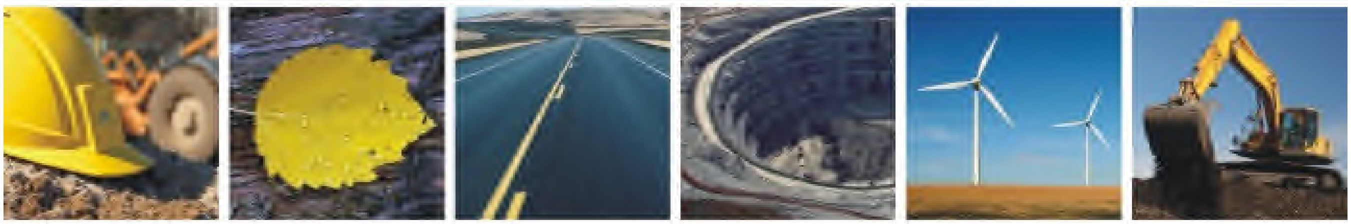
THE CITY OF CALGARY

DESIGN GUIDELINES – LOW IMPACT DEVELOPMENT PERMEABLE PAVEMENT – MODULE 6 CALGARY, ALBERTA



REPORT

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1.0 INTRODUCTION

This document provides technical guidance on the design considerations of permeable pavement structures that are to be integrated into the development of residential and commercial properties within The City of Calgary (The City). These considerations are part of the City's Low Impact Development (LID) protocol that minimizes the impact of stormwater on watersheds by integration of measures to detain, retain, and treat stormwater using soil infiltration and percolation.

These guidelines were developed to provide guidance for designers of permeable paving systems and are to be used in conjunction with the LID Geotechnical and Hydrogeological Considerations.

2.0 BACKGROUND

Porous pavement is a permeable pavement surface with an underlying stone reservoir that temporarily stores surface runoff before infiltrating into the subsoil utilizing some other form of evacuation. Porous pavement has recently gained more interest, largely due to the potential to alter the typical land development hydrologic cycle that reduces infiltration, increases direct runoff, and increases pollutants associated with surface runoff. Therefore, in terms of stormwater management, porous pavements not only promote infiltration and reduce and/or detain the quantity of runoff (and reduce or eliminate the need for retention areas) but also significantly improve the quality of the water that directly infiltrates to recharge the groundwater or discharges via an underdrain.

There are three types of permeable pavement designs depending on the subsurface conditions (Urban Drainage and Flood Control District):

- Full Infiltration Design, which allows for a full infiltration of stormwater into the subgrade soils (Figure 1).
- Partial Infiltration Design, which does not include an impermeable liner and allows partial infiltration into the subgrade but requires an underdrain system (Figure 2).
- No-Infiltration Design, which includes an underdrain and an impermeable liner that prevents infiltration of stormwater into the subgrade soils and is utilized if there is a possibility of groundwater contamination or the subgrade soils are of low permeability, have a high swelling potential, or consist of bedrock (Figure 3).

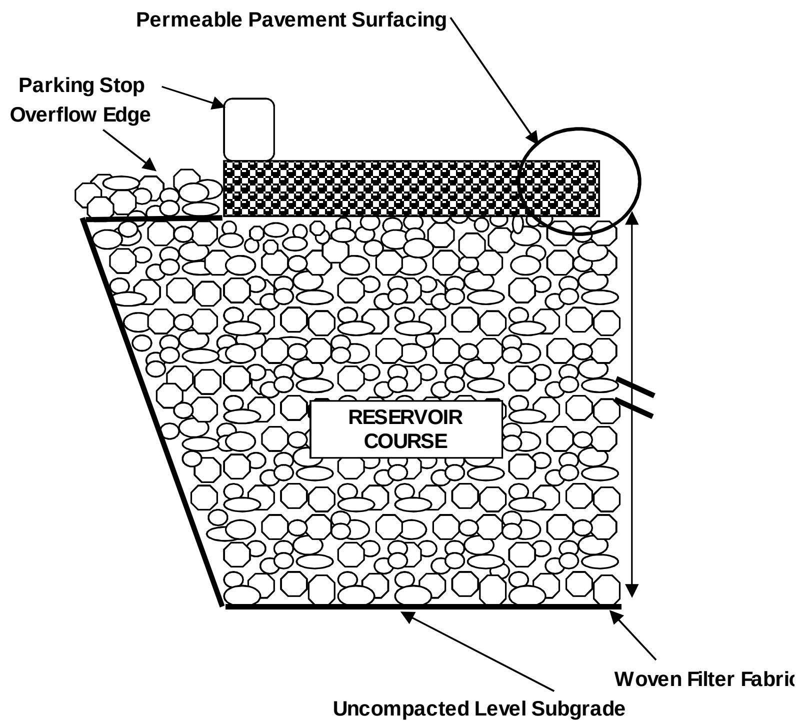

Figure 1: Typical Porous Pavement Section Infiltrating to Subgrade

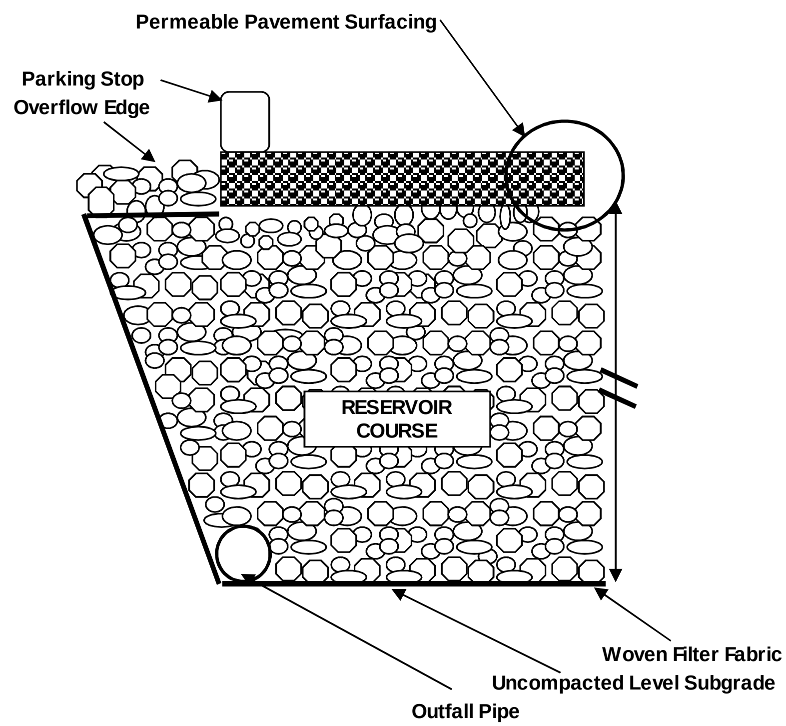

Figure 2: Typical Partial infiltration Porous Pavement Section with Subdrain System

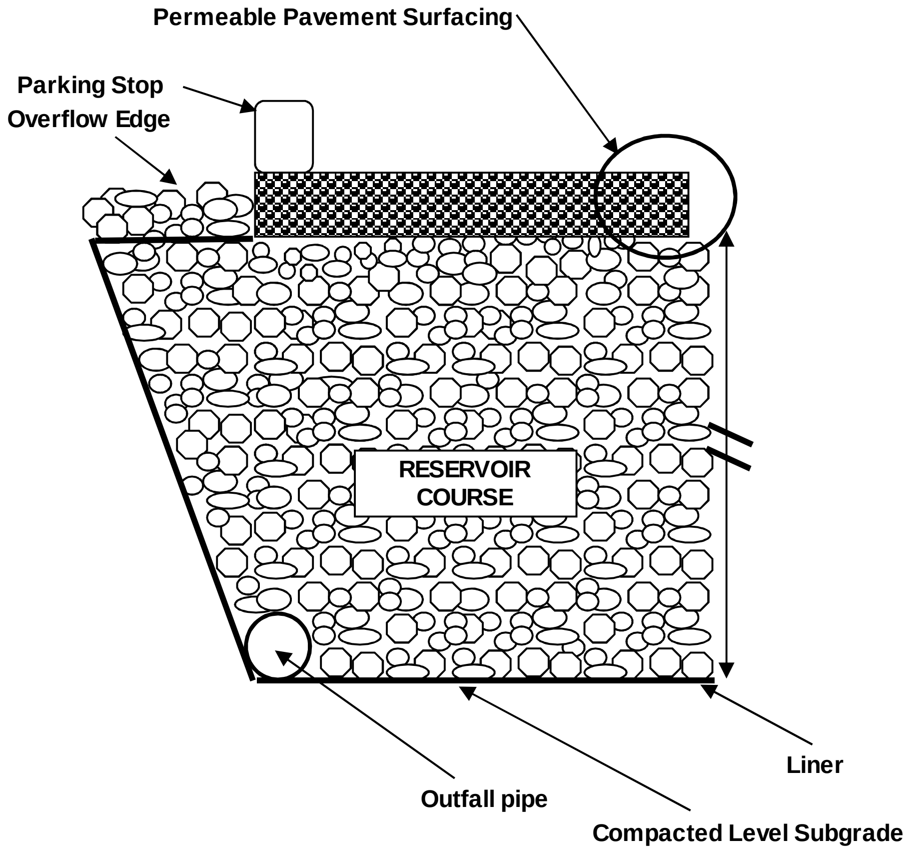

Figure 3: Typical No Infiltration Porous Pavement Section with Subdrain System

A typical porous pavement comprises the following elements:

- Porous Surfacing System – porous pavers, turf pavement, pervious concrete, or porous asphalt.
- Granular Choker Course – the choker course provides a platform for the porous surfacing and its maximum size is smaller than the reservoir course.
- Reservoir Course – the reservoir course is the key to the porous pavement in that it provides the stormwater storage such that infiltration into the underlying subsoil can occur. It should be a uniformly graded stone aggregate with 40% minimum void space and designed for runoff detention, frost penetration, and structural capacity.
- A Geotextile/Filter Fabric.
- Pervious Subsoil – pervious subsoil with sufficient permeability to enable infiltration of stormwater is necessary to eliminate the need for another method of stormwater conveyance.
- Subdrain system if the subsoil permeability is low (hydraulic conductivity less than 10^{-6} m/s) and the stormwater is conveyed to the existing storm sewer system or stormwater retention ponds, as determined by The City.

There are several permeable pavement surfacing options, including porous asphalt, pervious concrete, permeable pavers, and turf paving. The best locations for usage include parking lots, low-volume roads, driveways paths, shoulders, or recreational areas, such as basketball and tennis courts.

Porous asphalt and pervious concrete mixes are designed with no fines to provide a high voids ratio that allows water to pass through. Permeable pavers are made up of impervious concrete paving units with joints that allow water to percolate between them. Permeable pavers include products such as plastic lattice, grid systems, interlocking concrete modules, and brick pavers. Turf paving consists of a structural load bearing matrix, predominantly concrete, and filled with permeable materials such as gravel or soil. Examples of permeable systems are presented in Figure 4.

Examples of Porous Pavers

Examples of Green Pavements

Figure 4: Porous Surfacing Products

Porous pavements offer several stormwater management and environmental related advantages, including:

- Reduction of runoff peak rates and volumes that may otherwise lead to downstream flooding and bank erosion;
- Recharging of groundwater and maintaining a balance of water in the soil, groundwater, and streams;
- Improvement in water quality due to sedimentation and filtration;
- Reduction in downstream storm sewer flows;
- Space conservation on development sites when not using retention areas such as ponds; and

- Reduced overall costs due to reduction or no utilization of storm sewers or drainage structures.

3.0 PERMEABLE SURFACING MATERIALS

There are three surfacing materials used in permeable pavement systems: porous asphalt concrete, pervious concrete, and interlocking concrete pavers (including concrete grid porous pavers and recycled plastic grid systems). The properties of each system are discussed separately.

3.1 Porous Asphalt Concrete

3.1.1 General

Porous asphalt comprises an open-graded mix designed with a relatively high void content to allow for rapid infiltration of water. Advantages of this material are lower cost and the ability to place the material with conventional equipment and procedures.

The United States Department of Transportation and the Federal Highway Administration (FHWA) recommends that porous pavement structures consist of three components: a surface course, a filter course, and a reservoir course, which are to be constructed on a permeable subgrade base. The surface course typically consists of 50 mm – 100 mm (2 inches – 4 inches) of an open-graded asphalt mix. The filter course or bedding material thickness ranges between 25 mm – 50 mm (1 inch – 2 inches) consisting of crushed aggregate that provides filtering and an adequate platform for paving. The reservoir course has a typical maximum size aggregate of 40 mm – 80 mm with a variable storage depth designed to meet structural and storage requirements.

3.1.2 Mixture Properties

Porous asphalt pavements were first developed in the 1970s at the Franklin Institute in Philadelphia. Porous asphalt mixtures typically consist of standard bituminous asphalt in which the aggregate fines (particles smaller than 0.6 mm) are minimized to allow water to pass through the asphalt.

The asphalt concrete mix type recommended is not necessarily specific to porous pavement applications. Porous asphalt concrete mixes are commonly referred to as open-graded friction courses (OGFC) when used on highways. The early mixes were typically specified using the Marshall mix design method with the only requirements being aggregate quality, gradation, and minimum asphalt content. Unmodified cement binders were used in the early mixes.

The specifications adopted for porous asphalt pavement projects reflect improved materials selection and mix design protocols. The outcome product is a mix which generally has a higher void content than previous OGFC materials, increasing the rate of infiltration of water. Also, mix design requirements are in place to optimize the durability characteristics of the surfacing. These two aspects, high void content and durability, serve to improve the performance of these materials in cold climates subject to numerous freeze-thaw cycles. Porous pavements have also proven to be durable, to have good surface friction, and to decrease splash and spray during rain events.

Porous asphalt generally consists of asphalt cement (binder) and various coarse and fine aggregate gradations. Porous asphalt mixtures have higher percentages of air voids compared to conventional mixes.

The typical air void percentage for porous asphalt, which was recommended by the National Asphalt Pavement Association (NAPA) or FHWA, ranges between 16% and 22% (or higher). Performance graded asphalt cements (PGACs) are typically specified in porous asphalt concrete pavements.

The design guidelines for surface courses for porous asphalt are similar to the guidelines provided for an open-graded friction (surface) course (NAPA 2008). A typical method considered in the mix design is the one outlined in the National Centre for Asphalt Technology publication *"Design, Construction, and Performance of New-Generation Open Graded Friction Courses, Information Series 115 (2002)."*

Porous asphalt pavements were known to fail due to lack of stiffness in the mix. To mitigate failures, the grade of binder was recommended to be increased two grades higher than what is normally specified for a specific region (NAPA 2008). Alternatively, asphalt modifiers can be utilized to assist in reducing temperature susceptibility of the asphalt mixture. Caltrans' specifications for OGFC utilize a performance grade binder that is stiffer than the binder typically specified in the area. Anti-stripping additives can be used to provide adequate adhesion between the binder and the aggregates. Typical asphalt cement content for porous asphalt mixtures ranges between 5.5% - 6.5% (NAPA 2008, Cahill 2003). When a lower asphalt content was used, some surface scuffing and/or ravelling was observed on the pavement surface (Cahill 2003).

The properties and gradation of the aggregates in the surface course are essential factors in providing the high air voids in the mix. A high proportion of coarse aggregate (percentage of aggregate retained on sieve size 5.0 mm) compared to fine aggregates is typically required to design porous asphalt mixes. The properties of the coarse and fine aggregate, such as Los Angeles Abrasion, fractured faces, flat and elongated faces, and fine aggregate angularity of porous asphalt mixtures, are provided by NAPA (2008).

There are number of guides and specifications available for porous asphalt mixes that can be used for installations in Calgary:

- National Centre for Asphalt Technology publication National Asphalt Pavement Association (NAPA), *Porous Asphalt Pavements for Stormwater Management: Design, Construction, and Maintenance Guide,* Publication IS-131, 2008.
- National Asphalt Pavement Association (NAPA) publication IS-115, *Design, Construction, and Maintenance of Open-Graded Friction Course Mix Design.*
- National Center for Asphalt Technology (NCAT), *Design, Construction, and Performance of New Generation Open-Graded Friction Course Mixes,* NCAT Report 2000-01.

3.1.3 Performance Criteria of Porous Asphalt Mixes

- Type of mix – Superpave or Marshall mixes.
- Type of binder –PGACs are typically specified in porous asphalt concrete pavements. The asphalt cement should be one or two grades stiffer than what would be required for temperature. Asphalt content range – 5.5% - 6.5% by weight of total mix for mix durability.
- Air voids – 18% to 22% to assure permeability of the mix.

- Draindown – 0.3% maximum to assure that the asphalt binder does not drain down during silo storage, transportation, and placement. Polymer-modified binder and/or the addition of fibres to the mix effectively minimize drain down potential.
- Moisture susceptibility – As measured by tensile strength ratio (TSR), should be a minimum of 80%.

The testing protocol shall follow The City Roads Construction Specifications and the Permeable Pavements Specifications contained in Appendix D.

3.2 Pervious Concrete

3.2.1 General

Pervious concrete can be an important part of LID, being used to improve water quality by capturing the first flush of surface runoff, increasing base flow, and reducing flooding potential by creating short-term storage detention of rainfall. The term “pervious concrete” refers to a zero slump, open-graded material composed of Portland cement, coarse aggregate, little or no fine aggregate, water, and admixtures. The combination of these ingredients will produce material with the compressive strength in the range of 28 MPa and an air void content between 18% and 35%. The drainage rate of pervious concrete depends on the aggregate size and the density of the mixture but will generally be in the range between 80 and 730 L/min/m^2 (ACI Committee Report 522R-06). Applications for pervious concrete include low volume pavements, residential roads and alleys, sidewalks, parking lots, tennis courts, patios, tree grates in sidewalks, and pavement edge drains (Figure 5).

