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SF PERMEABLE PAVING STONE SYSTEMS

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1.0 INTRODUCTION

Environmental responsibility through green initiatives is being embraced in the transportation industry from grass roots community groups to the federal government. The initiatives are far reaching from community tree planting events to sustainable infrastructure design. One such tool in the sustainable infrastructure design arsenal is the use of permeable pavement systems. The ability to use the large areas occupied by pavements to improve hydrology and groundwater recharge has many potential benefits.

Traditional pavement surfaces are virtually impermeable and are used in conjunction with ditches and storm drains to channelize precipitation towards storm water management facilities. These facilities have a tendency to bypass natural watersheds and groundwater recharge regimes.

Permeable pavements provide a different approach. Rather than channelizing precipitation along the surface of the pavement, the water is allowed to infiltrate and flow through the pavement surface where it can be stored and slowly allowed to return into the local groundwater system. The benefits of this approach are well documented [1] and their use by designers is encouraged through the Leadership in Energy and Environmental Design (LEED®) Green Building Rating System™.

SF-RIMA™ has been leading the development of paving stone permeable pavement systems for over a decade. The VS 5™ Eco and VS 5™ Drain products provide reliable pavement systems to meet the structural requirements of a traditional pavement and provide the additional benefits of a permeable surface.

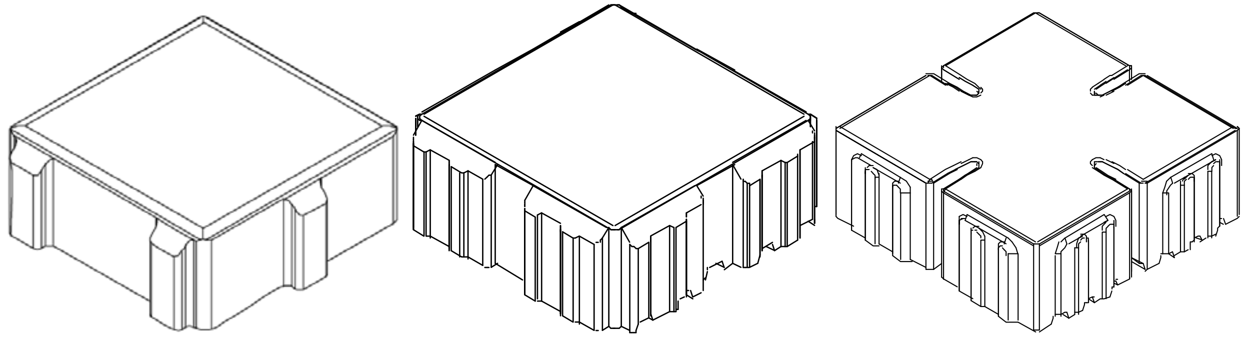
2.0 SF PERMEABLE INTERLOCKING CONCRETE PAVING SYSTEMS

SF Permeable interlocking concrete paving systems offers an environmentally friendly way of providing long lasting beautiful walkways, driveways and parking areas. The pavement system effectively filters and drains stormwater back into the native soil.

Permeable paving systems are recognized by environmental protection agencies in the United States and in Canada as a best management practice (BMP) for stormwater control. SF Permeable interlocking concrete paving systems allow infiltration of rain water directly into the pavement and can capture additional runoff from adjacent impermeable areas.

SF Permeable interlocking concrete paving systems are constructed over an open-graded crushed stone base. The base provides infiltration and partial treatment of stormwater pollution for improved water quality and slow release of captured water to the underlying subgrade soil.

The paving stones themselves (shown below) are constructed with no slump concrete and have compressive strength in excess of 55 MPa (8,000 psi). The paving stones use patented technology to maximize drainage and strength while using the shape of the paving stones to transfer surface loads to adjacent blocks and to resist lateral shifting.



3.0 ENVIRONMENTAL BENEFITS OF THE SF-RIMA PERMEABLE PAVEMENT SYSTEMS

SF permeable paving systems assist with effective environmental management and help to reduce the impacts of land development. As pavement surfaces can contribute a significant percentage of usable development area, it is critical to assess their impact on the environment. The use of permeable pavements and permeable paving stone systems can provide significant measurable benefits that reduce the impact of development and foster sustainability.

The LEED® program has been active in educating design professionals on the environment effects of infrastructure design and acknowledging those who are working to reduce the impact of development on the environment.

According to the U.S. and Canadian Green Building Councils [2], LEED® is a third-party certification program and an internationally accepted benchmark for the design, construction and operation of high performance green buildings. It provides building owners and operators the tools they need to have an immediate and measurable impact on their buildings' performance.

LEED® promotes a whole-building approach to sustainability by recognizing performance in five key areas of human and environmental health:

- sustainable site development;
- water efficiency;
- energy efficiency;
- materials selection; and
- indoor environmental quality.

By providing a rating system and guidance in its use, design professionals are encouraged to utilize techniques and materials that have a positive impact on the environment. Specifically for permeable pavers, there are several credits that can be used to demonstrate the sustainability of a project. Some of the potential credits available are summarized in Table 1.

