board*, 1968.

ADA. *Americans with Disabilities Act*, 1990.

ADAAG. *ADA Accessibility Guidelines*, 1990.

AODA. *Accessibility for Ontarians with Disabilities Act*, 2005.

ASTM D3385. *Standard Test Method for Infiltration Rate of Soils in Field using Double-ring Infiltrometer*. Annual Book of ASTM Standards, Vol. 04.08. ASTM International, 2009.

ASTM D2487. *Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)*. Annual Book of ASTM Standards, Vol. 04.08. ASTM International, 2011a.

ASTM E2835. *Standard Test Method for Measuring Deflections using a Portable Impulse Plate Load Test Device*. Annual Book of ASTM Standards, Vol. 04.03. ASTM International, 2011b.

ASTM D448. *Standard Classification for Sizes of Aggregate for Road and Bridge Construction*, Annual Book of ASTM Standards, Vol. 04.03. ASTM International, 2012a.

ASTM D698. *Standard Test Methods for Laboratory Compaction Characteristics of Soil using Standard Effort [12,400 ft-lbf/ft^3 (600 kN-m/m^3)]*. Annual Book of ASTM Standards, Vol. 04.08. ASTM International, 2012b.

ASTM D2844/D2844M-13. *Standard Test Method for Resistance R-value and Expansion Pressure of Compacted Soils*. Annual Book of ASTM Standards, Vol. 04.08. ASTM International, 2013b.

ASTM C131/C131M-14. *Standard Test Method for Resistance to Degradation of Small-size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine*. Annual Book of ASTM Standards, Vol. 04.02. ASTM International, 2014a.

ASTM C136/C136M-14. *Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates*. Annual Book of ASTM Standards, Vol. 04.02. ASTM International, 2014b.

ASTM C1781. *Standard Test Method for Surface Infiltration Rate of Permeable Unit Pavement System*. Annual Book of ASTM Standards, Vol. 04.05. ASTM International, 2015.

ASTM C33/C33M-16. *Standard Specification for Concrete Aggregates*. Annual Book of ASTM Standards, Vol. 04.02. ASTM International, 2016a.

ASTM C535. *Standard Test Method for Resistance to Degradation of Large-size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine*. Annual Book of ASTM Standards, Vol. 04.02. ASTM International, 2016b.

ASTM C936/C936M-16. *Standard Specification for Solid Concrete Interlocking Paving Units*. Annual Book of ASTM Standards, Vol. 04.03. ASTM International, 2016c.

ASTM C979/C979M-16. *Standard Specification for Pigments for Integrally Colored Concrete*. Annual Book of ASTM Standards, Vol. 04.05. ASTM International, 2016d.

ASTM C1645. *Standard Test Method for Freeze–Thaw and De-icing Salt Durability of Solid Concrete Interlocking Pavement Units*, ASTM International, 2016e.

ASTM D1883. *Standard Test Method for CBR (California Bearing Ratio) of Laboratory Compacted Soils*. Annual Book of ASTM Standards, Vol. 04.08. ASTM International, 2016f.

ASTM D5126-16e1. *Standard Guide for Comparison of Field Methods for Determining Hydraulic Conductivity in Vadose Zone*. Annual Book of ASTM Standards, Vol. 04.08. ASTM International, 2016g.

ASTM C29/C29M. *Standard Test Method for Bulk Density (Unit Weight) and Voids in Aggregate*. Annual Book of ASTM Standards, Vol. 04.02. ASTM International, 2017a.

ASTM C117-17. *Standard Test Method for Materials Finer than 75-μm (No. 200) Sieve in Mineral Aggregates by Washing*, ASTM International, 2017b.

ASTM C140. *Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units*. Annual Book of ASTM Standards, Vol. 04.05, ASTM International, 2017c.

ASTM C1701/1701M. *Standard Test Method for Infiltration Rate of In Place Pervious Concrete*. Annual Book of ASTM Standards, Vol. 04.02, ASTM International, 2017d.

ASTM D6938. *Standard Test Method for In-place Density and Water Content of Soil and Soil-aggregate by Nuclear Methods (Shallow Depth)*. Annual Book of ASTM Standards, Vol. 04.09. ASTM International, 2017e.

CSA A23.1/A23.2. *Concrete Materials and Methods of Concrete Construction/Test Methods and Standard Practices for Concrete*, Canadian Standards Association, 2014a.

CSA A231.2. *Precast Concrete Pavers*, Canadian Standards Association, 2014b.

CSA A23.2A (A23.2-14). *Sieve Analysis of Fine and Coarse Aggregates. Concrete Materials and Methods of Concrete Construction/Test Methods and Standard Practices for Concrete*, Canadian Standards Association, 2014c.

CSA A23.2-10A. *Density of Aggregate. Concrete Materials and Methods of Concrete Construction*, Canadian Standards Association, 2014d.

CSA A23.2-16A. *Resistance to Degradation of Small-size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine (for Aggregate ≤ 40 mm). Concrete Materials and Methods of Concrete Construction/Test Methods and Standard Practices for Concrete*, Canadian Standards Association, 2014e.

CSA A23.2-17A. *Resistance to Degradation of Large-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine (for Aggregate > 40 mm). Concrete Materials and Methods of Concrete Construction/Test Methods and Standard Practices for Concrete*, Canadian Standards Association, 2014f.