Pervious concrete has been used in construction since the 1850s in Europe, but it was referenced as no-fines or gap-graded concrete. The first reported use of pervious concrete in Canada was in 1960 for housing in Toronto and as a non-structural material in a federal building in Ottawa.

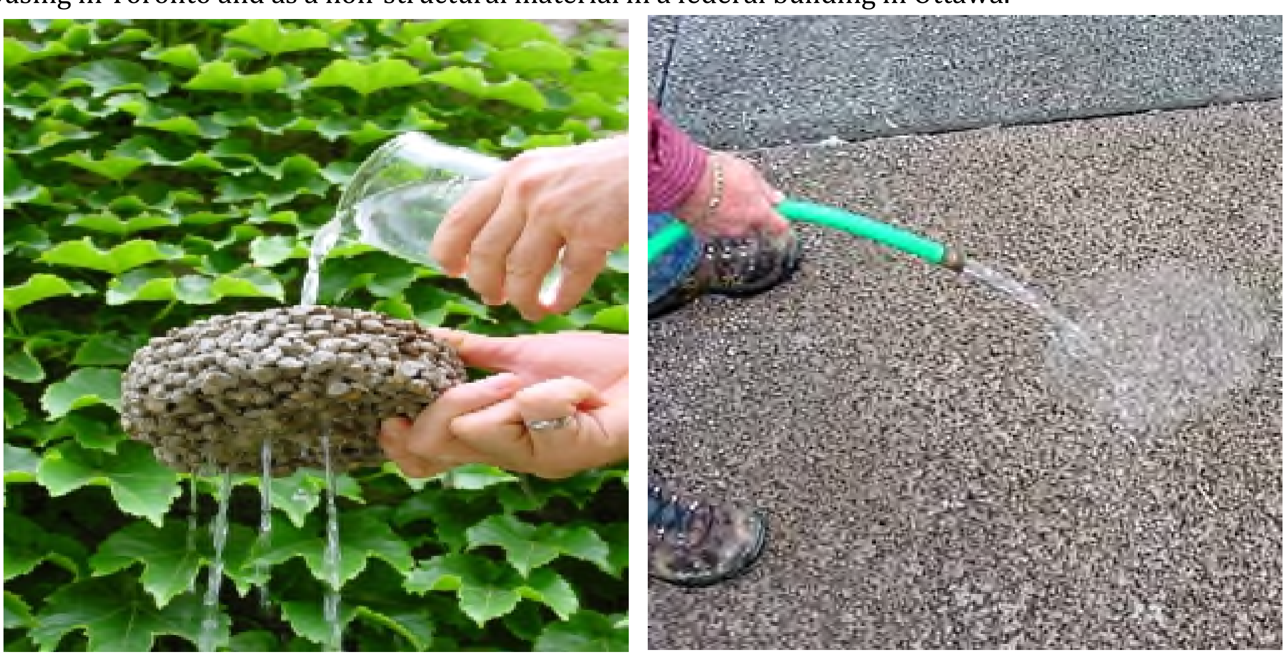

Figure 5: Pervious Concrete

3.2.2 Mixture Properties

In pervious concrete, controlled amounts of water and cementitious materials are used to create a paste that forms a thick coating around aggregate particles. The pervious concrete mix contains little or no sand and the coarse aggregate is gap-graded. The guidelines for pervious concrete are contained in the Portland Cement Association (PCA) publication, *Pervious Concrete Pavements*.

The plastic pervious concrete mixture is stiff when compared to traditional concrete. The compacted mixture exhibits an open matrix with the aggregates tightly adhered to one another. The gradation and compaction level have a significant impact on the compressive strength and permeability of the pervious mixtures. Virtual pervious concrete microstructural models have been developed to design an optimum pervious structure that is resistant to freezing and thawing cycles and to clogging (Bentz 2008). A recent study indicated that as the porosity increases, the strength decreases, and permeability increases (Neptune and Putman 2010). The porosity of the pervious concrete may be estimated from the bulk density of the aggregate (Mahboub et al. 2009). Cementitious materials used for pervious concrete production are similar to that used in traditional concretes. Supplementary cementing materials (SCMs) such as fly ash and ground-granulated blast furnace slag may be used. Fine aggregate content is limited in pervious concrete and a narrow coarse aggregate gradation is recommended. Water to cementitious materials ratios (w/cm) are between 0.27 and 0.30. Higher w/cm, up to 0.4, is used, but the strength of such mixes may be adversely affected. The limits for mixing water quality are similar to a traditional Portland cement concrete. Concrete admixtures such as water reducers, retarders, and air-entraining admixtures are commonly used. General information on mixture proportioning is contained in the PCA report (Tennis et al. 2004). Materials proportions are project/site specific and are selected for optimum permeability, strength, and durability requirements.

3.2.3 Performance Criteria of Pervious Concrete

- Type of cement – Type GU (normal Portland hydraulic cement) or Type HE (high early strength hydraulic cement) is utilized in the mix.
- Supplementary cementing materials – silica fume and fly ash.
- Compressive strength – 30 MPa minimum for structural performance and durability in cold climates.
- Air void content: 18% to 35%.
- Permeability – the flow rate through pervious concrete depends on materials and placing operations. Typical flow rates are 2×10^{-3} m/s to 6×10^{-3} m/s.
- w/cm: 0.27 to 0.34.
- The limits for mixing water quality are similar to a traditional Portland cement concrete.
- Concrete admixtures such as water reducers, retarders, and air-entraining admixtures are commonly used.

3.3 Permeable Interlocking Concrete Pavers

3.3.1 General

Porous pavers are designed with voids within the pavers and/or additional spacing between individual pavers to enable water to easily infiltrate the underlying zone. They are typically built on an open-graded crushed aggregate base (Figure 6). Typical application sites include low traffic volume roadways like residential streets and parking lots. For paver design purposes, the interlocking configuration provides regular void spacing for the permeable system. The voids between pavers are typically filled with sand to allow for appropriate drainage.

Advantages of porous pavers include relatively low maintenance requirements, and they are characterized by their aesthetic properties and availability in a wide variety of shapes and colours, which can be suited to any architectural design concept.

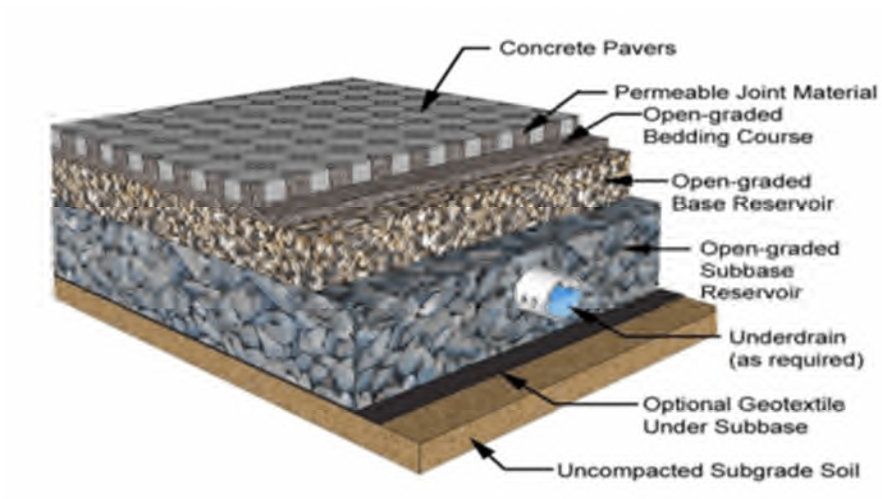

Figure 6: Typical Details (Smith 2009)

Three design options were identified for permeable interlocking concrete pavements (Smith 2009), which include full, partial, or no infiltration of open-graded base and sub-base into the soil. The design for the full infiltration option includes using an open-graded base and sub-base with aggregate-filled joints that allows maximum infiltration and increased storage capacity. Partial infiltration does not include full disposition of water into the underlying soil. A portion of the water infiltrates into the soil and the remainder is drained out by pipes. The "no infiltration" design option does not include any discharge of water into the soil. This could be due to low permeability subgrade soils or other factors such as shallow water or bedrock depths. A liner is typically used when no exfiltration is required.

Permeable interlocking concrete pavers are available in a number of paver designs that allow stormwater infiltration. The paver materials are not permeable, but the infiltration occurs in the designed gaps and openings within or between pavers. The properties are determined in the American Society for Testing and Materials (ASTM) C936 – Standard Specification for Solid Concrete Interlocking Paving Units. Type GU (General Use) Portland cement is most commonly used and the water content of the mix remains low.

Additional specific information on the properties of pavers should be provided by the concrete paver manufacturer.

3.3.2 Types of Permeable Interlocking Pavers

The Interlocking Concrete Pavement Institute (ICPI) suggests that there are various shapes and sizes of permeable interlocking concrete pavers, which may be categorized into four groups: interlocking shapes, enlarged permeable joints, porous concrete units, and concrete grid pavers.

- **Interlocking shapes with openings** – Interlocking shapes with openings are designed with various specific architectural patterns. These patterns have drainage holes that allow fluid to drain while maintaining high side-to-side contact among the units for stability under vehicular loads (Figure 7).

Figure 7: Interlocking Shapes with Openings

- **Enlarged permeable joints** – These are pavers constructed with wide joints or spacers allowing and facilitating rainfall to flow through the permeable system (Figure 8). The joints can be as wide as 35 mm. These joints can be filled with either open-graded aggregate or grass (and topsoil) if the joints are wide.

Figure 8: Enlarged Permeable Joints

- **Porous concrete pavers** – These pavers allow rainfall to pass directly through the concrete (Figure 9). Like other pavers, the units are constructed beside one another over the bedding sand. These pavers are constructed carefully such that joint sand would not clog the openings in the surface of the units. These types of units are used in non-freeze-thaw areas only and are best for pedestrian areas and bicycle paths.

Figure 9: Porous Concrete Pavers (David Smith 2005)

- **Concrete grid pavers** – these pavers are typically used in what could be referred to as green pavement (Figure 10). This system is typically comprised of cells (concrete or geosynthetic), which when filled with sand and grass provide both the load carrying capacity for light traffic and a natural aesthetic. Specialty grass types are used to ensure root systems do not compromise the porosity of the surfacing. Compared to porous pavers, this type of surfacing requires increased maintenance much like any grass landscape area, and in the dry and sunny Calgary climate, the vegetation may be compromised due to heat coming from the concrete pavers.

Figure 10: Concrete Grid Porous Pavers

Performance criteria of concrete interlocking pavers and concrete grid porous pavers include the following:

- Compressive strength of pavers – Typically 60 MPa for structural performance and durability.
- Water absorption – Maximum 5% for freezing and thawing durability.
- Drainage void area – 12% to 50% per square metre, depending on the paver design and geometry.
- Ensure interlocking on all sides.

Composite grid pavers – They are used to stabilize soils while holding gravel in place or creating support to grow grass and are referred as turf pavements.

They provide an interlocking grid system for grass reinforcement, ground stabilization or gravel retention. Typically, the plastic is UV stabilized for better durability and the grids are marketed under several brand names. The load bearing capacity of composite grid pavers is somewhat lower than that of concrete grid pavers but they provide good support for light trafficked areas (Figure 11). Their properties are product specific and they are not standardized for applications in permeable pavement systems.

Figure 11: Composite Pavement

3.3.3 Other Considerations

- For cold climate regions in Canada and the northern United States, ICPI 2008 recommended to stockpile snow with chloride or sand away from the permeable pavement, in areas like parking lot islands where the quality of the infiltrate will not be compromised by a high concentration of chloride ions. It was suggested that chlorides should not be placed in permeable interlocking concrete pavers' areas, because the chlorides would kill the grass and affect the quality of groundwater. Sand would clog and reduce the infiltration capacity of the permeable pavement.
- Maintenance inspection should be undertaken in the spring to ensure no surface sediments exist, and the groundwater should be monitored for chloride concentration.
- The subgrade should still be compacted to at least 95% of the modified proctor density.
- High quality fabric/geotextiles are often used in permeable pavements. These materials should be specified such that no punctures occur during construction.

4.0 BEDDING AGGREGATE AND RESERVOIR COURSE

The properties of the granular materials are defined by the void space required for water retention and by the infiltration rates required for managing surface runoff. Both these parameters are achieved by a proper gradation. The properties of granular materials are specified in The City 2012 Standard Specifications Road Construction, Section 303.00.00 Granular Material and the properties of the granular materials used in the design and construction of permeable pavement systems are contained in the specifications in Appendix C.

4.1 General

Bedding materials range from ASTM (D448) No. 7 to ASTM No. 9 bedding sand. The use of 2 mm – 5 mm aggregate (ASTM No. 9) was found to be the best in terms of infiltration capacity and structural performance (Shackel et al. 1996). It is typically used in bedding and jointing the pavers.

Research indicated that crushed stone or an open-graded base with 40% voids space (Cahill 2003) and a high infiltration rate (above 10^{-3} m/sec) be utilized. The open-graded base is known as the reservoir course. The reservoir course is the key to the porous pavement. It provides the stormwater storage such that infiltration into the underlying subsoil can occur. ASTM No. 57 crushed aggregate has been widely used as a reservoir course in permeable pavements constructed in the United States and Canada.

The thickness of the granular reservoir course is the most important parameter in the pavement design to avoid a compressive failure at the subgrade interface. The reservoir course should be designed for runoff detention, frost penetration, and structural capacity. In most instances, thickness considerations for frost penetration and/or runoff detention govern, and the resulting thickness exceeds that required to accommodate the anticipated traffic loading. Most design references suggest that the depth of the porous pavement structure should exceed the depth of frost penetration. Generally, this is considered to be impractical in locations such as Calgary, Alberta, where the depth of frost penetration could exceed 2 m. The resulting porous pavement structure would not only be very expensive but also difficult to construct.

Virginia DCR Stormwater Design Specification No. 7 indicates that the thickness of the reservoir layer is determined by runoff storage needs, the infiltration rate of in-situ soils, structural requirements of the pavement sub-base, depth to water table and bedrock, and frost depth conditions. It states the following:

- The reservoir below the permeable pavement surface should be composed of clean, washed stone aggregate and sized for both the storm event to be treated and the structural requirements of the expected traffic loading.
- The storage layer may consist of clean washed ASTM No. 57 stone, although ASTM No. 2 stone is preferred because it provides additional storage and structural stability.
- The bottom of the reservoir layer should be completely flat so that runoff will be able to infiltrate evenly through the entire surface with the exception of the design for a no infiltration system.

Most agencies recommend using ASTM No. 8 crushed aggregate as a filter layer between the permeable surfacing and the reservoir course (Ferguson 2005). The primary purpose for using the filter course is to provide an even and smooth surface on top of the reservoir course. It also stabilizes and acts as a choking medium for the open-graded base. The thickness of this layer can be up to 75 mm (3 inches) prior to compaction. ASTM No. 8 can also be utilized to fill the joint openings of permeable pavers. The gradation specifications for both the reservoir course and filter course are provided in the ICPI design manual.

4.2 Bedding Aggregate

Bedding aggregate for permeable pavers should have a grain size between 2 mm and 5 mm (ASTM No. 9).

4.3 Filter Surfacing

The filter layer is the layer between the permeable surfacing and the reservoir course and should have a grain size between 10 mm and 2 mm (ASTM No. 8 crushed aggregate or an equivalent).

4.4 Reservoir Course

The reservoir course below the permeable pavement surface should be composed of clean, washed stone aggregate. The reservoir course should have a minimum of 40% voids space and a high infiltration rate (above 10^{-3} m/sec). ASTM No. 57 crushed aggregate or an approved alternative can be used provided that it has a minimum void content of 40%.

The bottom of the reservoir layer should be as flat as practical so that runoff will be able to infiltrate evenly through the entire subgrade surface.

5.0 GEOTEXTILES

Geotextile fabrics are man-made or synthetic fabric used in the control of soil erosion, stormwater drainage systems, filtration to prevent clogging and to extend the life of the drainage system, and road bed separation and stabilization. The selection of the fabric depends on the use and on the individual site condition. Filter fabrics are divided into three categories: (a) non-woven needle punched geotextiles, (b) woven filtration geotextiles, and (c) woven stabilization geotextiles.

Woven monofilament geotextile fabrics with high strength and excellent hydraulic properties provide immediate and long-term solutions for most drainage and filtration applications. Woven filter fabrics have a wide range of "percent open area," which allows for both water and particles to pass through the geotextile. Non-woven fabrics have little or no percent open area and often trap soil particles within the fabric thus clogging the geotextile. Based on the properties of the geotextiles, only woven filter fabrics should be used in permeable pavement applications where clogging prevention is important in providing long-term performance of the pavement structure. There are numerous suppliers of woven filtration geotextiles and the percent open area for these products ranges from 6% to 30% allowing for a range of flow rates.

Geotechnical situations that are considered prone to clogging problems with subdrain systems are characterized by high silt content, but the presence of clay together with silt also plays a role in filter clogging. Research conducted at Purdue University (Lee and Bourdeau 2006) indicated that the soil type and the degree of compaction should be a factor in selecting filter fabrics. Another important factor is the thickness of the fabric; the thicker the geotextile, the more likely a particle will encounter a constriction smaller than its size. High silt content soils can be effectively filtered by thick geotextiles with small openings rather than by thin fabric with large openings. The relationship between filter fabric opening size and soil grain size distribution is also important.

Filter fabrics in permeable pavement applications are used as separators between the non-compacted permeable native soils, and, in subdrain systems for partial infiltration or no-infiltration pavement designs. In addition, filter fabrics may be used as a separator between the leveling sand in interlocking paver construction and the reservoir. In these applications, selection of a filter fabric is critical and the properties of the fabric with respect to percent open area and flow rate must be considered in conjunction with the gradation of the granular materials and the subsoil characteristics. The properties of the geotextile used in permeable pavement design have to match the properties of soils and the granular materials to minimize clogging and are site specific.