Table 1. Potential LEED Credits Available to Permeable Pavements

Credit No.	Credit Name	Credit Requirements	Product Compatibility
6.1	Stormwater Management: Rate and Quantity	To minimize impervious surfaces and to encourage the natural processes of infiltration. Determine existing site imperviousness. Design for 50 percent or less imperviousness within a 1.5 year, 24 hr peak discharge rate.	SF-Rima™ ,VS 5 – Drain and VS 5 – Eco, permeable concrete pavements can reduce runoff up to 100 percent from frequent, low intensity and short rainstorms. The long-term infiltration rate is estimated at 97 mm/hr (3.8 in/hr) for a 20-year initial service life. It is recommended however, to provide drainage swales to handle flows that exceed the design rainstorm.
6.2	Stormwater Management: Treatment	Removes 80 percent of the average annual post-development total suspended solids (TSS) and 40 percent of the average annual post-development total phosphorous (TP) based on the average annual loadings from all storms less than or equal to the 2-year/24-hour storm.	SF permeable concrete pavements can reduce TSS by up to 95 percent and TP by up to 70 percent.
7.1	Heat Island Effect: Non-Roof	Provide shade (within 5 years) and/or use light-coloured / high-albedo materials (reflectance of at least 0.3) and/or open grid pavement for at least 30 percent of the site's non-roof impervious surfaces, including parking lots, walkways, plazas, etc.	SF permeable pavements which are light coloured can assist in meeting this LEED requirement.
4.1 & 4.2	Recycled Content: 7.5 percent and 15 percent (post consumer + ½ post industrial)	7.5 percent to 15 percent recycled content as a project average (by weight) of all Division 2-10 project materials.	Products may contain post-industrial and post-consumer recycled content.
5.1 & 5.2	Regional Materials: 10 percent and 20 percent (Extracted and Manufactured Regionally)	10 percent to 20 percent of all Division 2-10 project materials (by weight) to be extracted and manufactured within 800 to 2,400 km (500 to 1,500 miles) via truck or rail respectively.	This criteria is dependent on manufacturer and site location.

Source: Green Alberta Product Evaluation No. 08-001-V01 [2]

In most cases, the primary advantage of permeable pavements is the storm water management aspects with the control of runoff and the reduction of the imperviousness. By encouraging water from storms to recharge the groundwater table rather than storm water treatment systems, these permeable pavement systems can have a profound effect on localized ecosystems.

In addition, it may be possible to obtain LEED credits based on a reduction of heat island effect as well as recycled content of the pavement structure (paving layer, base and subbase). This should be reviewed on a project by project basis to obtain the maximum number of LEED credits possible

4.0 DESIGN REQUIREMENTS

Permeable pavement systems have become widely used across North America with an increasing body of experience guiding design and construction. The design details and guidance provided in this document are based on a combination of this experience, extensive research, and hydrology theory. This guide is provided to help mitigate risk and ensure a functional and conservative pavement design. The design inputs are outlined in detail to provide guidance and allow customized designs for various site layouts, structural and hydrological requirements. Additional guidance is also available from the Interlocking Concrete Pavement Institute in their Permeable Interlocking Concrete Pavements manual [3]. The process used to determine the optimal design is outlined in Figure 1.