The main disadvantage of using geotextiles for bedding course and reservoir course separation is the risk of reducing flow rates due to clogging of the geotextile with fine sediments and reducing the friction between permeable layers. As such, the use of geotextiles for bedding course and reservoir course separation shall not be accepted by The City.

There are no general rules for use of geotextiles, and the selection and geotextile properties should be site-specific. The properties of the geotextile used in permeable pavement design have to match to properties of soils and the granular materials to minimize clogging. Guidelines on the properties of geotextiles are manufacturer/supplier specific and are typically contained in technical data and application manuals provided by each geosynthetics supplier.

6.0 PERMEABLE PAVEMENT DESIGN

6.1 General Design Principle

The layer thickness design for permeable pavements is typically integration between structural and hydrological designs. ICPI introduced a software program in 2008 called Permeable Design Pro, which integrates hydrological and structural design solutions for permeable interlocking concrete pavement. This software determines if the volume of water from user-selected rainfall events can be stored and discharged by the design pavement structure. The critical inter-relationship between precipitation potential, pervious concrete system characteristics, and site geometry are vital parts of design considerations (Leming et al. 2007).

For pavement structural design, many local agencies allow using the American Association of State Highway and Transportation Officials (AASHTO) *Guide for Design of Pavement Structures* (1993), which is based on empirical principles developed from data obtained from the 1950's AASHTO Road Test. The AASHTO 1993 equation calculates a Structural Number or SN based on traffic loading, soil type or strength, and serviceability. As indicated in the literature, this design approach can be applicable to permeable pavements. The design pavement structure, which includes the surfacing and base materials, should meet or exceed the required structural number. The AASHTO 1993 has been the primary pavement design methodology in many jurisdictions within Canada and the United States.

There are several theories with pavement design that are based on the Mechanistic-Empirical Pavement Design Guide (MEPDG). The AASHTO 2002 *Mechanistic–Empirical Pavement Design Guide* is now being used by many agencies. This design guide is based on mechanistic design, which is characterized by the analysis of loads and output stresses and strains at different pavement layers and at the soil subgrade. It uses a wide range of traffic, climate, and soil conditions but has not been calibrated for permeable pavements.

The structural design of permeable pavements involves consideration of four main site elements:

- Total traffic;
- In-situ soil strength;
- Environmental elements; and
- Bedding and reservoir layer design.

Smith (2009) suggested that soil borings be taken up to 1.5 m in depth to determine the water table depth and depth of bedrock. No-infiltration design options can then be adopted if the water table or bedrock depth is shallow. Soil classification (in accordance with Unified Soil Classification System), moisture content, soaked California bearing ratio (CBR), AASHTO 1993, and tests for rate of infiltration of soils are the required minimum as suggested by Smith (2009).

The thickness of the different layers in the permeable system must be appropriate to support structural loads and to temporarily store the design storm volume. The resulting structural requirements may include, but are not limited to, the thickness of the pavement, filter, and reservoir layer.

The basic design methodology for pervious concrete pavement is described in several documents such as Hydrologic Design of Pervious Concrete (Lemming et al. 2007) and Pervious Concrete Pavements (Tennis 2006). The design software PerviousPave issued by American Concrete Pavement Association (ACPA) provides results optimized for both structural and stormwater management by determining the required minimum thickness for pervious concrete pavement based on the design traffic, design life, and structural inputs. The required reservoir thickness necessary to satisfy stormwater management requirements is based on the volume of water to be processed by the pavement within the required maximum detention time. The design storm amount is available from the 2011 Stormwater Management and Design Manual, The City Water Resources.

6.2 Design Objectives

In the process of urbanization and land development, natural and undisturbed areas are being replaced with impervious surfaces such as asphalt concrete and Portland cement concrete roads, buildings, and parking lots. The expanding impervious cover may result in an increase in the surface runoff and a decrease in infiltration. The management of increased levels of stormwater runoff is becoming a major concern for municipalities with regards to pollutants found in surface waters and the impact on storm sewer systems. Stormwater source control practices (SCPs) are activities or practices that divert, detain, or retain stormwater runoff and/or reduce pollutant concentrations. The purpose of implementing SCPs is to reduce or eliminate the impacts that stormwater runoff has on the environment. Current stormwater quality criteria for The City requires the removal of a minimum of 85% total suspended solids (TSS) for particle size greater than, or equal to, 50 µm (2011 Stormwater Management & Design Manual). In addition, runoff volume targets exist for selected critical watersheds. Better planning practices (BPPs) are designed to reduce the amount of impervious cover, to increase natural lands set aside for conservation, and to use pervious areas for more effective stormwater treatment.

The term Permeable Pavement System used in this manual refers to a type of pavement that allows movement of water into the layers below the pavement surface. There are several design objectives in SCPs and BPPs that are considered in the hydrological and structural design of permeable pavements:

- Limiting impervious cover to reduce stormwater runoff and pollutants from development.
- Limiting runoff volumes to near pre-development levels.
- Maintaining groundwater recharge rates to sustain ecosystems and recharge aquifers.
- Capturing and treating stormwater runoff to reduce pollutant loadings.
- Mitigation of stream bank erosion and enhancing stream channel protection by infiltration and detention of runoff.
- Reducing downstream flooding by keeping the post-development peak discharge rate equal to pre-development rates.

Permeable paving systems may be designed to meet more than one of the objectives discussed above. It is the responsibility of the designer to develop the system that not only serves its intended purpose(s) but also meets federal, provincial, and municipal rules, regulations, and relevant design and construction specifications of The City.

6.3 Site Selection

A subsurface study shall be conducted by a geotechnical engineer to determine the feasibility and the selection of the permeable pavement system. Typical geotechnical investigations should include drilling or test pitting programs to characterize subsurface conditions, groundwater conditions, presence of bedrock, and anticipated ranges of infiltration. Laboratory testing performed on samples from the drilling program or test pitting allow characterizing the subgrade for supporting traffic loads and potential for infiltration. Detailed recommendations for the subgrade exploration and testing are provided in Module 1 of the LID Manual – Geotechnical and Hydrogeological Considerations.

The site selected for the permeable pavement system should meet the following criteria:

- Surface Slope – Paving system should not exceed 4%.
- Traffic volume – Daily traffic number AADT should not exceed 1,000.
- Subgrade – Subgrade soil CBR should not be less than 3.
- Land Use – Permeable paving should not be located downstream of high sediment generating activities and the following site conditions should be satisfied:
  - The concentration of TSS is less than 500 mg/L,
  - The ratio of upstream impervious to permeable pavement area ratio (I/P) is less than 4.
  - The sediment deposition should be less than 0.5 mm/year.
- Stability – Infiltration from the base of the permeable paving system should not be undertaken where soft, compressible, and saturated soils are identified by a geotechnical investigation. Alternate designs such as no-infiltration systems with the use of impermeable liners and geotextiles shall be considered.
- Minimum depth to bedrock or seasonal high water table below the bottom of the pavement infiltration reservoir should be 0.6 m.

7.0 HYDROLOGICAL/HYDROGEOLOGICAL DESIGN

Permeable pavement systems may be designed as retention or detention structures. A retention permeable pavement has the ability to pond rainfall in the pavement structure until infiltration into subgrade soils occurs. A detention permeable pavement is designed to divert water from the pavement structure by a drainage system to other SCPs, ponds, or storm sewer systems.

The basis for the hydrological design is to estimate the volume and rate of runoff from the pavement structure and surrounding catchment. Excess surface runoff is the amount of rain that falls, less the amount intercepted by ground cover or infiltrated into the soil. Runoff is also affected by the slope of the land and the type and extent of vegetation. The infiltration rate of a soil will depend on the soil type and will vary with the amount of moisture already in the soil. Values of typical infiltration rates are published in several sources, but professional judgement is required in selecting appropriate values for the hydrological design of permeable pavement systems. This is discussed in detail in Module 1 – Geotechnical and Hydrogeological Considerations of The City of Calgary LID Manual.

7.1 Hydrological/Hydrogeological Design Considerations

Permeable pavements may either simply replace an impervious surface or may be designed to handle much more rainfall than will fall on the pavement itself. The simple replacement of an impervious surface is a passive mitigation system that can capture much of the precipitation directly falling onto the permeable pavement structure but is not intended to offset excess runoff from adjacent impervious surfaces. An active mitigation system is designed to achieve the desired (pre-established) runoff rate, runoff volume, and water quality objectives, and can receive runoff from adjacent impervious surfaces up to the limits of Section 6.3.

The design inputs are outlined below.

7.1.1 Rainfall and Design Storm Event

The hydrological design objectives for a permeable pavement structure are a function of the locally relevant runoff rate, runoff volume and water quality objectives and shall be established in close collaboration with a stormwater professional. Typically, runoff rate and surface ponding performance is analyzed for a 1:100 year design storm event. A continuous simulation is required to analyze the runoff volume and water quality benefits of the proposed permeable pavement structure. Guidance with respect to the stormwater computations is provided in the 2011 Stormwater Management & Design Manual.

7.1.2 Permeability

In general, the permeability of the pavement structure itself is not a critical design parameter. The permeability of the pavement system, including surfacing and the reservoir, will be much higher than the infiltration rate of almost all soils as long as the pavement structure is properly constructed and adequately maintained. While clogging of the pavement structure will happen with time, as long as the infiltration rates of the granular reservoir is more than a factor of 100 greater than underlying soils, clogging of the reservoir will not be an issue (LID Geotechnical and Hydrogeological Considerations, Section 3.2.2).

Designers should ensure that the permeability of the pavement system is sufficient to accommodate all rain falling on the surface, and that the surface runoff from the adjacent structures is considered in the reservoir course design. Heavy sediment loading into the permeable area and its susceptibility to clogging should be taken into consideration in the design; the best strategy to prevent clogging is to ensure that adjacent pervious areas have adequate vegetation cover and that the maintenance strategy includes twice a year suction brushing.

7.1.3 Storage Capacity

The required storage capacity of permeable pavement systems is a function of the desired level of service, accounting for the hydrological design objectives as per Section 7.1.1., and the permeability as per Section 7.1.2. The total storage capacity of a permeable pavement system includes the capacity of the surfacing layer and that of the reservoir/base course used, and may also be increased with optional storage features such as curbs or underground tanks. The theoretical storage capacity of the pavement system is its effective porosity, i.e., the portion of the system that can be filled with rain in service, minus the sediment accumulation over the design life of the pavement structure. The sub-base is an important source of storage and its effective porosity should be taken into consideration in the design. It is expected that the granular material used for the construction of the reservoir will provide 30% to 40% voids (refer to Appendix E, Section A, contained in this document).

7.1.4 Effects of Slope

An important assumption in the storage capacity calculations is that the entire system is level. If the surfacing is not level and the intensity of the rainfall is greater than the infiltration rate of the soil, the upper portion of the pavement system will not be filled and the stormwater will quickly run to the lowest part of the pavement structure. Once the lower part is filled, the stormwater will run out of the lower end of the pavement and the available capacity of the reservoir is not utilized. Higher slopes of the pavement surfacing may also result in surface runoff instead of infiltration into the reservoir course of the pavement system. Therefore, the slope of the paving system should not exceed 4%.

7.1.5 Effects of Subgrade Soils

Infiltration into the subgrade is important for full and partial infiltration pavement systems. The process of soil infiltration is complex, but simplistic models using conservative estimates for infiltration rates are satisfactory. Values of typical infiltration rates are published. In accordance with the 1999 Stormwater Management Guidelines for the Province of Alberta, native soils with a percolation rate higher than 15 mm/h (4.2×10^{-6} m/s) are considered suitable as the subgrade under permeable pavements. Subgrade soils with lower infiltration rates will require a design of either a no-infiltration or a partial-infiltration permeable pavement system.

7.2 Hydrological Design Methods

While design software such as PerviousPave issued by the ACPA may provide the thickness of the reservoir necessary to satisfy stormwater management requirements, the methodology used in the hydrological design of permeable pavement systems should comply with The City 2011 Stormwater Management and Design Manual and LID – Geotechnical and Hydrogeological Considerations.

8.0 STRUCTURAL DESIGN

Permeable pavements do not follow the traditional design of typical pavements. A traditional pavement structure requires the subgrade to be compacted to increase the soil strength. In permeable pavement design, the subgrade should not be compacted to avoid reduction of the infiltration rate; however, the CBR value has to be greater than three. In addition, typical pavements are constructed with a dense, impermeable surface and, in the permeable pavement design, water flows through the surface and into the reservoir to provide temporary storage capacity prior to infiltration into the soil or diversion by the subdrain system.

The structural design of permeable pavements includes consideration of five main site elements:

- Traffic loading.
- In-situ (native) soil strength.
- Environmental requirements.
- Bedding and reservoir layer design.
- Site characteristics.

Detailed information on design inputs is contained in Appendix A contained in this document.

8.1 Structural Design Methodology

The AASHTO *Guide for Design of Pavement Structures* (1993) is a widely accepted design methodology and is the primary pavement design methodology in many jurisdictions within Canada and the United States, including Calgary. The *Guide for the Design of Pavement Structures* provides a comprehensive set of procedures that can be used for the design of flexible pavements, rigid pavements, and permeable pavements and aggregate surfaced low-volume roads. The design is based on empirical principles developed from data obtained from the 1950s AASHTO Road Test. The AASHTO 93 equation calculates a structural number (SN) based on traffic loading, soil type or strength, and serviceability. The design pavement structure, which includes the surfacing and base materials, should meet or exceed the required structural number. This design methodology is incorporated in The City 2012 Standard Specifications Road Construction, Section 308.00.00 – Pavement Design, for new construction of major and industrial roadways. Standard pavement structures, as per Section 308.02.00, are utilized for major collectors, minor collectors, and residential roadways. There is no specific section in The City 2012 Standard Specifications Road Construction for permeable pavements and the 1993 AASHTO *Guide for Design of Pavement Structures* should be the basis for the structural aspects of the permeable pavements. In addition, prior to constructing surface improvements, a pavement design has to be submitted to The City, Transportation, Roads, Materials & Research for approval. All permeable pavement designs are to be submitted to The City for approvals, including back lanes, walkways, and parking lots. The submissions should include traffic loading data, native soil strength and drainage ability, environmental requirements of the site, bedding and reservoir layer design, and site characteristics.

Computerized versions of the 1993 AASHTO *Guide for Design of Pavement Structures* are available: AASTHTOWare® DARWin 3.1 – Pavement Design and Analysis System, WinPAS Pavement Analysis Software, and PerviousPave – Structural and Hydrogeological Design, Software for Pervious Pavements.

8.1.1 Design Inputs

The permeable pavement structural design can be considered as similar to a flexible pavement design and rigid pavement design. The design of permeable pavements involves consideration of the following design inputs, which are taken from the AASHTO *Guide for Design of Pavement Structures*, The City 2012 Standard Specifications Road Construction, and the relevant guidelines for permeable pavement design cited in this section:

- Design equivalent single axle loads (ESALs) – As the permeable pavement systems are typically designed for low traffic loading conditions, such as light traffic residential streets, back alleys, and parking structures, the ESALs should not exceed 120,000. For higher ESALs, other non-permeable pavement types should be considered.
- The modulus of subgrade should be determined using a soaked CBR in accordance with the ASTM D1883. The modulus of the subgrade for fine-grained soils can then be determined using the empirical equation:

$$M_r\ (\text{MPa}) = 10.3 \times CBR_{soaked}$$

- The initial serviceability and terminal serviceability should be 4.2 and 2.5, respectively.
- The standard deviation, S_o, is 0.45.
- The reliability, R, is 75%.
- The structural layer coefficient for the porous asphalt, pervious concrete, and permeable pavers is 0.40.
- The structural layer coefficient for the reservoir layer is 0.12.

8.1.2 Permeable Surfacing Standard Thickness Design

The following design thickness criteria are provided for the permeable surfacing:

- The minimum paver thickness should be 80 mm.
- The porous asphalt concrete surfacing should consist of 75 mm to 100 mm of an open-graded porous asphalt mix.
- The pervious Portland cement concrete surfacing should consist of 100 mm to 150 mm of an open-graded porous concrete mix.
- The filter course or bedding material thickness should be at least 50 mm for constructability, if utilized in the design of a permeable pavement system.

Composite grid pavers are recommended for light trafficked areas and are frequently placed on subgrade soils with higher infiltration rates. As such, their thickness is not a part of the permeable pavement structural design and is determined by the grid type supplied by the manufacturer, typically in the 30 mm range.

8.1.3 Reservoir Thickness Design

The design of the reservoir course is determined by the storage capacity of the granular material and the hydrological requirements as determined in The City 2011 Stormwater Management and Design Manual and Module 1 – Geotechnical and Hydrogeological Considerations prepared for The City LID Guidelines.

8.1.4 Design Factors in Cold Climates

The design of permeable pavements in cold climates should take into consideration the effects of prolonged freezing temperatures on the performance of the pavement system. Frost durability of the surfacing materials must be ensured. Frost heave of a saturated subgrade may cause excessive movement during long periods of freezing followed by a significant loss of subgrade support during spring thaws. Durability of the permeable surfacing may be compromised if it freezes while fully saturated. Frost durability of the aggregate in the surfacing material and in the reservoir must be confirmed in accordance with The City 2012 Standard Specifications Road Construction.

9.0 CONSTRUCTION CONSIDERATIONS

9.1 General

Construction practices have a significant effect on the performance of porous pavement systems. Construction methods are similar to that of conventional pavement systems but an increased level of management is required to ensure a properly constructed system. Construction aspects that require consideration for all porous pavement systems include:

- Soil conditions;
- Erosion and sediment control;
- Excavation techniques;
- Layer placement and compaction;
- Geotextile installation; and
- Underdrain installation.

These considerations are discussed in detail below.

9.2 Soil Conditions

Prior to starting construction, the soil conditions need to be evaluated by a geotechnical investigation. This should include information, at a minimum, of the following:

- Soil classification, including stratigraphy and moisture contents;
- Standard Proctor Maximum Dry Density (SPD) and CBR;
- Infiltration rates; and
- Groundwater table.

9.3 Erosion and Sediment Control

Sediment entering a porous pavement system during construction can greatly diminish the performance of the finished product. Sediment infiltration at any stage can reduce the permeability of the subgrade soil, clog the reservoir and choker courses, as well as the permeable pavement surface.

Prior to construction activities an erosion and sediment control plan shall be submitted for approval. All porous pavement areas must be protected from sediment laden runoff for the duration of construction. The ICPI recommends the following, which is applicable for the all porous pavement systems.

Preventing and diverting sediment from entering the base and pavement surface during construction must be the highest priority. Extraordinary care must be applied to **keeping sediment completely away** from the area. Simple practices such as keeping muddy construction equipment away from the area, installing silt fences, staged excavation, and temporary drainage swales that divert runoff from the area will make the difference between a pavement that infiltrates well or poorly. Moreover, **the pavement should not**

receive runoff until the entire contributing drainage area is stabilized (Permeable Interlocking Concrete Pavements 2000).

For an area of the site intended ultimately to be a permeable pavement area, a minimum of 600 mm of cover must be maintained above the final design elevation of the bottom of the reservoir course. All sediment deposits shall be removed prior to installing the permeable pavement system.

Signage should be used to notify personnel to keep sediment and other debris from entering the site.

The 2011 City of Calgary ESC guidelines should be followed.

9.4 Excavation Techniques

When excavating and preparing the areas intended for a porous pavement system, the contractor shall employ practices which do not further compact the subgrade soil or compromise the area. The following practices shall be considered:

- Porous pavement areas shall be protected from excessive heavy equipment and vehicular traffic to avoid over compaction and the reduction of the permeability of the subgrade soil;
- Where possible, excavate the area from the sides to minimize subgrade compaction;
  - Contractors can utilize a cell construction approach, whereby the proposed permeable pavement area is split into temporary cells with an earth bridge in between, so that cells can be excavated from the side;
- Avoid the use of excavation equipment with narrow rubber tires to minimize subgrade compaction. Tracked equipment is recommended; and
- Stockpile excavated materials away from existing and proposed porous pavement areas and outside of the sediment control devices so as not to jeopardize the area.

9.5 Layer Placement and Compaction

Over-compaction in porous pavement systems can greatly reduce their effectiveness by reducing layer permeability. Compaction of the different types of porous surfacing layers is discussed individually in subsequent sections. Compaction considerations for the subgrade, reservoir course, and granular choker course are as follows.

9.5.1 Subgrade

- The subgrade shall be stripped of all topsoil or other organics and either excavated or filled to the final subgrade level;
- When fill is required, use only approved material free of organics, debris and other deleterious inclusions;
- Subgrade soils for which full or partial-infiltration is designed shall be scarified or tilled to a depth of 75 mm to 100 mm prior to the placement of the geotextile. This will increase the infiltration capacity of the subgrade;

- In applications of permeable pavement systems overlying weak soils, the subgrade may need to be compacted to achieve the desired load-bearing capacity. When the subgrade is compacted, the permeability and infiltration is greatly reduced, which must be considered in the hydrologic design;
- Compaction levels shall be checked by a certified testing agency to validate required minimum and maximum compaction levels for load-bearing capacity and permeability, respectively; and
- The subgrade surface shall be inspected for proper grades for the intended infiltration and/or drainage and for sharp or abrupt protrusions which may damage the geotextile.

9.5.2 Reservoir Course

- Take care to avoid segregation and/or contamination during handling of the materials;
- Place aggregate for the reservoir course with care not to damage the filter fabric; replace any areas which are torn, punctured, or otherwise compromised;
- Place aggregate for the reservoir course in a moistened condition in lifts of 150 mm;
- Ensure there is at least 100 mm of aggregate cover above the underdrains before compaction, where applicable;
- Compact the reservoir course layers with a vibratory roller in static mode until there is no visible movement of the aggregate; and
- Avoid crushing of the aggregate induced by the roller as it can reduce the void space in the reservoir course.

9.5.3 Granular Choker Course

- The purpose of the choker course is to stabilize the surface for the paving equipment. The purpose is not to cover the large stone in the reservoir course but to fill some of the surface voids and lock up the aggregate;
- Place and level aggregate for the choker course in a moistened condition to the appropriate depth;
- The choker course must be pressed (choked) into the reservoir course with at least four (4) passes of a ten-ton steel drum static roller; and
- Equipment operators should be instructed to avoid disturbing the surface of the choker course by abrupt acceleration, stopping, or making sharp turns.

9.6 Geotextile Installation

The geotextile or liner is placed at around the bottom and sides of the porous pavement system to protect the layers from becoming contaminated with subgrade materials. The following shall be considered during installation:

- The materials must be clean and free of sediment, debris and other deleterious materials when placed;

- It should be placed as soon as the subgrade has been prepared to prevent sediment-laden runoff from entering the base;
- Overlap of geotextile and filter fabric joints shall be a minimum of 0.6 m;
- Fabric sections at higher elevations must be on the outside of excavation to prevent sediment infiltration;
- Care must be taken during placement as not to damage the material by tearing, puncturing, stretching, or otherwise compromising the material;
- Leave slack in the material when placing to avoid tearing due to settlement of the subgrade and compaction of the reservoir course; and
- The material shall be secured a minimum of 0.6 m beyond the edge of the excavation, and not be trimmed until the site is fully stabilized.

9.7 Underdrain Installation

For porous pavement systems with partial or no infiltration, underdrains are required to convey water to designated drainage systems such as bioswales or stormwater systems. The underdrain installation should follow The City 2013 Sewer Construction Specification, Section 403.15.00 – Underdrain Specifications. Underdrains are typically 100 mm or 150 mm diameter perforated pipe wrapped in filter fabric or rock filter layer. When installing underdrains, the following should be considered:

- The underdrains shall slope down towards the outlet at a minimum grade of 0.5%;
- Provide a minimum of 50 mm of aggregate above and below the underdrains;
- The up-gradient ends of the underdrains in the reservoir course must be capped; and
- Vertical observation wells shall be attached to the underdrains and kept free of contamination for inspection and cleaning.

9.8 Permeable Interlocking Concrete Pavers

Permeable interlocking concrete pavers are designed with additional spacing between individual pavers to enable water to easily infiltrate the underlying zone. Typical application sites include low traffic volume roadways like residential streets and parking lots; although, some pavers are designed for more demanding traffic loads. Manufacturers' guidelines, including recommended bedding material, joint filler material, placement, and compaction, should be strictly adhered to. When constructing a permeable interlocking concrete paver system, the following should be considered during construction in addition to items noted in Section 3.3.

9.8.1 Edge Restraints

- Install edge restraints before the bedding layer; and
- Ensure the edge restraints are installed and secured as defined in the specifications or by the manufacturer.

9.8.2 Bedding Layer

- The bedding material may or may not be the same material as the granular choker course, depending on the permeable interlocking concrete pavers utilized, use only what has been specified;
- The bedding material shall be moistened, spread, and levelled to a thickness defined in the specifications or by the manufacturer;
- The bedding material used for traditional concrete pavers is not to be used for porous interlocking concrete pavers;
- It is not necessary to compact the bedding layer before installing the pavers; and
- Do not subject the bedding layer to any vehicle or pedestrian traffic prior to placing the pavers.

9.8.3 Pavers

- Pavers shall be installed immediately after the bedding sand has been levelled;
- Pavers may be installed by hand or by machine;
- Install pavers in the pattern and with joint widths defined in the specifications or by the manufacturer;
- Maintain uniform and straight patterns throughout the porous paver area;
- Fill gaps at the edges of the porous paver area with cut units no smaller than one third of a whole unit; and
- Cut pavers with the appropriate tool such as a double-bladed splitter or a masonry saw.

9.8.4 Jointing Material

- The jointing material may or may not be the same material as the bedding material or granular choker course; depending on the permeable interlocking concrete pavers utilized, use only what has been specified;
- Fill the openings and joint between the pavers with the specified jointing material;
- Sweep any excess material from the surface of the pavers;
- Compact and seat the pavers into the bedding material with an appropriate compaction device defined in the specifications or by the manufacturer, or approved by the Engineer;
- Do not compact within 2 m of the unrestrained edges of the pavers;
- Apply additional aggregate to the openings and joints, filling them completely;
- Sweep the pavers clean and compact, taking care to fill all remaining openings and joints completely;
- Pavers shall be left fully compacted before the end of each day; and
- Continue to protect the pavement area from sediment and excessive construction loads until the site and upstream areas have stabilized.

9.9 Porous Asphalt Concrete Pavement

Porous asphalt concrete pavement, also known as OGFC, is asphalt concrete designed with specialized aggregate gradations and binder contents that provide sufficient interconnected voids, allowing water to infiltrate into the underlying layers. The porous asphalt concrete is placed on a granular choker course, which provides a uniform surface for construction. Equipment and methods used for porous asphalt concrete are similar to traditional asphalt concrete. When constructing a porous asphalt concrete system, the following shall be considered during construction in addition to items noted in Section 3.1:

- Preparation for paving as per The City Roads Construction 2012 Standard Specifications Section 307.02.04.3 (or the most current version of the specification);
- Prepare the granular choker course as described in Section 10.5.3, ensuring that the surface is uniform and level before paving;
- Plan routes for equipment and hauling vehicles which minimizes the disturbance of the granular choker course;
- Do not apply an asphalt emulsion or tack coat to the granular choker course or between asphalt lifts;
- Asphalt placing temperature as per Roads 2012 Section 307.02.04.4;
- Hours of operation as per Roads 2012 Section 307.02.04.5;
- Transportation of porous asphalt as per Roads 2012 Section 307.02.04.6;
- Asphalt pavers or spreaders as per Roads 2012 Section 307.02.04.7;
- Paving operations as per Roads 2012 Section 307.02.04.10;
- Place the porous asphalt layer in lifts of 50 mm to 100 mm;
- Areas inaccessible to the paving machine as per Roads 2012 Section 307.02.04.11;
- Joints as per Roads 2012 Section 307.02.04.13;
- Transverse and longitudinal joints should be minimized;
- Apply only minimal amounts of asphalt emulsion (tack) to the vertical surface of joints to promote adhesion;
- Compact the asphalt in two (2) to four (4) passes of a steel drum static roller;
- Pneumatic-tired rollers and rollers over ten-ton are not permitted;
- It may be necessary to let the mix cool before beginning compaction;
- To remove roller marks left in the surface, a lighter roller may be utilized after the mat has cooled substantially;
- Opening to traffic as per Roads 2012 Section 307.02.04.14;
- Do not allow traffic on the pavement for 24 hours after placement; and

- Continue to protect the pavement area from sediment and excessive construction loads until the site and upstream areas have stabilized.

9.10 Pervious Concrete Pavement

Pervious concrete pavement is Portland cement concrete designed with constituents proportioned in such a manner that provide sufficient interconnected voids, allowing water to infiltrate into the underlying layers. The pervious concrete pavement is a low or zero slump mixture and can therefore be placed directly on the stone reservoir course, with no requirement for a granular choker course. When constructing a pervious concrete pavement system, the following shall be considered during construction in addition to items noted in Section 3.2:

- Concrete production and delivery as per The City Roads Construction 2012 Standard Specifications (Roads 2012) Section 312.04.01;
- Pervious concrete mixture must be placed within one hour of mixing unless a hydration stabilizer is utilized upon approval by the Engineer;
- At no point during placement and finishing will adding water to the concrete be permitted;
- Forms as per Roads 2012 Section 312.04.04;
- Riser strips of sizes relative to the depth of pavement and placing method should be placed on top of the forms for initial strike-off, and removed prior to compaction;
- Slip form pavers may be used as per Roads 2012 Section 312.04.03;
- Do not attempt to pump pervious concrete;
- Concrete paving operations as per Roads 2012 Section 312.05.00;
- Concrete should be placed as close to its final position as possible, commonly done by direct discharge from the chute of the ready-mix truck;
- After depositing concrete, cut it to a rough elevation using a rake or hand tool;
- Care should be taken to minimize excessive handling of the concrete during placement, contaminating concrete with foreign material, walking on concrete, and filling voids in the concrete;
- As soon as possible after placement and rough levelling, strike-off the concrete using a mechanical screed;
- Strike-off using hand tools will only be accepted where the width of the slab changes, or with the approval of the Engineer;
- Consolidate the concrete to the level of the forms using a steel roller, plate compactor, or an alternate method approved by the Engineer;
- No internal vibration of the concrete is permitted;
- If jointing is required, complete it to the specified depth immediately after consolidation with a jointing roller;

- Do not saw-cut joints into the concrete as the cuttings can clog the system;
- No later than 15 minutes after concrete has been consolidated and jointing, begin curing procedures;
- The surface shall be completely covered with an approved polyethylene sheet or other covering material;
- Secure the curing cover in place for a minimum of seven days, or as directed by the Engineer;
- No traffic shall be permitted on the pervious concrete until the cover is removed;
- No truck traffic shall be permitted on the pervious concrete for a minimum of 14 days; and
- Continue to protect the pavement area from sediment and excessive construction loads until the site and upstream areas have stabilized.

10.0 QUALITY MANAGEMENT

Quality management throughout the construction of a permeable pavement system is integral in ensuring a finished system that will perform as required for the entirety of the design life. Quality management incorporates observation of the construction process throughout, from initial site preparation to final acceptance. The following sections outline the minimum quality management practices to be undertaken.

10.1 Personnel

10.1.1 Inspector

The inspector shall be appointed by The City. The inspector shall be familiar with all aspects of permeable pavements including design, construction, and maintenance. The responsibilities of the inspector will include the following:

- Providing feedback and clarifications to the contractor for construction purposes;
- Documenting activities, noting any deficiencies and informing the contractor of said deficiencies;
- The contractor shall correct the deficiencies and receive approval from the inspector before continuing work on the section in question;
- The inspector shall notify the appropriate personnel immediately if the contractor does not comply with their requests; and
- Continuing to protect the pavement area from sediment and excessive construction loads until the site has stabilized.

10.1.2 Contractor

This will include introducing work practices that do not compromise the permeable pavement system, creating modes of communication to notify the inspector and other key stakeholders of updates, schedule changes, and problems or incidents encountered. Contractor's responsibilities will include the following:

- Educate all personnel conducting work on the permeable pavement system, and those working inside the contributing drainage area of the system's function and unique construction requirements;
- Create and maintain lines of communication between the required stakeholders including the Owner, inspector, and any required testing agency;
- Provide a minimum of 24 hours' notice to the inspector and other relevant personnel of the schedule and any changes thereto;
- Inform the inspector immediately of any changes to construction practices or work methods; and
- Inform the inspector immediately of any problems, accidents, or changes.

10.2 Pre-Construction

Prior to the start of construction of the permeable pavement system, complete the following:

- Hold a pre-construction meeting with all key project personnel in attendance to address:
  - The erosion and sediment control plan;
  - Any outstanding requirements, such as soil testing, which still needs to be completed;
  - The construction schedule;
  - Work practices;
  - Lines of communication; and
  - Address any concerns.
- Secure the site, implementing the erosion and sediment control plan; and
- Notify stakeholders of the work to be completed, addressing how it will impact them and responding to concerns.

10.3 Construction

During the construction of the permeable pavement system, quality management will continue through all stages of construction.

10.3.1 Site Preparation and Excavation

The site will be prepared for construction by accomplishing the following:

- Implement and monitor the sediment control system, maintaining as required;
- Secure the permeable pavement system area, establishing temporary roadways and installing barriers and signage as required; and
- Upon completion of the excavation, complete any surveying and required soil testing and receive approval by the inspector before proceeding.

10.3.2 Layer Construction

- Ensure the subgrade has been constructed to the required grade and elevation and is free of soft areas, protrusions, and any deleterious materials;
- Install the geotextiles as specified, and receive approval by the inspector before proceeding;
- Place the reservoir course in the specified lifts, compacting to the specifications and to the satisfaction of the inspector;
- If necessary, complete compaction (ASTM D6938) testing on the reservoir course;
- Ensure the reservoir course is compacted sufficiently and is uniformly to the proper elevation, correcting any deficiencies; and
- If necessary, place the geotextile, granular choker course, or bedding material as specified and prepare for surface construction.

10.3.3 Surface Construction

- Before starting surface construction, hold a meeting with all key project personnel in attendance to address:
  - Schedule including daily start-up and shut-down;
  - Work sequencing;
  - Site access and material routing;
  - Work practices;
  - Responsibility for quality control and quality assurance; and
  - Address any concerns.
- Before starting surface construction, ensure the base has been constructed to the required grade and elevation and is free of soft areas, inconsistencies, and any deleterious materials.

10.3.4 Post-Construction Performance Verification

The post-construction verification shall consist of the following testing:

- Flooding the permeable pavement to check for visual water infiltration to the system.
- Infiltration rate determination using double-ring infiltrometer (ASTM D5093). This initial infiltration rate will serve as a baseline for the future changes of infiltration rates due to clogging.
- Coring of permeable surfacing to determine void content and infiltration rates on cores.
- Additional testing for the properties of permeable surfacing if the quality control/assurance confirmed non-compliance with the project specifications.

11.0 OPERATION OF PERMEABLE PAVEMENTS

Operations on permeable pavements should not adversely impact the performance or reduce its expected service life. There are several activities that should be prevented on permeable pavement structures:

- Construction equipment should be limited to avoid tracking and spilling dirt onto the pavement;
- Construction equipment and hazardous materials carriers should be prohibited from entering permeable pavements to limit the potential for groundwater contamination;
- Construction staging and storage of soil and landscaping materials should not be allowed on unprotected pavement surface;
- Snow plowing is acceptable but the blade setting has to be at least 2 cm higher than usual for impermeable pavements. Plowed snow should not be stored on permeable pavements but in designated snow dumping areas;
- Sanding of permeable pavements should not be allowed;
- Non-toxic organic de-icers are preferable over regular salts;
- All impervious areas contributing to the drainage area (such as sidewalks and impervious pavement surfaces) should be regularly swept and kept clear of litter, debris, and soil;
- Use of herbicides and pesticides on surrounding vegetation should not be permitted to avoid groundwater contamination with these chemicals;
- When a permeable pavement is constructed with permeable pavers or grid pavers that have been planted with grass, regular mowing including removal of the clippings is recommended; and
- Signage identifying permeable pavement should be posted in visible access areas.