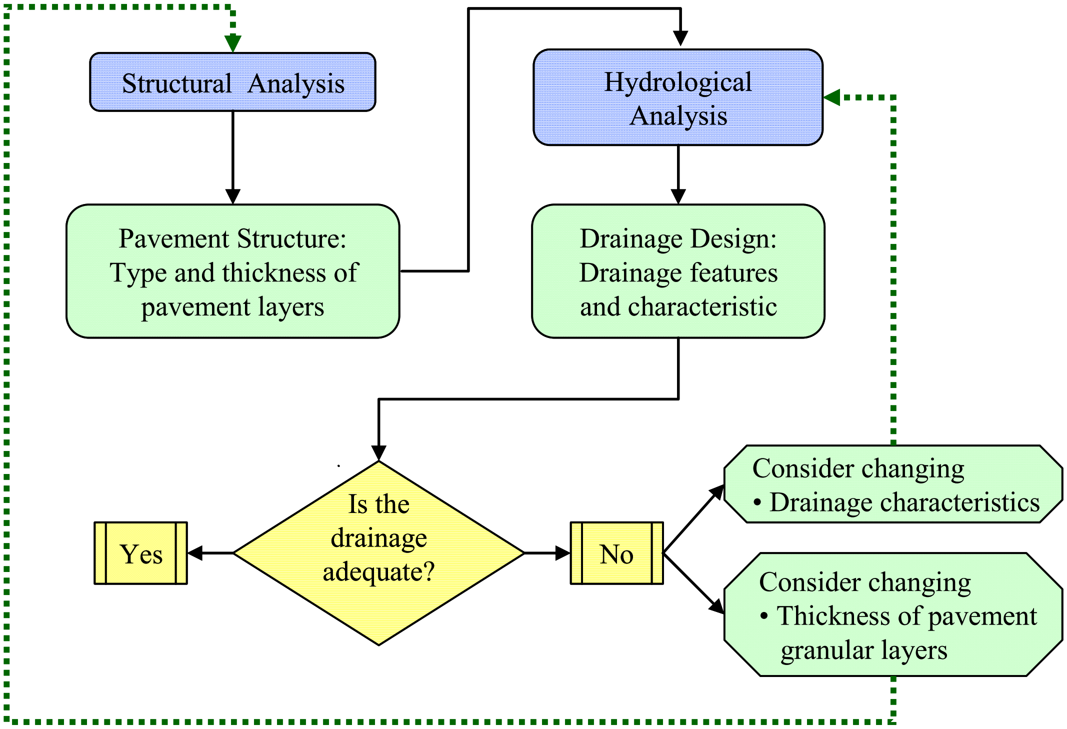


Figure 1. Design Procedure Flowchart

A well designed permeable pavement must be structurally adequate to support vehicles and have sufficient drainage characteristics. To complete this process, the structural capacity needs of the pavement are determined based on the subgrade type, condition and anticipated traffic loading. This cross-section is then evaluated to determine if it will meet the drainage requirements based on the hydrological analysis. If the drainage capacity is not adequate, changes to the hydrological design are made by changing materials, increasing the thickness of the water storage layer, or adding subdrains and other drainage features.

4.1 Site Feasibility

Permeable pavement systems are most commonly used in areas with lower traffic volumes such as parking lots, driveways and low volume roadways. Not every site is appropriate for a permeable pavement system. It is important that the site is not subject to frequent heavy traffic and that water captured by the pavement can be accommodated through either infiltration into the subgrade or through other drainage features.

Any environmental issues should also be considered before selecting a permeable pavement for the site. The potential for surface contaminants such as oil from vehicles to enter the groundwater table should be considered. Additional design options such as water treatment, geotextiles, and/or contaminant filter layers may be recommend based on an overall environmental assessment.

The hydrologic performance of the site is also an important permeable pavement design consideration. With water moving though the pavement system into the natural soil beneath, it is important that the water be able to infiltrate into the soil within a reasonable time frame. It is also important to ensure that the pavement structure be at least 1.2 m (4 ft) above the depth of the water. If the subgrade has low permeability, or the water table is close to the surface, other water removal options such as subdrains may need to be considered.

4.2 Pavement Structural Design

The structural design of paving stone surfaced pavements in North America commonly follows the flexible pavement design methodology outlined in the 1993 American Association of State and Highway Transportation Officials (AASHTO) Guide for the Design of Pavement Structures [4]. The AASHTO design procedure incorporates the strength of the individual pavement layers and calculates the thickness of each layer required to protect the underlying subgrade material from permanent deformation.

Traffic Requirements

Traffic loading is a critical component of the structural design. This represents the vehicular loads that the pavement is expected to support over its service life. The anticipated traffic and loading information is characterized by the AASHTO design procedure in terms of the Equivalent Single Axle Loads (ESALs) that the pavement is expected to support over its design life. The design ESALs represent the wear to the pavement caused by an equivalent number of 80 kN (18,000 lb) axles driving on the pavement.

To estimate the total number of ESALs expected over the design life of the pavement, the number and types of vehicles driving on the road need to be determined. Vehicles driving on the pavement have different characteristics including the number and spacing of axles and vehicle weight. Examples of truck weight factors are provided in the AASHTO Design Guide [4] and can be used to estimate the total number of ESALs expected over the entire design life.

Since permeable paver systems are typically used for low traffic volume locations, it is common to make general assumptions for the design traffic rather than complete detailed traffic surveys.

Figure 2. Traffic on Permeable Pavements

Roadways

To estimate the total number of ESALs expected over the life of the pavement, the number and types of vehicles driving on the pavement surface need to be determined. The types of vehicles have different characteristics including number and spacing of axles and axle weights. The total number of ESALs is calculated using the following formula.

Annual ESALs** = **AADT** x **Directional Distribution** x **Lane Distribution** x **% Commercial Vehicles** x **Vehicle Equivalency Factor** x **Traffic Days

Where:

AADT: Annual Average Daily Traffic
Directional Distribution: Percent of heavy vehicles travelling in each direction
Lane Distribution: Percent of heavy vehicles in each lane
% Commercial: Percent of commercial vehicles in the AADT
Vehicle Equivalency Factor: Number of ESALs per commercial vehicle
Traffic Days: Number of days per year when the pavement is subject to traffic

The above ESAL formula uses the best available traffic information to estimate the highest number of ESALs to which the pavement will be subjected in a year. It combines the Annual Average Daily Traffic (AADT), the percent of heavy commercial vehicles, an ESAL equivalency factor for commercial vehicles, and information on which lanes these vehicles are driving in. This is then factored to estimate the total ESALs over the entire design life of the pavement using an appropriate traffic growth rate.