11.1 Protection

The permeable pavement system must be protected from excessive amounts of sediment that can clog the system. The following protection practices will help mitigate the sediment load on the permeable pavement system:

- Educate grounds keeping and maintenance personnel on the requirements of the site; signs should be posted to inform the general public of the system;
- The site should not be located downstream of any sediment generating activities;
- Measures should be taken to protect the site from any anticipated runoff containing TSS concentrations greater than 500 mg/l in accordance with Section 6.3;
- Surrounding landscaped surfaces should be well vegetated and maintained to prevent soil erosion;
- No stockpiling of materials including snow, aggregate or mulch should take place on the permeable pavement system or **within the contributing drainage area**;

- Avoid using the system as a route for vehicles carrying materials which can contaminate the system or the groundwater such as construction vehicles carrying material or trucks hauling dangerous goods;
- When possible, prevent vehicles from tracking dirt or debris onto the site. Installing a "Texas Gate" or cattle guard at entry points to the site can help remove sediment and debris from incoming vehicles;
- Snow removal should be done carefully, raising the blade by 20 mm off the surface to prevent damage;
- De-icing compounds should be used minimally, if at all, as they can contaminate the groundwater and/or stormwater; and
- Do not apply sand or other granular material on or adjacent to the permeable pavement system for abrasive purposes.

12.0 MAINTENANCE OF PERMEABLE PAVING

12.1 General

The long-term performance of permeable paving relies heavily on reducing the sediment loading into the permeable area as the susceptibility to clogging is the main concern for permeable paving systems. The best strategy to prevent clogging is to ensure that adjacent pervious areas have adequate vegetation cover and a winter maintenance program that does not include sanding. Some agencies recommend mechanical suction brushing at least twice a year to maintain the infiltration capacity (Permeable Pavement Design Guidelines, North Shore City, 2004, Low Impact Development Stormwater Management Planning and Design Guide, Toronto and Region, 2010).

Limited research indicated that infiltration decreases with age due to deposit of fine materials such as dirt, vegetation in joints, and clogging of the base and geotextiles used. Maintenance improves infiltration rates significantly for existing conditions. Infiltration rates may increase by 40% after maintenance (Bean 2004). The study conducted at the University of Calgary indicated that both concrete pavers and permeable asphalt concrete surfacing systems exhibited excellent fines removal characteristics and may be optimized by choosing appropriate materials and geotextiles in the pavement (Brown et al. 2009). Research conducted by Mata and Lemming (2012) indicates that most sand sediments are trapped on top of the concrete but part of the fine sand fraction is deposited or travels through the concrete. The clogging of the near surface region can be partially mitigated by maintenance involving vacuum sweeping. The functionality of the porous surfacing can be maintained partially due to its auto-cleaning capacity in highways with relatively high speed and high volumes of traffic by the suction generated by tires rolling on the permeable surfacing; however, cleaning of the voids by pressure washing and air suction is recommended twice a year (Alvarez et al. 2006).

An acceptable vacuum excavator that combines pressure washing and vacuuming to provide deep cleaning of permeable asphalt pavements and pervious concrete pavements is presented in Figure 12.

Figure 12: Pressure Vacuum and Washing Equipment (Courtesy of Concrete Construction June 2013)

12.1.1 Cleaning Permeable Interlocking Concrete Pavers

When cleaning a permeable pavement system surfaced with permeable interlocking concrete pavers, the vacuum levels may need to be adjusted to avoid the removal of the jointing material and/or displacing individual pavers. In the event of the removal of the jointing material, it should be replaced immediately with new material.

12.2 Maintenance Issues

Ongoing maintenance of a permeable pavement system is integral in ensuring adequate performance over the design life. The primary goal of maintenance is to prevent clogging of the system, which reduces infiltration rates, limiting the system's ability to capture and convey rainfall and runoff. The following sections provide guidelines for mitigating the possibility of clogging and damage to permeable pavement systems as well as practices for inspection, cleaning, and repair.

Conventional pavements have two levels of acceptance; substantial completion and final completion. With permeable pavements, these two levels should be achieved in short succession to reduce the risk of damage due to ongoing construction. Construction scheduling for permeable pavements should consider the effects of completing the permeable pavement system prior to establishing long-term erosion and sediment control measures such as vegetation.

Maintenance (protection, inspection, cleaning, and repair) responsibility falls onto the contractor during construction, after the substantial completion certificate is granted (SCC), up until the final completion certificate is granted (FCC). At this time, the maintenance responsibility is assumed by the owner.

Maintaining the performance of any permeable pavement over the lifespan of the structure requires that the facilities be inspected and maintained at least twice a year. When the permeable pavements are installed on private property, it is imperative that a maintenance agreement between The City and the facility owner is established and enforced.

The primary goal of permeable pavement maintenance is to prevent the pavement surface and underlying infiltration bed from being clogged with fine sediments. It is generally accepted that there is a decrease in total infiltration as the pavement ages and this should be taken into an account at the pavement design stage. The procedures to reduce clogging should be implemented at the construction stage, after permeable pavement installation, while construction of surrounding areas is undergoing and as a vital part of the operations and maintenance schedule.

This will mitigate the deposition of fine materials such as dirt, vegetation in the joints, and clogging of the base and geotextiles.

12.3 Reduction of Clogging at the Construction Stage

The highest priority at the time of construction of the permeable pavements is the prevention and diversion of sediment from entering the base. Preventive measures may include one or more of the following:

- Muddy construction equipment and associated mud tracking should be kept from the area at all stages of site development.
- Installing silt fences.
- Staged excavation.
- Temporary drainage swales.
- Timing of permeable pavement construction so that the pavement reservoir is not exposed to surface runoff and elements for an extended period of time.

12.4 New Permeable Pavement

The impact of the construction activities around newly constructed permeable pavement should be taken into consideration in early-age clogging prevention:

- All construction traffic should be kept away from the permeable pavements to prevent mud tracking.
- The pavement should be protected from any soil washout from the construction site, either by silt fences or temporary drainage swales.
- Landscaping materials such as topsoil, gravel, bark, and plants should not be stored on permeable pavements. Placing some of the landscaping materials on tarps may be accepted providing that no rain is in the forecast resulting in fine particle washout from the stockpiles.
- Planted areas adjacent to permeable pavements should be well maintained to prevent soil washout onto the pavement.

12.5 Ongoing Inspection and Maintenance

Permeable pavement requires regular inspection and maintenance to ensure that it functions properly and that the infiltration rate is not reduced dramatically. It is recommended that signs be posted on the site identifying permeable paver and porous pavement areas in visible areas. A maintenance plan should be developed incorporating the following maintenance procedures and preventive measures. The schedule below outlines timing for checks and maintenance activities.

12.6 Inspection

Inspection of the permeable pavement system should be undertaken annually. The best time for inspection is during or shortly after a rainfall event. Alternatively, local flooding of the system can be induced by using a water truck. The inspector should identify:

- Areas of ponding or reduced infiltration;
- Areas where the surface is damaged or irregular;
- Check vertical cleanouts of the underdrains for standing water and/or sediment; and
- Note the condition of the drainage area including areas which may require maintenance or protection to reduce sediment loading.

12.7 Surface Sweeping

Sweeping should occur twice a year. Commercial vacuum sweeping units are to be used to mitigate sediment accumulation and ensure continued porosity. When cleaning permeable pavements with compressed air units and pressurized water systems, care should be taken to prevent pushing sediments deeper into the pavement.

After cleaning permeable pavers with a vacuum sweeper, the joint material should be evaluated and topped up as necessary.

12.8 Inlet Structures

Structures draining to the gravel base course and drainage pipes should be cleaned at least once a year. They should be inspected after heavy storms to check for clogging in the drainage system. When inspection chambers are installed, an after-storm inspection should include monitoring water levels in the base course. The pavement reservoir should drain completely within 72 hours after the end of the storm event.

12.9 Landscaping

Flows from landscaped areas should be diverted away from the permeable pavements to prevent sediment accumulation on the pavement surfaces and clogging of the gravel base course. Planted areas should be inspected on a semi-annual basis. The washout from damaged vegetation should be diverted from the permeable pavement structure. Any bare spots or eroded areas should be replanted and/or stabilized.

12.10 Permeable Pavement Repairs

Small repairs to permeable pavements are a part of the ongoing maintenance but different methodologies from impermeable surface repairs should be applied. Traditional pavement repair materials may be used for small areas only so the overall infiltration rate of the permeable pavement is not significantly reduced. If patching areas are large, an option of replacing permeable surfacing should be considered.

12.10.1 Potholes

Isolated potholes in porous asphalt or pervious concrete surfaces can be patched with standard patching mixes. Patching is no longer a viable repair when the structural integrity of the pavement is compromised and/or stormwater can no longer drain to the gravel sub-base.

12.10.2 Uneven Pavers

Lows and highs in permeable paver surfaces can be repaired by removing pavers from affected areas, redistributing the bedding layer followed by placement of pavers to the original grade. New joint material should be swept into areas of repairs.

12.10.3 Seal Coating

Seal coats must never be applied to permeable pavements. Since porous asphalt and permeable concrete surfaces may look similar to their impervious versions, the owners (current and future) must be aware of permeable pavement areas to avoid the possibility of sealants application.

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APPENDIX A

DESIGN CHECKLIST FOR A PERMEABLE PAVEMENT SYSTEM

1.0 SITE CONSIDERATIONS

When selecting a site, the following considerations and required information should be gathered.

Table 1 – Site Considerations and Required Information

Considerations and Required Information	
Total area of site	
Contributing drainage area including site	
Identify gradients: slope, presence of trapped lows, etc.	
Underlying soil types tested for California bearing ratio (CBR) and infiltration rate	
Subsurface conditions, including groundwater table, bedrock, existing shallow and deep utilities and buried objects	
Identify existing stormwater lines and catchments	
Intended land use (parking area, roadway, walkway, etc.)	

2.0 SITE FEASIBILITY

The site being considered for a permeable pavement system must meet several criteria for the system to function properly in regards to structural performance and hydrological control in addition to being economically feasible and constructible. The site should meet these requirements and all items on the feasibility checklist must be satisfied.

Table 2 – Site Feasibility Checklist

Feasibility Checklist	YES	NO
Pavement slope does not exceed 4%		
Subgrade soaked CBR value greater than 3%		
Design traffic (DTN) less than 1,000 vehicles per day		
Equivalent single axle loads (ESALs) less than 120,000		
Site is not located downstream of high sediment and/or contaminant generating activities		
Seasonal high groundwater table, bedrock, and existing utilities or buried objects are not within 0.6 m of the proposed bottom of the infiltration reservoir		
Permeable pavement structure feasible		
The stormwater is not contaminated		

3.0 PERMEABLE PAVEMENT SYSTEM SELECTION

Once the site has been deemed appropriate for a permeable pavement system, the type of system must be selected.

Table 3 – Infiltration Type

Infiltration* Type Selection		Yes	No
Full infiltration design	Soil infiltration rate greater than 10^{-6} m/s		
	No possibility of presence of contaminated soils		
Partial infiltration design	Partial infiltration into soil		
	No possibility of contamination of surrounding soil		
	Outflow water collection systems available and/or underdrain system can be constructed		
	Limitation on depth of reservoir course		
No infiltration design	Low soil infiltration rate		
	No possibility of presence of contaminated soils		
	Outflow water collection systems available and/or underdrain system can be constructed		
	Limitation on depth of reservoir course		
Selected infiltration type			

*Infiltration rates should be determined on a representative sample taken from the proposed infiltration surface as per LID Geotechnical and Hydrogeological Considerations – Module 1

4.0 PERMEABLE PAVEMENT SYSTEM SURFACE TYPE

Once the site has been deemed appropriate for a permeable pavement system, the type of permeable surface must be selected. This selection should consider the following.

Table 4 – Surface Type

Surface Type Selection	PICP*	Porous Asphalt	Pervious Concrete
Constructability rating based on area, accessibility, timeframe, season of construction, etc.			
Construction costs ($)			
Maintenance costs per year ($)			
Expected design life (years)	20	20	20
Surface infiltration rate (cm/s)			
Aesthetics rating – 1, 2, 3			
Competent contractor available			
Selected surfacing			

*Permeable Interlocking Concrete Pavers (PICP)

The criteria contained in Table 4, the design concept, and the Owner's preference will determine the type of selected surfacing.

5.0 HYDROLOGICAL DESIGN

Table 5 – Hydrological Design Inputs

Design Inputs	Value Used
Porous pavement area (m^2)	
Contributing drainage area including site (m^2)	
I/P ratio	
Design storm event	
Design storm event intensity (mm/hr)	
Pavement system selected	
Subgrade infiltration rate (cm/s)	
Required storage capacity (m^3)	
Required reservoir depth to process water (mm)	
Reservoir emptying time (hours)	
Detention time* (hours)	

*Based on minimum UARR method as per Section 3.1.2.3 of the Stormwater Management & Design Manual 2011 issued by The City Water Resources

6.0 STRUCTURAL DESIGN

The pavement structure shall be designed using AASHTO (1993) and the 2012 City Standard Specification Roads Construction Section 308.00.00 – Pavement Design.

Table 6 – Layer Design

Input	Specification	Value Used
Subgrade strength, CBR_{soaked} (%)	3% minimum	
Resilient modulus, M_r (10.3 x CBR_{soaked}) (MPa)	30.9 MPa minimum	
Initial serviceability	4.2	
Terminal serviceability	2.5	
Standard deviation, S_o	0.45	
Reliability, R (%)	75%	
Design period (years)	20 years	
Growth rate (%)	2%	
Annual Average Daily Traffic (AADT)	300 maximum	
Single unit trucks (% of DTN)	--	
Tractor trailer combinations (% of DTN)	--	
Transit buses (% of DTN)	--	
Design ESALs	5 maximum	
Drainage coefficients	1.0	
Required structural number (SN)	--	
Structural layer coefficient of surface	0.40	
Structural layer coefficient of reservoir	0.12	
Thickness of PICP (mm)	80 mm minimum	
Thickness of porous asphalt (mm)	75 mm to 100 mm	
Thickness of pervious concrete (mm)	100 mm to 150 mm	
Thickness of bedding/choker layer (mm) (if applicable)	50 mm	
Required thickness of reservoir (mm)	to satisfy minimum SN	

7.0 MATERIAL SELECTION

Table 7 – Material Selection

Material Selection	Requirements	Proposed Material
PICP	Section D	
Porous asphalt	Section B	
Pervious concrete	Section C	
Bedding sand	ASTM No. 9 or equivalent	
Choker course	ASTM No. 8 or equivalent	
Reservoir course	ASTM No. 57 or equivalent	
	30% to 40% minimum effective porosity	
	10^{-2} m/s minimum infiltration rate	
Woven geotextile fabric for outfall pipe wrap (if applicable)	As per City of Calgary 2013 Sewer Construction Specification, Section 403.15.00 – Underdrain Specifications	
Woven geotextile fabric – reservoir course separation	As per City of Calgary 2013 Road Construction Specification, Section 319.00.00 – Geotextiles and Geomembranes	
Liner – for no infiltration system only	Impermeable	
Underdrains	As per City of Calgary 2013 Sewer Construction Specification, Section 403.15.00 – Underdrain Specifications	

8.0 FINAL DESIGN

Table 8 – Final Permeable Pavement System Design

Element	Type Used	Thickness (mm)
Surface		
Choker course		
Reservoir course*		
Total system		
Underdrains		
Geotextile – bedding course separation		
Geotextile – reservoir course separation		
Liner – for no infiltration system only		

*Must be considered based on hydrological and structural requirements

APPENDIX B

DESIGN EXAMPLE FOR A PERMEABLE PAVEMENT SYSTEM

1.0 SITE CONSIDERATIONS

When selecting a site, the following considerations and required information should be gathered.

Table 1 – Site Considerations and Required Information

Considerations and Required Information	
Total area of site	784 m^2
Contributing drainage area including site	1,560 m^2
Identify gradients: slope, trapped lows, etc.	1.5% slope, trapped low
Underlying soil types tested for California bearing ratio (CBR) and infiltration rate.	3%, <10^{-4} m/s
Subsurface conditions including groundwater table, bedrock, existing shallow and deep utilities and buried objects	Buried utilities at 0.8 m requiring 0.3 m min. cover
Identify existing stormwater lines and catchments – identify distances and types	Yes
Intended land use (parking area, roadway, walkway, etc.)	Back alley

2.0 SITE FEASIBILITY

The site being considered for a permeable pavement system must meet several criteria for the system to function properly in regards to structural performance and hydrological control in addition to being economically feasible and constructible. The site should meet these requirements.

Table 2 – Site Feasibility Checklist (All Must Be Satisfied)

Feasibility Checklist	YES	NO
Pavement slope does not exceed 5%	X	
Subgrade soaked CBR value greater than 3%	X	
Design traffic (DTN) less than 3,000 vehicles per day	X	
Equivalent single axle loads (ESALs) less than 120,000	X	
Site is not located downstream of high sediment and/or contaminant generating activities	X	
Seasonal high groundwater table, bedrock, and existing utilities or buried objects are not within 0.6 m of the proposed surface.	X	
Stormwater is not contaminated	X	

3.0 PERMEABLE PAVEMENT SYSTEM SELECTION

Once the site has been deemed appropriate for a permeable pavement system, the type of system must be selected.

Table 3 – Infiltration Type

Infiltration* Type Selection		YES	NO
Full infiltration design	Soil infiltration rate greater than 10^{-4} m/s		X
	No possibility of presence of contaminated soils		X
Partial infiltration design	Partial infiltration into soil		X
	No possibility of contamination of surrounding soil		X
	Outflow water collection systems available and/or underdrain system can be constructed	X	
	Limitation on depth of reservoir course	X	
No infiltration design	Low soil infiltration rate	X	
	Possibility of contaminated soils	X	
	Outflow water collection systems available and/or underdrain system can be constructed	X	
	Limitation on depth of reservoir course	X	
Selected infiltration design		No infiltration design	

*Infiltration rates should be determined on a representative sample taken from the proposed infiltration surface as per LID Geotechnical and Hydrogeological Considerations – Module 1

4.0 PERMEABLE PAVEMENT SYSTEM SURFACE TYPE

Once the site has been deemed appropriate for a permeable pavement system, the type of permeable surface must be selected. This selection should consider the following.

Table 4 – Surface Type (for illustrative purpose only)

Surface Type Selection*	PICP**	Porous Asphalt	Pervious Concrete
Constructability rating based on area, accessibility, timeframe, season of construction, etc.	1	2	3
Construction costs ($)	$	$$	$$$
Maintenance costs per year ($)	$	$	$
Expected design life (years)	20	20	20
Surface infiltration rate (cm/s)	1.0 cm/s	0.5 cm/s	0.5 cm/s
Aesthetics rating	1	3	2
Competent contractor available	Yes	Yes	Yes
Selected surfacing	X		

*Composite grid pavers are used for light traffic applications only

**Permeable interlocking concrete pavers (PICP)

5.0 HYDROLOGICAL DESIGN

Table 5 – Hydrological Design Inputs

Design Inputs	Value Used
Porous pavement area (m^2)	784 m^2
Contributing drainage area including site (m^2)	1,560 m^2
I/P ratio	2.0
Design storm event	1:100
Design storm event intensity (mm/24hr)	60.4 mm
Pavement system selected	No infiltration
Subgrade infiltration rate (cm/s)	< 10^{-3} cm/s
Required storage capacity (m^3)	353 m^3
Required reservoir depth to process water (mm)	450 mm
Reservoir emptying time (hours)	48 hours
Detention time* (hours)	1.5 hours

*Based on minimum UARR method as per Section 3.1.2.3 of the Stormwater Management & Design Manual 2011 issued by The City Water Resources

6.0 STRUCTURAL DESIGN

The pavement structure shall be designed using AASHTO (1993) and the 2012 City Standard Specification Roads Construction Section 308.00.00 – Pavement Design.

Table 6 – Layer Design

Input	Specification	Value Used
Subgrade strength, CBR_{soaked} (%)	3% minimum	3%
Resilient modulus, M_r (10.3 x CBR_{soaked}) (MPa)	30.9 MPa minimum	30.9 MPa
Initial serviceability	4.2	4.2
Terminal serviceability	2.5	2.5
Standard deviation, S_o	0.45	0.45
Reliability, R (%)	75%	75%
Design period (years)	20 years	20 years
Growth rate (%)	2%	2%
Daily traffic number (DTN)	3,000 maximum	160
Single unit trucks (% of DTN)	--	1.5%
Tractor trailer combinations (% of DTN)	--	0%
Transit buses (% of DTN)	--	0%
Design ESALs	36,500 maximum	10,950
Drainage coefficients	1.0	1.0
Required structural number (SN)	--	50
Structural layer coefficient of surface	0.40	0.40
Structural layer coefficient of reservoir	0.12	0.12
Thickness of PICP (mm)	80 mm minimum	80
Thickness of porous asphalt (mm)	75 mm to 100 mm	--
Thickness of pervious concrete (mm)	100 mm to 150 mm	--
Thickness of bedding/choker layer (mm)	50 mm	50
Required thickness of reservoir (mm)	to satisfy minimum SN	125 mm

7.0 MATERIAL SELECTION

Table 7 – Material Selection

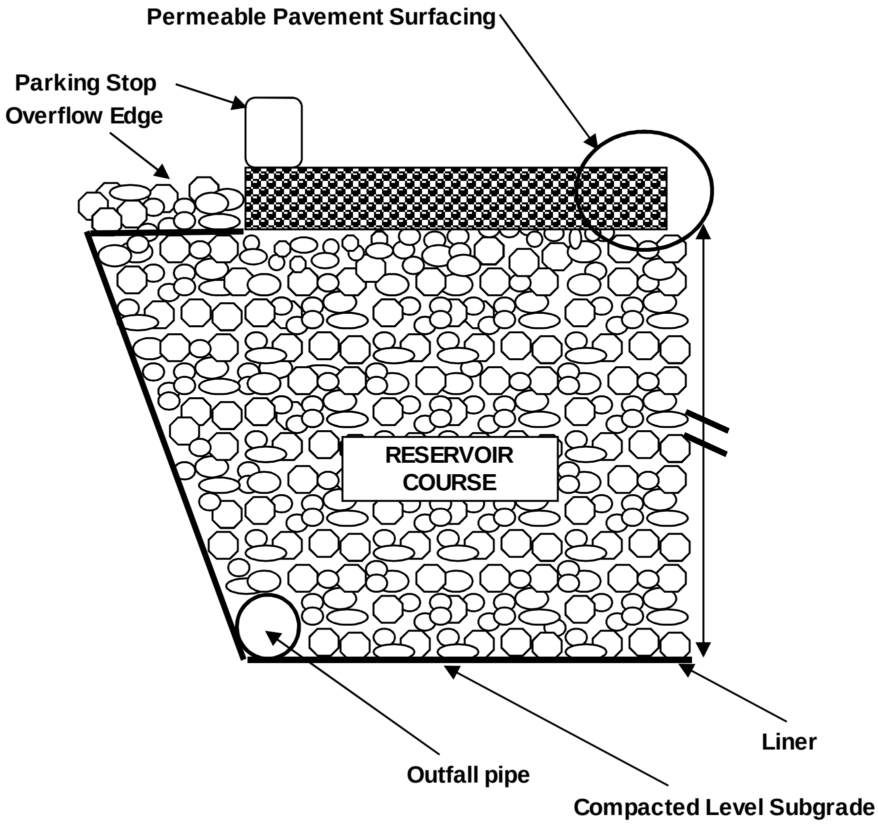
Material Selection	Requirements	Actual
PICP	Section D	Product A
Porous asphalt	Section B	Not used
Pervious concrete	Section C	Not used
Bedding sand	ASTM No. 9 or equivalent	ASTM No. 9
Choker course	ASTM No. 8 or equivalent	Not used
Reservoir course	ASTM No. 57 or equivalent	ASTM No. 57
	30% to 40% minimum effective porosity	40%
	10^{-2} m/s minimum infiltration rate	10^{-2} m/s
Woven geotextile fabric for outfall pipe wrap (if applicable)	As per City of Calgary 2013 Sewer Construction Specification, Section 403.15.00 – Underdrain Specifications	Not used
Woven geotextile fabric – reservoir course separation	As per City of Calgary 2013 Road Construction Specification, Section 319.00.00 – Geotextiles and Geomembranes	Not used
	Impermeable	Not used
Liner – for no infiltration system only	Impermeable	Yes
Underdrains	As per City of Calgary 2013 Sewer Construction Specification, Section 403.15.00 – Underdrain Specifications	Yes

8.0 FINAL DESIGN

Table 8 – Final Permeable Pavement System Design

Element	Type Used	Thickness (mm)
Surface	PICP – Product A	80
Choker course	ASTM No. 9 Bedding sand	50
Reservoir course*	ASTM No. 57	450
Total system thickness	--	580
Underdrains	Yes	
Geotextile – bedding course separation	Not used	
Geotextile – reservoir course separation	Not used	
Liner – for no infiltration system only	Yes	

*Must be considered based on hydrological and structural requirements


Permeable Pavement Surfacing
Parking Stop
Overflow Edge
RESERVOIR
COURSE
Liner
Outfall pipe
Compacted Level Subgrade

APPENDIX C

LID SPECIFICATIONS – PERMEABLE PAVEMENT CONSTRUCTION

PERMEABLE PAVEMENT CONSTRUCTION

1. GENERAL

.1 Section A refers to those portions of the work that include supply of materials and construction of porous pavement. This section must be referenced to and interpreted simultaneously with all other sections pertinent to the works described herein.

.2 Related Work

.1	Porous Asphalt Concrete Paving.	Section B
.2	Pervious Concrete.	Section C
.3	Permeable Interlocking Concrete Pavers.	Section D
.4	The City of Calgary Roads Construction 2012 Standard Specifications, Section 303 – Granular Material.	
.5	The City of Calgary Roads Construction 2013 Standard specifications, Section 310 – Portland Cement Concrete.	
.6	The City of Calgary Roads Construction 2013 Standard specifications, Section 311 – Concrete Sidewalk, Curb and Gutter.	

.3 Reference Standards

.1 All cast-in-place concrete such as curbs, gutters, headers, and sidewalks shall comply with The City of Calgary Roads Construction Standard Specifications.

.2 ASTM D5093 – Standard Test Method for Field Measurements of Infiltration Rate Using Double-Ring Infiltrometer with Sealed-Inner Ring.

.3 ASTM D2434 – Standard Test Method for Permeability of Granular Soils (Constant Head).

.4 Approvals

.1 Submit to the Engineer processed aggregate samples for approval at least two weeks prior to commencing the work.

.2 If, in the opinion of the Engineer, materials from proposed source do not meet specified requirements, locate alternative source or demonstrate that materials from the source in question can be processed to meet specified requirements.

.3 Should a change of material source be proposed during work, advise the Engineer two weeks in advance of the proposed change to allow review of new samples.

.4 Acceptance of material does not preclude future rejection if it is subsequently found to lack uniformity, or if it fails to conform to requirements specified, or if its field performance is found to be unsatisfactory.

.5 Submit to the Engineer the intended supplier of non-woven geotextile and/or geomembrane and manufacturer's certification of compliance with specified requirements.

2. PRODUCTS

.1 Non-Woven Geotextile

.1 Non-woven geotextile is to meet the requirements of The City of Calgary Road Construction 2013 Standard Specification, Section 319 – Geotextiles and Geomembranes.

.2 Aggregate Materials – General

.1 Gravel is to be composed of inert, durable material, reasonably uniform in quality and free from deleterious materials. Unless otherwise specified, granular materials shall meet the requirements of The City of Calgary Roads Construction Standard 2013 Specifications, Section 303 – Granular Material.

.2 Handle aggregates to minimize contamination or degradation.

.3 Reservoir Course

.1 Reservoir course aggregate shall meet the following gradation requirements when tested according to CSA A23.2-2A.

Sieve Size (mm)	Percentage Passing (by mass)
80	100
63	90 – 100
50	35 – 70
40	0 – 15
20	0 – 5
0.080	0 – 2

.4 Choker Course

.1 Choker course aggregate shall meet the following gradation requirements when tested according to test CSA A23.2-2A.

Sieve Size (mm)	Percent Passing (by mass)
12.5	100
10	40 – 75
5	5 – 25
2.5	0 – 10
1.25	0 – 5

.5 Bedding Course and Joint/Opening Filler

.1 Bedding course sand and joint/opening filler for the installation of permeable interlocking concrete pavers shall meet the following gradation requirements when tested according to test CSA A23.2-2A.

Sieve Size (mm)	Percent Passing (by mass)
12.5	100
10	85 – 100
5	10 – 30
2.5	0 – 10
1.25	0 – 5

3. EXECUTION

.1 Excavation

.1 Excavation shall be such that no excavator or construction traffic is directly on the subgrade surface. Do not compact subgrade.

.2 The footprint of the excavation shall be as shown on the drawings to the limits of the porous pavement, and shall be sloped with depth inward at 1:1, or as directed by the Engineer.

.3 Excavating shall be with a smooth-edged bucket and the final subgrade surface shall be a smooth surface to the required elevations ± 25 mm.

.2 Geotextile Placement

.1 Place geotextile only after the excavated subgrade has been approved by the Engineer.

.2 Place the geotextile such that it extends up the sides of the excavation and 1,000 mm beyond the porous pavement footprint and secured prior to placement of the reservoir course.

.3 Overlay all geotextile joints by a minimum 400 mm.

.4 Protect the geotextile fabric at all times during construction. No traffic shall be allowed directly on the geotextile. Any geotextile damaged shall be replaced at the Contractor's expense.

.3 Reservoir Course

.1 Do not place reservoir course material until the entire geotextile fabric has been placed and approved by the Engineer.

.2 End dump the initial lift of reservoir course material such that no traffic is directly on the geotextile. The initial lift of reservoir course shall be 300 mm. Subsequent lifts shall be 200 mm maximum.

.3 Compact each lift of the reservoir course using two vibratory passes with a steel wheel vibratory roller with a minimum drum axle mass of 6,000 kg over the entire reservoir area.

.4 Grade the final lift of reservoir course material to the required elevation ± 20 mm.

.4 Choker Course

.1 Do not place choker course material until the entire reservoir course has been placed and approved by the Engineer.

.2 Place the choker course material in a manner that does not damage or rut the reservoir course surface. The choker course shall be a nominal 50 mm thickness placed in one lift.

.3 Compact the choker course using a minimum two passes with a steel wheel roller with a minimum drum axle mass of 6,000 kg over the entire reservoir area.

.4 The surface of the choker course shall be ± 10 mm of the design grade, but not consistently high.

.5 Porous Asphalt Concrete Placement

.1 Produce, deliver, place, and compact porous asphalt concrete in accordance with Section B.

.2 Place the porous asphalt concrete in a manner that does not damage or rut the choker course surface.

.3 The porous asphalt concrete shall be placed in one lift with a compacted thickness of 75 mm ± 5 mm.

.4 Avoid all traffic on the completed porous asphalt concrete surface.

.6 Pervious Concrete Placement

.1 Produce, deliver, place, and compact and finish pervious concrete in accordance with Section C.

.2 Place the pervious concrete in a manner that does not damage or rut the choker course surface.

.3 The porous asphalt concrete shall be placed in one lift with a designed compacted thickness ± 5 mm.

.4 Avoid all traffic on the completed pervious concrete surface for a minimum of ten days after placement.

.7 Permeable Interlocking Concrete Pavers Placement

.1 Install permeable interlocking concrete pavers in accordance with Section D.

.2 Spread bedding sand evenly over the base course and screed to a nominal 30 mm to 40 mm thickness.

.3 Lay pavers in pattern(s) shown on Contract Drawings. Place units tight without using hammers. Make horizontal adjustments to placement of laid pavers with rubber hammers and pry bars as required.

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

4. PROTECTION

.1 After surfacing work is complete, the Contractor shall be responsible for protecting work from sediment deposition and damage due to subsequent construction activity on site.

5. MEASUREMENT AND PAYMENT

.1 Payment for Porous Pavement will be full compensation for all materials and construction necessary to meet the specified requirements herein, excluding porous asphalt concrete, porous concrete, permeable interlocking concrete pavers, and flat concrete curb, at the lump sum unit price.

END OF SECTION

APPENDIX D

LID SPECIFICATIONS – POROUS ASPHALT CONCRETE PAVING

POROUS ASPHALT CONCRETE PAVING

1. GENERAL

.1 Section B refers to those portions of the work that are unique to the supply and placement of porous asphalt concrete. This section must be referenced to and interpreted simultaneously with all other sections pertinent to the works described herein.

.2 Related Work

.1	Porous Pavement Construction.	Section A
.2	Pervious Concrete.	Section C
.3	Permeable Interlocking Concrete Pavers.	Section D
.4	The City of Calgary Roads Construction 2012 Standard Specifications, Section 303 – Granular Material.	
.5	The City of Calgary Roads Construction 2013 Standard Specifications, Section 310 – Portland Cement Concrete.	
.6	The City of Calgary Roads Construction 2013 Standard Specifications, Section 311 – Concrete Sidewalk, Curb and Gutter.	

.3 References Standards

.1 All cast-in-place concrete such as curbs, gutters, headers, and sidewalks shall comply with The City of Calgary Roads Construction Standard Specifications.

.2 ASTM D2172 – Standard Test Methods for Quantitative Extraction of Bitumen From Bituminous Paving Mixtures.

.3 ASTM C117 – Standard Test Method for Materials Finer than 75-μm (No. 200) Sieve in Mineral Aggregates by Washing.

.4 ASTM C136 – Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates.

.5 ASTM D2041 – Standard Test Method for Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures.

.6 ASTM D2726 – Standard Test Method for Bulk Specific Gravity and Density of Non-Absorptive Compacted Bituminous Mixtures.

.7 ASTM D3203 – Standard Test Method for Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures.

.8 ASTM D5821 – Standard Test Method for Determining the Percentage of Fractured Particles in Coarse Aggregate.

.9 ASTM D6926 – Standard Practice for Preparation of Bituminous Specimens Using Marshall Apparatus.

.10 ASTM D6927 – Standard Test Method for Marshall Stability and Flow of Bituminous Mixtures.

.11 ASTM D1883 – Standard Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils.

.12 ASTM D6390 – Standard Test Method for Determination of Draindown Characteristics in Uncompacted Asphalt Mixtures.

.13 ASTM D6938 – Standard Test Method for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth).

.14 AASHTO T312 – Standard Method for Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor.

.15 AASHTO T283 – Resistance of Compacted Hot-Mix Asphalt (HMA) to Moisture-Induced Damage.

.16 ASTM D448 – Standard Classification for Sizes of Aggregate for Road and Bridge Construction.

.4 Material Certification

.1 At least two weeks prior to commencing work, submit viscosity – temperature chart for porous asphalt cement to be supplied showing Kinematic Viscosity in centistokes, temperature range 105°C to 175°C.

.2 Upon request, submit manufacturer's test data and certification that asphalt cement meets requirements of this section.