$$ESALs = AnnualESALs\left(\frac{(1+GrowthRate)^{ServiceLife}-1}{GrowthRate}\right)$$

Parking Areas

Detailed ESAL calculations are not typically completed for parking areas where traffic is typically lower and less channelized than for roadways. It is more common to assume the design ESALs based on the types of vehicles expected to use the pavement. For example, design period ESALs for a typical parking lot can be estimated as follows:

- Category I - Cars ESALs = 7,500
- Category II - Cars and Light Trucks ESALs = 30,000
- Category III - Cars and Occasional Heavy Vehicles - ESALs = 75,000

Service Life

The service life of a pavement is the expected years of service prior to major rehabilitation. Major rehabilitation typically consists of removal of the pavers and bedding layer, repairs to the base material, drainage improvements and replacement of the bedding layer and pavers. Rehabilitation is typically required to address shear failure of the bedding, base, subbase or subgrade soils as typically indicated by surface deformation from wheel loads or settlements.

Design Reliability

Reliability is a concept used in the AASHTO 1993 design guide to account for variability of pavement materials, layer thicknesses, and construction. Reliability is a measure of the design risk of the pavement reaching its intended design life. Reliability is expressed in terms of a percentage. For example, a reliability of 90 percent means that the selected design should achieve or exceed its intended service life, 9 times out of 10. The higher the reliability level, the thicker the pavement for a given number of design ESALs. Typically, higher reliability levels are selected for higher volume pavements. For example, a major highway may be designed with a reliability level of 90 or 95 percent, whereas a parking lot pavement might be designed with a reliability of 70 or 75 percent.

Material Information

The materials selected for the pavement layers are very important and can have a significant impact on the performance of the pavement. The typically permeable pavement structure, shown in Figure 3, includes a paver surface over bedding material granular base, granular subbase, on top of the native subgrade.

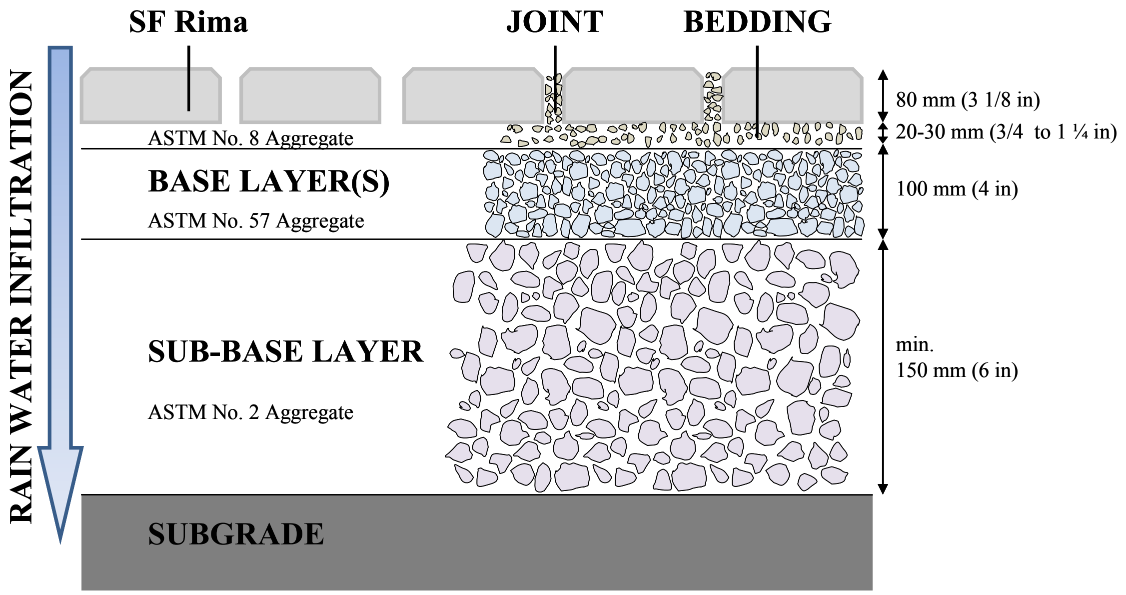


Figure 3. Typical Cross-Section and Materials

Subgrade Material

The support capability of the subgrade needs to be determined for all pavement designs. For the 1993 AASHTO design procedure, resilient modulus is used to describe the strength of the subgrade soil. Resilient modulus provides an indication of the load/deformation characteristics of the subgrade. This can also be determined directly from laboratory testing or through surrogates such as California Bearing Ratio (CBR), R-value or Florida Limerock Bearing Ratio (LBR) tests. The resilient modulus of the subgrade is determined in the moisture condition expected during the life of the pavement. For preliminary investigations, or if it is not possible to perform laboratory tests, typical resilient modulus values are available based on soil classification like the system shown in Table 2.