.5 Submission

.1 Submit porous asphalt concrete mix design and trial mix test results to the Engineer for review at least one week prior to commencing work.

.2 Prior to commencing the work, submit a detailed Paving Plan showing the proposed schedule, sequence of work, dedicated equipment, and work force for Engineer approval.

.6 Delivery and Storage

.1 When necessary to blend aggregates from one or more sources to produce required gradation, do not blend in stockpiles.

.2 When dryer drum mixing plant is used, stockpile fine aggregate separately from coarse aggregate.

.3 Provide approved storage, heating tanks, and pumping facilities for asphalt cement.

2. PRODUCTS

.1 Asphalt Binder

.1 150/200A Asphalt Cement.

.2 Aggregates

.1 Aggregates meeting the following requirements:

.1 Crushed stone or gravel consisting of hard, durable, angular particles, free from clay lumps, cementation, organic material, frozen material, and other deleterious materials.

.2 Gradations to be within the following specified when tested to ASTM C136 and ASTM C117.

Sieve Size (mm)	Percentage by Mass Passing
16	100
12.5	95 – 100
10	50 – 75
5	10 – 30
2.5	5 – 15
0.080	2 – 5

.3 Los Angeles abrasion: Grading B, to ASTM C131.
Maximum loss by mass: 25%.

.4 Flat and elongated particles: (width to length ratio greater than 3): Maximum by mass: 20%.

.5 Crushed coarse aggregate: (two or more faces, plus 5 mm): Minimum by mass: 95%.

.6 Regardless of compliance with specified physical requirements, fine aggregates may be accepted or rejected on basis of past field performance.

.3 Asphalt Concrete Design

.1 Submit the job-mix formula to the Engineer for review and approval.

.2 Design of mix: by the methods outlined in the National Centre for Asphalt Technology publication "Design, Construction and Performance of New-Generation Open Graded Friction Courses, NCAT Report No. 2000-01" available at www.eng.auburn.edu/centre/ncat, and as outlined in Appendix A of this specification.

.3 Mix Physical Requirements

Property	Requirement
Voids in Coarse Aggregate of Mixture (VCA), %	Less than Voids in Coarse Aggregate, Dry Rodded Condition (VCA_{DRC})
Voids in Total Mixture (VTM), %	18 minimum
Draindown, %	0.3 maximum
Abrasion Loss (Unaged), %	20 maximum
Abrasion Loss (Aged), %	30 maximum
Tensile Strength Ratio (1 freeze/thaw cycle), %	80 minimum

.4 Measure physical requirements as follows:

.1 Air voids: ASTM D3203.

.2 Abrasion Loss: Cantabro Test (Appendix A).

.3 Tensile Strength Ratio: AASHTO T-283 (Appendix A).

.4 Do not change job mix without prior approval of the Engineer. Should a change in material source be proposed, the new job mix formula is to be submitted to the Engineer for review and approval.

3. EXECUTION

.1 Plant and Mixing Requirements

.1 Batch and Continuous Mixing Plants

.1 Heat asphalt cement and aggregate to mixing temperature directed by Engineer. Do not heat asphalt cement above 160°C.

.2 Before mixing, dry aggregate to a moisture content not greater than 1% by mass or to a lesser moisture content if required to meet mix design requirements.

.3 Make available current asphalt cement viscosity data at plant. With information relative to viscosity of asphalt being used, Contractor will determine temperature of completed mix at plant and at paver after considering hauling and placing conditions.

.4 Feed aggregates from individual stockpiles through separate bins to cold elevator feeders.

.5 Feed cold aggregates to plant in proportions that will ensure continuous operations.

.6 Immediately after drying, screen aggregates into hot storage bins in sizes to permit recombining into gradation meeting job mix requirements.

.7 Store hot screened aggregates in a manner to minimize segregation and temperature loss.

.8 Maintain temperature of materials within plus or minus 5°C of specified mix temperature during mixing.

.9 Mixing Time

.1 In batch plants, both dry and wet mixing times as directed by the Engineer. Continue wet mixing as long as necessary to obtain a thoroughly blended mix but no less than 30 s or more than 75 s.

.2 In continuous mixing plants, mixing time as directed by the Engineer but not less than 45 s.

.3 Do not alter mixing time unless directed by the Engineer.

.2 Dryer Drum Mixing Plant

.1 Feed aggregates to burner end of dryer drum by means of a multi-bin cold feed unit and blend to meet job-mix requirements by adjustments of variable speed feed belts and gates on each bin.

.2 Meter total flow of aggregate by an electric weigh belt system with an indicator that can be monitored by plant operator and which is interlocked with asphalt pump so that proportions of aggregate and asphalt entering mixer remain constant.

.3 Provide for easy calibration of weighing systems for aggregates without having material enter mixer.

.4 Make provision for conveniently sampling the full flow of materials from the cold feed.

.5 Provide screens or other suitable devices to reject oversize particles or lumps of aggregate from cold feed prior to entering drum.

.6 Provide a system interlock which will stop all feed components if either asphalt or aggregate from any bin stops flowing.

.7 Accomplish heating and mixing of asphalt mix in an approved parallel flow dryer-mixer in which aggregate and asphalt enter drum at burner end and travel parallel to flame and exhaust gas steam. Control heating to prevent fracture of aggregate or excessive oxidation of asphalt. Equip system with automatic burner controls and provide for continuous temperature sensing of asphalt mixture at discharge, with a printing recorder that can be monitored by plant operator. Submit printed record of mix temperatures at end of each day.

.8 Mixing period and temperature to produce a uniform mixture in which particles are thoroughly coated and moisture content of materials as it leaves mixer to be less than 0.5%.

.3 Temporary Storage of Hot Mix

.1 Provide mix storage of sufficient capacity to permit continuous operation and designed to prevent segregation.

.2 Do not store asphalt mix in storage bins in excess of 3 h.

.4 While producing asphalt mix for this project, do not produce mix for other users unless separate storage and pumping facilities are provided for materials supplied to this project.

.5 Mixing Tolerances

.1 Permissible variations in aggregate gradation from job mix formula (percent of total mass):

.1 5 mm sieve and larger: ± 5.0%.

.2 2.5 mm sieve: ±4.0%.

.3 0.080 mm sieve: ±1.0%.

.2 Permissible variation of asphalt cement from job mix, 0.3%.

.3 Permissible variation of mix temperature at discharge from plant, 5°C.

.2 Equipment

.1 Pavers: Mechanical grade-controlled self-powered pavers capable of spreading mix within specified tolerances, true to line, grade, and crown as shown on Contract Drawings.

.2 Rollers, General

.1 Rollers: Sufficient number of rollers of type and weight to obtain the necessary compaction of the porous asphalt mix.

.1 Static rollers.

.2 Minimum drum diameter: 1200 mm.

.3 Minimum mass: 8 tonne.

.3 Haul Trucks

.1 Haul trucks of adequate size, speed, and condition to ensure orderly and continuous operation.

.2 The hauling vehicles shall have tight, smooth, metal boxes cleaned of all accumulations of asphalt concrete and foreign materials. Prior to loading, the truck box may be lightly lubricated with a heat resistant asphalt releasing emulsion, having a maximum silicone content of 1 part per 1,000 parts of diluted emulsion. Lubrication with diesel fuel will not be permitted.

.3 Covers of sufficient size and weight to completely cover and protect asphalt mix when truck fully loaded.

.4 In cool weather or for long hauls, insulate entire contact area of each box.

.5 Trucks which cannot be weighed in a single operation on scales supplied will not be accepted.

.6 Hauling vehicles shall be in sound mechanical condition and free from oil and fuel leaks.

.4 Hand Tools

.1 Lutes or rakes with covered teeth for spreading and finishing operations.

.2 Tamping irons having mass not less than 12 kg and a bearing area not exceeding 310 cm^2 for compacting material along curbs, gutters, and other structures inaccessible to roller. Mechanical compaction equipment, when approved by the Engineer, may be used instead of tamping irons.

.3 Straight edges, 3.0 m in length, to test finished surface.

.3 Preparation

.1 Prior to laying mix, clean surfaces of loose and foreign material.

.4 Transportation of Mix

.1 Transport mix to job site in vehicles cleaned of foreign material.

.2 Paint or spray truck beds with light oil, limewater, soap, or detergent solution, at least once a day or as required. Elevate truck bed and thoroughly drain. No excess solution will be permitted.

.3 Schedule delivery of material for placing in daylight, unless the Engineer approves artificial light.

.4 Deliver material to paver at a uniform rate and in an amount within capacity of paving and compacting equipment.

.5 Deliver loads continuously in covered vehicles and immediately spread and compact.

.5 Placing

.1 Obtain the Engineer's approval of choker course prior to placing porous asphalt mix.

.2 Place asphalt concrete to thicknesses, grades, and lines as shown on Contract Drawings or as directed by the Engineer.

.3 Placing Conditions

   .1 Place asphalt mixtures only when air temperature is above 10°C with a lay down temperature between 120°C and 135°C.

.4 Place porous asphalt concrete in one lift of the specified thickness.

.5 Construct longitudinal joints and edges true to line markings. Position and operate paver to follow established line closely.

.6 If segregation occurs, immediately suspend spreading operation until cause is determined and corrected.

.7 Correct irregularities in alignment left by paver by trimming directly behind machine.

.8 Correct irregularities in surface of pavement course directly behind paver. Remove by shovel or lute excess material forming high spots. Fill and smooth indented areas with hot mix.

.9 Do not throw surplus material on freshly screeded surfaces.

.10 When Hand Spreading Is Used

   .1 Approved wood or steel forms rigidly supported to assure correct grade and cross-section may be used. Use measuring blocks and intermediate strips to aid in obtaining required cross-section.

   .2 Distribute material uniformly. Do not broadcast material.

   .3 During spreading operation, thoroughly loosen and uniformly distribute material that has formed into lumps and does not break down readily.

   .4 After placing and before rolling, check surface with templates and straightedges and correct irregularities.

   .5 Provide heating equipment to keep hand tools free from asphalt. Avoid high temperatures which may burn material. Do not use tools at a higher temperature than temperature of mix being placed.

.6 Compaction

.1 The mixture shall be compacted using a minimum of two passes of a static tandem steel wheel roller. The maximum capacity for each roller shall be 1,200 square metres per hour.

.2 General

.1 Pneumatic tire rollers or vibratory compaction are prohibited.

.2 Start rolling operations as soon as placed mix can bear weight of roller without undue displacement of material or cracking of surface.

.3 Operate roller slowly initially to avoid displacement of material. For subsequent rolling, do not exceed 5 km/h for static steel-wheeled rollers.

.4 Keep wheels of roller slightly moistened with water to prevent pick-up of material but do not over-water.

.5 Do not permit heavy equipment or rollers to stand on finished surface before it has been compacted and has thoroughly cooled.

.6 After transverse and longitudinal joints and outside edge have been compacted, start rolling longitudinally at low side and progress to high side.

.7 When paving in echelon, leave unrolled 50 mm to 75 mm of edge which second paver is following and roll when joint between lanes is rolled.

.8 Where rolling causes displacement of material, loosen affected areas at once with lutes or shovels and restore to original grade of loose material before re-rolling.

.7 Joints

.1 General

.1 Remove surplus material from surface of previously laid strip. Do not dispose on surface of freshly laid strip.

.2 Construct joints between porous asphalt concrete pavement and Portland cement concrete pavement as specified.

.3 Paint contact surfaces of existing structures such as manholes, curbs, or gutters with bituminous material prior to placing adjacent pavement.

.2 Transverse Joints

.1 Cut back to full depth vertical face and tack face with thin coat of asphalt prior to continuing paving.

.2 Compact transverse joints to provide a smooth riding surface.

.3 Longitudinal Joints

.1 Offset longitudinal joints in succeeding lifts by at least 150 mm.

.2 Cold joint is defined as joint where asphalt mix is placed, compacted, and left to cool below 100°C prior to paving of adjacent lane.

.1 If cold joint cannot be avoided, tack face of adjacent lane with thin coat of asphalt prior to continuing paving.

.3 Overlap previously laid strip with spreader by 100 mm.

.4 Before rolling, carefully remove and discard coarse aggregate in material overlapping joint with a lute or rake.

.5 Roll longitudinal joints directly behind paving operation.

.6 When rolling with static roller, shift roller over onto previously placed lane in order that 100 mm to 150 mm of drum width rides on newly laid lane, then operate roller to pinch and press fines gradually across joint. Continue rolling until thoroughly compacted neat joint is obtained.

.4 Overbuild at flat concrete curb locations as directed by the Engineer, and saw cut to provide a straight line as shown on Contract Drawings.

.8 Finish Tolerances

.1 Finished asphalt surface to be within 6 mm of design elevation but not uniformly high or low.

.2 Finished asphalt surface not to have irregularities exceeding 6 mm when checked with a 3 m straight edge placed in any direction.

.9 Defective Work

.1 Correct irregularities which develop before completion of rolling by loosening surface mix and removing or adding material as required. If irregularities or defects remain after final compaction, remove surface course promptly and lay new material to form a true and even surface and compact immediately to specified density.

.2 Replace areas showing, checking, or rippling.

.3 Adjust roller operation and screed settings on paver to prevent further defects such as rippling and checking of pavement.

4. MEASUREMENT AND PAYMENT

.1 Payment for Porous Asphalt Concrete will be made at the unit price per square metre.

APPENDIX A

RECOMMENDED OGFC MIXTURE DESIGN PROCEDURE

Step 1: Materials Selection

The first step in the mix design process is to select materials suitable for OGFC. Materials needed for OGFC include aggregates, asphalt binders, and additives. Additives include asphalt binder modifiers, such as polymers and fibres.

Step 2: Selection of Design Gradation

Selection of the design gradation should entail blending selected aggregate stockpiles to produce three trial blends. It is suggested that the three trial gradations fall along the coarse and fine limits of the specified gradation range along with one in the middle. For each trial gradation, determine the dry-rodded voids in the coarse aggregate fraction (VCA_{DRC}) in accordance with AASHTO T19 (Note 1). Coarse aggregate is defined as the aggregate fraction retained on the 4.75 mm sieve.

For each trial gradation, compact specimens at between 6.0 and 6.5 percent asphalt binder using 50 gyrations of the Superpave gyratory compactor. If fibres are a selected material, they should be included in these trial mixes. Determine the voids in the coarse aggregate (VCA) for each compacted mix (Notes 2 and 3). If the VCA of the compacted mix is equal to or less than the VCA_{DRC}, stone-on-stone contact exists. To select the design gradation, choose a trial gradation that has stone-on-stone contact combined with high voids in total mix.

Step 3: Determine Optimum Asphalt Content

Using the selected design gradation, prepare OGFC mixes at three binder contents in increments of 0.5 percent (e.g., 5.5, 6.0, and 6.5%). Conduct draindown tests on loose mix at a temperature 15^{o}C higher than the anticipated production temperature (Note 4). Compact using 50 gyrations of a Superpave gyratory compactor and determine the air void contents. Conduct the Cantabro abrasion test on un-aged and aged (seven days @ 60^{o}C) samples (Note 5). The asphalt content that meets the following criteria is selected as the optimum asphalt content.

1. **Air Voids**. A minimum of 18 percent is required, although higher values are more desirable. The higher the air voids are the more permeable the OGFC.

2. **Abrasion Loss on Un-aged Specimens**. The abrasion loss from the Cantabro test must not exceed 20 percent.

3. **Abrasion Loss on Aged Specimens**. The abrasion loss from the Cantabro test must not exceed 30 percent.

4. **Draindown**. The maximum permissible draindown should not exceed 0.3 percent by mass of total mixture.

If none of the binder contents tested meet all four criteria, remedial action is required. Air voids within the OGFC are controlled by the binder content. If air voids are too low, the asphalt binder content should be reduced. If the abrasion loss on un-aged specimens is greater than 20 percent, more asphalt binder is needed. Abrasion loss values of aged specimens in excess of 30 percent can be remedied by either increasing the binder content or changing the type of binder additive. If the draindown values are in excess of 0.3 percent, the amount of binder and/or the type of binder additive can be adjusted. Fibre stabilizers are typically incorporated into the mix at a rate of 0.2 to 0.5% of the total mixture.

Step 4: Evaluate Mix for Moisture Susceptibility

The mix designed with Step 1 through 4 shall be evaluated for moisture susceptibility using the modified Lottman method (AASHTO T283) with five freeze/thaw cycles in lieu of one cycle. Specimens are tested at the design air void content (rather than at +/- 7% air voids) and the saturation of conditioned specimens is not required. The retained tensile strength (TSR) shall be a minimum of 80 percent.

Note 1: The VCA_{DRC} can be calculated using the following equation:

$$VCA_{DRC} = (G_{CA} \times a_w \times a_s / G_{CA} \times a_w) \times 100$$

Where:

G_{CA} = bulk specific gravity of the coarse aggregate.

a_s = unit weight of the coarse aggregate fraction in the dry-rodded condition (kg/cu.m).

a_w = unit weight of water (998 kg/cu.m).

Note 2: Bulk specific gravity measurements determined by volumetric measurements or, alternatively, the Core-Lok procedure.

Note 3: The VCA can be calculated using the following equation:

$$VCA = 100 – (G_{MB} / G_{CA} \times P_{CA})$$

Where:

G_{MB} = bulk specific gravity of the compacted mix.

G_{CA} = bulk specific gravity of the coarse aggregate.

P_{CA} = percent of coarse aggregate in the mix by mass of total mix.

Note 4: The draindown characteristics are measured using the NCAT test method. A sample of loose mixture to be tested is prepared in the laboratory or obtained from field production. The sample of known mass is placed in a wire basket which is positioned on a plate or other suitable container of known mass. The sample, basket, and plate are placed in a forced draft oven for one hour at the pre-selected temperature (i.e., 15^{o} C above the recommended mixing temperature). At the end of one hour, the basket containing the sample is removed from the oven along with the plate and the mass of the plate is determined. The amount of draindown is then calculated based on the mass of the binder drained onto the plate compared to the original mass of the mix.