Table 2. Typical Subgrade Materials

Class	Brief Description	Resilient Modulus MPa (psi)	Drainage Rating	Susceptibility to Frost Action
Boulders/ cobbles	Rock, rock fill, shattered rock, boulders/cobbles	>275 MPa (> 40,000 psi)	Excellent	None
GW, SW	Well graded gravels and sands suitable as granular borrow	160 - 250 MPa (23,000 - 36,000 psi)	Excellent	Negligible
GP, SP	Poorly graded gravels and sands	145 - 205 MPa (21,000 - 30,000 psi)	Excellent to fair	Negligible to slight
GM, SM	Silty gravels and sands	145 - 235 MPa (21,000 - 34,000 psi)	Fair to semi-impervious	Slight to moderate
GC, SC	Clayey gravels and sands	89 - 160 MPa (13,000 - 23,000 psi)	Practically impervious	Negligible to slight
ML, MI	Silts and sandy silts	70 - 105 MPa (10,000 - 15,000 psi)	Typically poor	Severe
CL, MH	Low plasticity clays and compressible silts	35 - 55 MPa (5,000-8,000 psi)	Practically impervious	Slight to severe
CI, CH	Medium to high plasticity clays	20 - 42 MPa (3,000 - 6,000 psi)	Semi-impervious to impervious	Negligible to severe

Bedding, Base and Subbase Material

In a permeable pavement system, the proper selection of the bedding layer, base and subbase is an important consideration. These layers not only provide a substantial contribution to the structural capacity, but also the short term water storage capacity required to ensure pavement structure drainage and a surface without ponding. Typically, open graded (porous) granular materials are used.

A permeable bedding layer is typically used for fine grading and to provide a stable base for the paving stones. The bedding layer is typically specified to be 20 to 30 mm (3/4 to 1 ¼ inches) and no more than 50 mm (2 inches) in thickness.

Aggregates should be crushed, angular materials to ensure strong interlock. Unbound base and subbase materials should meet the local state, provincial or municipal standards governing these materials. Where local specifications are unavailable, the base/subbase material should meet the gradation requirements of ASTM D 2940 [5].

Typical materials recommended for permeable pavements include a bedding layer of ASTM No. 8 aggregate, ASTM No. 57 base aggregate and ASTM No. 2 subbase aggregate. These materials are considered compatible for both drainage and filter requirements. Gradation requirements for these materials are provided in Table 3.

Table 3. Typical Granular Material Gradations

Sieve Size	Percent Passing
Bedding and Joint/Opening Filler (ASTM No. 8)	
12.5 mm (1/2 in.)	100
9.5 mm (3/8 in.)	85 to 100
4.75 mm (No. 4)	10 to 30
2.36 mm (No. 8)	0 to 10
1.16 mm (No. 16)	0 to 5
Base Material (ASTM No. 57)	
37.5 mm (1 1/2 in.)	100
25 mm (1 in.)	95 to 100
12.5 mm (1/2 in.)	25 to 60
4.75 mm (No. 4)	0 to 10
2.36 mm (No. 8)	0 to 5
Subbase Material (ASTM No. 2)	
75 mm (3 in.)	100
63 mm (2 1/2 in.)	90 to 100
50 mm (2 in.)	35 to 70
37.5 mm (1 1/2 in.)	0 to 15
19 mm (3/4 in.)	0 to 5

4.3 Filter Requirements.

When using open graded materials, care must be taken to prevent the layers from mixing. If the fine particles from one material migrate and fill the larger pore space of neighbouring materials, the storage capacity is decreased, permeability is reduced, and differential settlement may occur.

The materials selected must provide a reasonable ratio of particle size to prevent migration of the smaller aggregate particles into the spaces between the larger aggregate sizes. This is of particular importance at the transition between the pavement structure and the natural subgrade. The filter criteria should be applied to all combinations of adjacent layers, e.g. bedding layer/base, base/subbase, subbase/subgrade, etc. In situations where the filter criteria is not met, consideration should be given to using a geotextile or other separator layer. The following guidelines are recommended by the U.S. Federal Highway Administration (FHWA) to prevent the migration of granular materials but still encourage movement of water between layers:

D_{15} Layer 1/D_{15} Layer 2 >= 5
D_{15} Layer 1/D_{85} Layer 2 <= 5
D_{50} Layer 1 /D_{50} Layer 2 <= 25

Where: D_x is the sieve screen size in millimetres at which “x” percent of the particles, by weight are smaller

The criteria are also recommended along with a preference to avoid gap graded materials with Coefficients of Uniformity (C_U) of less than 20.

$C_u = D_{60}(\text{filter}) / D_{10}(\text{filter})$

These criteria will help to reduce the risk of particle migration and premature failure. The ASTM stone combinations recommended within this document meet the filter requirements.

4.4 Design for Structural Capacity

Once the site information, traffic, and materials to be used have been collected, the structural capacity required can be determined. The design inputs are used to produce a required Structural Number (SN) for a given pavement. This SN represents the thickness and strength of the required pavement layer materials to ensure that the subgrade is adequately protected from the traffic loads.