Note 5: The resistance of compacted OGFC specimens to abrasion loss is analysed by means of the Cantabro test. This is an abrasion and impact test carried out in the Los Angeles Abrasion machine (ASTM Method C131).

In this test, an un-aged OGFC specimen compacted with 50 blows on each side is used. The mass of the specimen is determined to the nearest 0.1 gram, and is recorded as P_1. The test specimen is then placed in the Los Angeles Rattler without the charge of steel balls. The operating temperature is usually 25^{o}C. The machine is operated for 300 revolutions at a speed of 30 to 33 rpm. The test specimen is the removed and its mass is determined to the nearest 0.1 gram (P_2). The percentage loss (P) is calculated according to the following formula:

$$P = (P_1 – P_2) / P_1 \times 100$$

Aged testing is accomplished by placing five Marshall specimens compacted with 50 blows in a forced draft oven at 60^{o}C for 168 hours (7 days). The specimens are then cooled to 25^{o}C and stored for four hours prior to testing. The abrasion loss is determined based on the average loss of the five specimens.

END OF SECTION

APPENDIX E

LID SPECIFICATIONS – PERVIOUS CONCRETE

PERVIOUS CONCRETE

1. GENERAL

.1 Pervious concrete pavement does not look or behave like conventional concrete pavement. Traditional concrete testing procedures and placement are not applicable for this type of concrete.

.2 Except where specifically stated otherwise, all materials and methods in this Section are to conform to requirements of the latest version of Canadian Standards Association (CSA) A23.1 and A23.2.

.3 Related Work

.1	Porous Pavement Construction.	Section A
.2	Porous Asphalt Concrete Paving.	Section B
.3	Permeable Interlocking Concrete Pavers.	Section D

.4 All cast-in-place concrete such as curbs, gutters, headers, and sidewalks shall comply with The City of Calgary Roads Construction Standard Specifications.

.4 Reference Standards

.1 Perform concrete work in accordance with the following standards, except where specified otherwise.

.1 CSA A3000-08, Cementitious Materials Compendium.

.2 CSA A23.1-09, Concrete Materials and Methods of Concrete Construction.

.3 CSA A23.2-09, Test Methods and Standard Practices for Concrete.

.4 CSA A283-06 Qualification Code for Concrete Testing Laboratories.

.5 The City of Calgary Roads Construction 2013 Standard Specifications, Section 310 – Portland Cement Concrete and Section 311 – Concrete Sidewalk Curb and Gutter.

.6 American Concrete Institute – ACI 522R, Pervious Concrete.

.7 ACI 522.1 Specification for Pervious Concrete Pavement.

.8 CSA A23.1 – Annex N (Informative) Requirements for pervious concrete.

.9 ASTM C1688 – Standard Test Method for Density and Void Content of Freshly Mixed Pervious Concrete.

.10 ASTM C1754 – Standard Test Method for Density and Void Content of Hardened Pervious Concrete.

.11 ASTM C1116 – Standard Specification for Fiber-Reinforced Concrete.

2. PRODUCTS

.1 Materials

.1 Portland cement: Type GU (General use hydraulic cement) conforming to CSA A3001-08.

.2 Fly ash: Class F conforming to CSA A3001-08.

.3 Aggregates: The aggregate shall meet the requirements of CSA A23.1-09, Table 12 – Limits for deleterious substances and physical properties of aggregates. Grading requirements for coarse aggregate shall meet CSA A23.1-09, Table 11, Group II, 20 – 10 mm. Grading for fine aggregate shall meet the limits of CSA A23.1-09, Table 10 for Group FA1.

.4 Admixtures: Air entraining admixtures conforming to the requirements of American Society for Testing and Materials (ASTM) C260. Water reducing admixtures conforming to the requirements of ASTM C494. Type A mid-range water reducing admixtures or Type F or G high range water reducing admixtures.

.5 Synthetic fibres: Synthetic fibre shall meet the requirements of ASTM C1116, 4.1.3, Type III and shall be olefin macro fibres.

.6 Water: Water for concrete production is to be clean and free from excessive amounts of oil, acid, alkali, soluble chlorides, organic matter, or sediment.

3. SUBMITTALS

.1 Submit the proposed mix design for the concrete mix to the Engineer for approval four weeks prior to the commencement of the work. Mix design documentation shall include all components of the mix and quantities of the materials used.

.2 Submit copies of mill certificate test reports of cement and fly ash.

.3 Submit the test results for each source of the aggregate to be used for compliance with CSA A23.1-09, Table 12.

.4 Submit data on all proposed concrete admixtures.

.5 Submit data on proposed fibres.

.6 Submit the results of trial batch testing for the pervious concrete for compliance with concrete properties specified in relevant sections of this Specification. Any change in the materials and/or quantities shall require new trial batch testing.

4. PERVIOUS CONCRETE MIXES

.1 Cement type: Type GU (General use hydraulic cement).

.2 Fly ash: Type F, maximum 20% by total mass of cementing materials.

.3 Minimum compressive strength at 28 days: 30 MPa.

.4 Void space: 15% to 25%.

.5 Aggregates

.1 Coarse aggregate: Gap-graded aggregate 20 – 10 mm. Larger aggregate sizes may increase porosity but can decrease workability and strength. Well graded aggregates shall be avoided as they may reduce porosity and may not provide adequate void content.

.2 Fine aggregate: Fine aggregate complying to CSA A23.1, Table 10 shall provide 6% ± 2% of total aggregate mass.

.3 A combined coarse and fine aggregate gradation shall be provided and a minimum of 10% of the material shall pass 5 mm sieve size. The inclusion of additional sand increase the freeze thaw durability and strength while still allowing adequate porosity.

.6 Water to cementing materials ratio: 0.27 to 0.32.

.7 Synthetic fibre: Optimum amount to reduce potential for overconsolidation and loss of void space, and for reducing ravelling.

.8 Air entrainment: Dosage should provide entrained air in 5% range for improved freeze thaw durability and workability.

.9 Slump at time and point of discharge: 20 mm to 50 mm.

.10 Hydraulic conductivity of properly designed and placed pervious concrete is in the range of 0.2 cm/s to 1.2 cm/s.

5. EXECUTION

.1 General

.1 Pervious concrete pavement shall be placed above the stormwater management system capable of preventing water from standing in the pavement following a storm event.

.2 Pavement design including pavement thickness and the size of the reservoir shall be conducted by a professional engineer.

.2 Notification

.1 The Engineer shall be notified at least 24 hours prior to all pervious concrete paving work.

.3 Subgrade Preparation

.1 Prepare subgrade as specified in contract documents.

.2 Construct subgrade to ensure that the required pavement thickness is obtained in all locations.

.4 Installation of Pervious Concrete Pavement

.1 Forms to CSA-A23.1-09. Formwork materials are acceptable to be of wood or steel and shall be full depth of the pavement. Caution should be used to protect the filter fabric and impermeable membranes from puncture or tear when placing forms and form pins. Forms shall be of sufficient strength and stability to support mechanical equipment without deformation of plan profiles following spreading, strike-off, and compaction operations. Forms may have a removable spacer of 10 mm to 20 mm thickness placed above the depth of pavement. The spacers shall be removed following placement and vibratory strike-off to allow roller compaction.

.2 Mixing and Transportation

.1 Production: Pervious concrete shall be manufactured and delivered in accordance with CSA A23.1-09 and shall be batched in central mixers.

.2 Transportation: The time between batch time and a discharge time of pervious concrete shall not exceed one hour.

.3 Discharge: Discharge shall be a continuous operation and shall be completed as quickly as possible. Concrete shall be deposited as close to its final position as practical and such that discharged concrete is incorporated into previously placed plastic concrete. Water shall not be added on site to improve workability.

.3 Placing and Finishing

.1 The base shall be in damp and semi-flooded condition at time of placement. Failure to provide a moist base will result in absorption of water from the pervious concrete into the base, subsequently reducing the concrete strength and overall quality of pavement.

.2 Concrete may be deposited into the forms by mixer track chute, conveyor, or buggy.

.3 Placing, finishing, and tooled jointing must be completed within 20 minutes from the time the pervious concrete is discharged from the truck.

.4 Unless otherwise permitted, the Contractor shall utilize a mechanical vibratory screed to strike off the concrete 10 mm to 20 mm above final elevation utilizing spacers described in Section 4.4.1. An alternative method of strike off and compaction is to use a motorized or hydraulically actuated weighted pipe roller screed.

.5 Care must be taken to prevent closing the void structure of pervious concrete. Internal vibration and high frequency vibrators shall not be permitted.

.6 Following strike-off, remove spacers and compact the concrete into the forms level utilizing a steel roller or a plate compactor on plywood.

.7 Freshly compacted concrete shall be protected from evaporation using one of more methods described in section 4.5.

.8 Cross rolling should be performed using the minimum number of passes required to achieve an acceptable surface. Over working the concrete surface will close voids and reduce porosity.

.4 Jointing

.1 Joints in pervious concrete may be omitted at the option of the Owner, who may instead choose to accept the appearance of random cracking.

.2 Contraction joints shall be installed at regular intervals not to exceed 6 m. Slab length shall not exceed 1.25 times slab width. Transverse contraction joints shall be installed at ¼ the depth of the thickness of the pavement. These joints are to be installed as quickly as possible in the plastic concrete.

.3 Joints installed in the plastic concrete may be constructed utilizing a small roller to which a bevelled fin with a minimum of ¼ of the thickness of the pavement has been attached around the circumference of the roller.

.4 Sawing of joints is not recommended due to the sediment introduced into the pavement and the increased probability of ravelling along the joints.

.5 Curing

Curing procedures shall commence immediately but no later than 20 minutes from the time pervious concrete is discharged from the truck. The pavement surface shall be covered with a minimum of 6 mil thick polyethylene sheet or other approved covering material. The cover shall overlap and be sealed at all edges and shall be secured to prevent uncovering due to winds or adjacent traffic conditions.

.1 Hot and cold weather concreting shall follow CSA A23.1-09 requirements.

.2 The surface of the pervious concrete is especially susceptible to drying out. The surface shall be kept moist and evaporation prevented by using some or all of the following methods.

.1 Fogging should start when the pervious concrete is deposited and should be continued until the plastic curing cover is placed.

.2 Application of spray applied curing compound, evaporation retarder, or monomolecular film.

.3 Application of water under the plastic covering. Care must be taken to properly re-secure the plastic cover to prevent evaporation.

.4 Immediately after each transverse jointing, the 6 mil polyethylene sheet curing shall be applied.

.5 Concrete shall be moist cured by protecting from it against loss of moisture, rapid temperature changes, rain, flowing water, and mechanical injury for a period of not less than seven days.

.6 Field Quality Control

.1 Inspection and testing of concrete and concrete materials will be carried out by a CSA certified laboratory designated by the Engineer.

.2 The Owner will employ an independent testing firm to carry out quality control checks on pervious concrete. The Contractor will be responsible for assisting the testing firm by giving 24 hours' notice of concrete pours, accommodating the testing firm's sampling needs, and otherwise assisting the testing firm as requested by the Engineer.

.3 Inspection or testing by the Engineer will not augment or replace Contractor quality control nor relieve him of his contractual responsibility.

6. MEASUREMENT AND PAYMENT

.1 Payment for Pervious Concrete will be made at the unit price per square metre.

END OF SECTION

APPENDIX F

LID SPECIFICATIONS – PERMEABLE INTERLOCKING CONCRETE PAVERS

PERMEABLE INTERLOCKING CONCRETE PAVERS

1. GENERAL

.1 Except where specifically stated otherwise, all materials and methods in this Section are to conform to requirements of the latest version of CSA A23.1, A23.2, and CSA A231.2.

.2 Related Work

.1 Porous Pavement Construction. Section A

.2 Porous Asphalt Concrete Pavement. Section B

.3 Pervious concrete. Section C

.4 The City of Calgary Roads Construction 2012 Standard Specifications, Section 303 – Granular Material.

.5 The City of Calgary Roads Construction 2013 Standard Specifications, Section 310 – Portland Cement Concrete.

.6 The City of Calgary Roads Construction 2013 Standard Specifications, Section 311 – Concrete Sidewalk, Curb and Gutter.

.3 Reference Standards

.1 Perform concrete work in accordance with the following standards, except where specified otherwise.

.1 CSA A3000-08, Cementitious Materials Compendium.

.2 CSA A23.1-09, Concrete Materials and Methods of Concrete Construction.

.3 CSA A23.2-09, Test Methods and Standard Practices for Concrete.

.4 CSA A283-06 Qualification Code for Concrete Testing Laboratories.

.5 CSA A231.2-06 (R2010), Precast Concrete Pavers.

.6 CSA A179-04 (R2009), Mortar and Grout for Unit Masonry.

2. PRODUCTS

.1 Concrete Pavers

.1 Concrete pavers to be supplied by a member of the Interlocking Concrete Pavement Institute (ICPI).

.2 The pavers shall meet the requirements of ASTM C936M-09, Standard Specification for Interlocking Concrete Paving Units and CSA A232.2-06.

.1 Average compressive strength of 55 MPa with no individual unit under 50 MPa.

.2 Average absorption of 5% with no unit greater than 7% when tested in accordance with ASTM C 140.

.3 Resistance to 50 freezing and thawing cycles when tested according to ASTM C67.

.3 The pavers shall meet the requirements of CSA A232.2-06.

.1 Minimum average cube compressive strength of 50 MPa for laboratory cured specimens or 40 MPa for unconditioned field samples.

.2 Resistance to 50 freezing and thawing cycles while immersed in a 3% saline solution with no greater mass loss than 225 g/m^2 of surface area after 28 cycles, or 500 g/m^2 after 49 cycles.

.2 Bedding and Joint Sand

.1 Bedding and joint sand shall be non-plastic, free from deleterious or foreign matter, natural, or manufactured from crushed rock.

.2 Bedding and joint sand shall meet the grading requirements specified in Section A, Porous Pavement Construction.

3. SUBMITTALS

.1 Submit manufacturer's drawings and details indicating perimeter condition, relationship to adjoining materials and assemblies, concrete paver layout, and patterns and installation details.

.2 Submit gradation analysis of the bedding sand in accordance with CSA A23.2-2A.

.3 Submit four representative full size samples of each paver type, thickness colour, and finish that indicate the range of colour variation and texture expected in the finished installation.

.4 Accepted samples become the standard for acceptance for the installation.

.5 Submit test results from an independent testing laboratory for compliance of the paving unit requirements to ASTM C936M-09 and CSA A231.2-06.

.6 Submit manufacturer's certification of concrete pavers by ICPI as having met applicable ASTM and CSA standards.

.7 Submit manufacturer's catalog product data, installation instructions, and material safety data sheets for the safe handling of the specified materials and products.

.8 Submit a copy of subcontractor's current certificate from the ICPI Concrete Paver Installer Certification Program.

4. EXECUTION

.1 Examination

.1 The elevations and surface tolerance of the subgrade material determine the final surface elevations of concrete pavers. The paver installation contractor cannot correct excavation and grading deficiencies with additional bedding materials.

.2 Surface elevations of the subgrade material shall be verified and accepted by the Engineer prior to installation of interlocking concrete pavers.

.3 Verify location, type, and elevations of edge restraints, utility structures, and drainage pipes and inlets.

.2 Notification

.1 The Engineer shall be notified at least 24 hours prior to installation of interlocking concrete pavers.

.3 Subgrade Preparation

.1 Prepare subgrade as specified in contract documents.

.2 Construct subgrade to ensure that the required subgrade elevations are met.

.4 Installation of Permeable Concrete Pavers

.1 Do not proceed with the installation of bedding and interlocking concrete pavers until subgrade material conditions are corrected by the Contractor.

.2 Keep area where pavement is to be constructed free from sediment during the entire job. Base and bedding materials contaminated with sediment shall be removed and replaced with clean materials.

.3 Do not damage drainpipes, overflow pipes, observation wells, or any inlets during installation. Report any damage immediately to the Engineer.

.4 Bedding Layer Placement

.1 Moisten, spread and screed bedding material. The surface tolerance of the screeded bedding material shall be ±10 mm over a 3 m straightedge.

.2 Screeded bedding materials shall not be subjected to any pedestrian or vehicular traffic before the pavers' installation.

.5 Placing and Finishing

.1 Lay the pavers in the patterns and joint widths shown on the drawings. Maintain straight pattern lines.

.2 Fill gaps at the edges of the paved area with cut units. Cut pavers subject to tire traffic shall be no smaller than 1/3 of a whole unit.

.3 Cut pavers and place along the edges with a masonry saw.

.4 Fill the openings with the joint sand.

.5 Remove excess aggregate on the surface by sweeping pavers clean.

.6 Compact and seat the pavers into the bedding material using low amplitude, 75-90 Hz plate compactor capable of at least 18 kN centrifugal compaction force. This will require at least two passes with the plate compactor.

.7 Do not compact within 2 m of the unrestrained area of the paving units.

.8 Apply additional aggregate to the openings and joints, filling them completely. Remove excess aggregate by sweeping then compact the pavers. This will require at least two passes with the plate compactor.

.9 All pavers within 2 m of the laying face must be left fully compacted at the completion of each day.

.10 The final tolerance of compacted pavers shall not deviate more than 10 mm under a 3 m long straightedge.

.11 The surface elevation of pavers shall be 3 mm to 6 mm above adjacent drainage inlets, concrete collars, or channels.

.6 Protection

.1 After installation is complete, the Contractor shall be responsible for protecting work from sediment deposition and damage due to subsequent construction activity on site.

.7 Field Quality Control

.1 After sweeping the surface clean, check final elevations for conformance to the drawings.

.2 Lippage: No greater than 3 mm difference in height between adjacent pavers.

6. MEASUREMENT AND PAYMENT

.1 Payment for Permeable Concrete pavers will be made at the unit price per square metre.

END OF SECTION