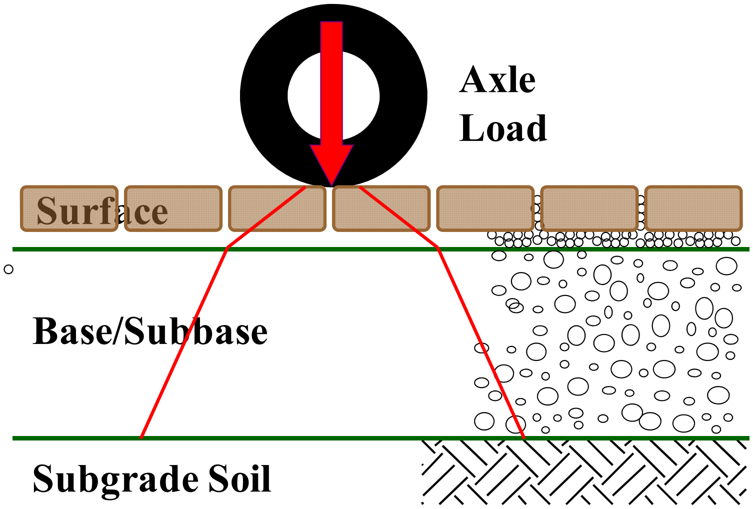


Figure 4. Distribution of Traffic Loads onto Underlying Layers

The 1993 AASHTO design procedure uses a series of layers to distribute the traffic loads and prevent large stresses on softer layers. The SN is obtained using the equation below [4]:

$$\log_{10} W_{18} = z_R \times s_0 + 9.36 \times \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left(\frac{\Delta PSI}{4.2-1.5}\right)}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \times \log_{10} M_R - 8.07$$

Where:

SN: Structural Number representing the minimum structure needed to support the traffic loads.

W_{18}: The traffic volume in terms of 18 kip (80 kN) equivalent single axle loads (ESALs).

z_R: The normal distribution statistic for the requested reliability (ie. $z_R = -0.6745$ for 75% reliability).

s_0: The standard error represents the variability in the traffic that the section will support due to variability in materials and construction ($s_0 = 0.45$).

ΔPSI: The acceptable change in serviceability change from the initial construction until significant rehabilitation or maintenance.

M_R: The resilient modulus is a measure of the stiffness of the subgrade soils. For the above equation, the M_R must be in U.S. customary units, i.e. pounds per square inch.

Design Reliability

The reliability design concepts are generally incorporated into the way the pavement designer assembles pavement design inputs. Although it is dependent on the application and importance of the pavement, a reliability level of 75 percent is typically recommended for low volume traffic pavements. This represents a low to medium reliability level. Higher levels of reliability may be considered for important thoroughfares. A standard error of 0.45 is recommended for paver systems.

Pavement Serviceability

The level of serviceability of pavers is an important aspect in determining the structural design. For most permeable paver systems the acceptable change of serviceability (ΔPSI) is expected to be 1.7. This value reflects the conditions, ease of construction, and typical expectations of low traffic volume pavements.

4.5 Design Layer Thickness

The Structural Number (SN) provides information on the total structural capacity of the pavement, but not on the thickness of the individual materials that are to be placed to create the pavement structure. To determine the thickness of the required layers, the various placed materials are assessed and totalled to determine if they meet the design structural number. The pavement structure is considered to be adequate of the placed layers have a structural number equal to or higher that calculated above. The SN is determined from the layers as:

$$SN = a_1D_1 + a_2D_2 + a_3D_3$$

Where:

SN: Structural number determined from the layer information. To meet the design, the layers must produce an SN equal to or greater than the design structural number. The SN is calculated as the sum of the layer thickness and structural layer coefficient products.

a: The ‘a’ values represent structural layer coefficients that are dependent on the materials being placed. The multiple ‘a’ values represent the multiple placed layers (ie. paving layer, base, and subbase).

D: The thickness of the layers. For the above equation, the D values must be in U.S. customary units, i.e. inches. The multiple thickness values represent the multiple placed layers.

For paving stone systems, the surface layer is composed of paving stones on a bedding layer material. The SF-Rima^{TM} VS 5 – Drain and VS 5 – Eco paving stones are 80 mm (3 1/8") thick and are placed on a bedding chip material typically 20 to 30 mm (3/4" to 1 1/4") thick. Based on research conducted by the Interlocking Concrete Pavement Institute, a layer coefficient 'a' value of 0.3 to 0.4 is recommended for the paving stone and bedding chip.

The thickness of the other layers is used to add additional structural capacity to the pavement. For open graded base materials, a layer coefficient 'a' value of approximately 0.05 to 0.10 is considered appropriate.

5.0 HYDROLOGIC DESIGN

The other major design variable that must be accounted for is the hydrologic properties. Since permeable pavement systems are expected to help accept incoming storm water and mitigate the rapid runoff, the behaviour during rainfall events must be considered.

The hydrology effects of the permeable pavement are evaluated through a detailed water balance. The water entering the permeable pavement is dissipated primarily though runoff or through infiltration into the subgrade. Supplementary subdrain systems may also be used to accommodate high water flow when slower drainage into the subgrade is expected (Figure 5).

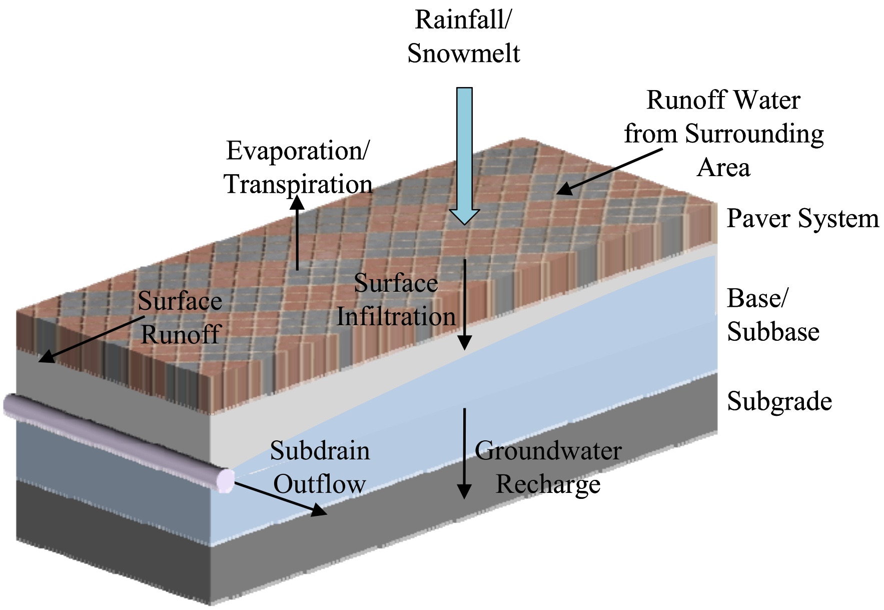


Figure 5. Inflow and Outflow of Water on a Permeable Pavement

The design for water balance is important as the pavement structure still must safely allow vehicles to move safely it is very important that no water ponds on the surface because this could cause hydroplaning. It is also important that all of the water that is transferred into the base/subbase drains in a reasonable time to accommodate multiple rain events.

When properly designed, runoff can be reduced by 100 percent from frequent, low intensity and short duration storms, whereby reducing or eliminating the need for retention ponds and storm sewer connections. The impact of the higher intensity storms can also be greatly reduced slowing the time it takes for the water to reach any surface outlets. The water balance for the pavement system is generated as a function of time to show that water arriving and leaving the system can occur at different rates throughout a storm period.

$$Water\ Volume(Time) = Initial\ Water\ Level + \int_{o}^{Time} Inflow(Time) - Outflow(Time)$$

For safety reasons, it is very important to prevent standing water on the surface of the pavement. Standing water can cause hydroplaning of vehicles, inconvenience for pedestrians, and potential flooding of neighbouring areas.

5.1 Rainfall Intensity and Pattern

The source of storm water primarily comes from precipitation events. These storms cause water to not only fall directly onto the pavement surface, but depending on the grading of adjacent areas, it is possible that water falling on adjacent areas will flow along the surface onto the pavement adding significant quantities of water to the permeable pavement.

In order to complete the hydrological design, it is necessary to know the intensity and duration of the rain event. The storm frequency, which is frequently used for design, represents how often a storm of a specified magnitude or greater will occur. For example, a 50 year storm indicates a storm intensity and duration that is only expected to occur once every 50 years.

In addition to the amount of water entering the permeable pavement, the storm pattern is also important. Since heavy rain events tend to take place over many hours, the rate at which the water arrives is important to consider. During the lighter intensity storms, it is possible that much of the water can infiltrate into the subgrade. During higher intensity portions of the storm, water may need to be stored within the pavement structure.

5.2 Surface Runoff

Surface runoff is important when designing permeable pavement systems. If the permeable pavement is sloped, some of the water may flow off the pavement into surrounding drainage systems or swales. If areas surrounding the permeable pavement are sloped toward the pavement, water not absorbed in these areas may flow onto the permeable pavement.

There are several ways to estimate the quantity of runoff from a surface area. The two most common ways are the U.S. Soil Conservations Service's curve numbers and the rational method.

Surface Runoff Estimation using Curve Numbers

The United States Department of Agriculture Natural Resources Conservation Service (NRCS) [7] in the US developed Curve Numbers (CN) far various materials to represent the effects of typical soil conditions and land use factors. For the SCS methodology, the following equation is used to estimate runoff [6]:

$$Q = \frac{\left(P - 0.2\times\left(\frac{100}{CN} - 10\right)\right)^2}{\left(P - 0.8\times\left(\frac{100}{CN} - 10\right)\right)}$$

Where:

Q: Direct Runoff (in)
P: Rainfall (in)
CN: Curve Number

The calculation of the runoff allows the inflow onto the surface of the permeable pavement to be estimated. The total runoff onto the permeable pavement surface is calculated as the sum of the runoff from all adjacent catchment areas. The runoff calculation above is then used to estimate the percentage of water at the surface of the pavement that filters into the granular materials.

Figure 6. Water Running onto a VS 5™ Drain Permeable Pavement

The Curve Number (CN) is typically based on the surface cover and condition of the areas. With some areas allowing water to be easily absorbed while other areas are practically impermeable, the selection of the CN value can greatly affect the surface runoff. A complete list of CN values has been published by the NRCS and a representative sample of values can be seen in Table 4. The soil groupings used within the NRCS system are based on primarily on underlying soil type where soil group A soils are well-drained sandy and gravelly soils, B soils are moderately well-drained with mixed fine and coarse soil particle texture, C soils are moderately fine to fine textured with low infiltration rates, and D soils are clay soils with high runoff potential.

Table 4. Curve Numbers for Example Runoff Areas

Cover type and hydrologic condition	**Average Impervious Area**	**Soil Group**			
		A	**B**	**C**	**D**
Open space (lawns, parks, golf courses, cemeteries, etc)[3]:					
Poor condition (grass cover <50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover >75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc		98	98	98	98

Cover type and hydrologic condition	Average Impervious Area	Soil Group			
		A	B	C	D
Streets and roads:					
Paved: curbs and storm sewers (excluding Right of Way (ROW))		98	98	98	98
Paved: open ditches (including ROW)		83	89	92	93
Gravel (including ROW)		76	85	89	91
Dirt (including ROW)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only)[4]		63	77	85	88
Artificial desert landscaping		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Newly graded areas (pervious areas only, no vegetation)[5]	77	86	91	94	

Surface Runoff Estimation using the Rational Method

The other primary method of identifying the quantity of water runoff is called the Rational Method and it uses standard coefficients based on surface land use to estimate how much water will run along the surface.

$$Q = C \times I \times A$$

Q: Peak discharge, cfs
C: Rational method runoff coefficient
I: Rainfall intensity, inch/hour
A: Drainage area, acre

This method uses a variety of runoff coefficients (C) that will represent the conditions at each location. Some typical values used in design can be seen in Table 5.

Timing of Surface Runoff

In conservative designs, it is common to assume that all water will arrive and need to be stored simultaneously. However, it is possible to better optimize the design by looking at the timing of the water and the storm events. This is possible because there is also a delay associated with how long it will take water from adjacent areas to reach the permeable pavement. This delay is important because in many cases it will cause the peak inflow of water to occur significantly after the peak intensity of the storm. This will allow some water to drain into the subgrade over the storm which would allow for an increase in capacity.

Table 5. Example Rational Runoff Coefficients.

Area Type	Area Description	Runoff Coefficient (c)
Flat roof Slope 3 to 5 %	Metal, glass, fiber reinforced cement Roofing felt Gravel	0.9 – 1.0 0.9 0.7
Green roof Slope 15 to 15%	Humus layer ≤ 10 cm thick Humus layer ≥ 10 cm thick	0.5 0.3
Streets, walkways, plazas (flat)	Asphalt, concrete without joints Paving stones with narrow joints Solid gravel layer Paving stones with open joints Loose gravel layer, gravel with grass Interlocking paving stones with joints Grid pavers (turfstone)	0.9 0.75 0.6 0.5 0.3 0.25 0.15
Slopes, shoulders and ditches with rainwater discharge to drainage system	Clayey soil Loamy sandy soil Gravel and sandy soil	0.5 0.4 0.3
Gardens, pastures and landscapes with rainwater discharge to drainage system	Flat ground Sloped ground	0.05 – 0.1 0.1 – 0.3

By determining the inflow at various times during the storm and accounting for the time for the water to reach the pavement, peak inflow rates can be determined along with an estimate of the amount of water stored in the system at any time point. The time lag is calculated as:

$$T_t = \frac{0.007 \times (n \times L)^{0.8}}{P^{0.5} \times s^{0.4}}$$

Where:

T_t:	Travel time (hours)
n:	Manning's roughness number
L:	Length of travel distance (ft)
P:	Precipitation (in)
s:	Slope of hydraulic grade line (%)

During high intensity rain events, it is also possible that water may runoff the surface of the permeable pavers. Generally, the nature of the paver system surface encourages water to flow along the gaps between the paving stones. This initiates the surface infiltration causing the water to enter in the open graded base layers. The only time where water is likely to runoff the pavement or pool on the surface is when the base is saturated or the infiltration rate has reached its capacity.

Based on the storage capacity of the pavement system, research by Borgwardt [8] in Germany has indicated that there is also a maximum rate of flow of water through the surface joints into the pavement system. Over time, depending on site conditions, the surface joints and granular material can become clogged and reduce this surface inflow by up to 85 percent. The maximum surface inflow rate is used in conjunction with the runoff rate to determine how much water can enter the system. The initial infiltration rate of SF-Rima™ is very high and can be conservatively estimated at 97 mm/hour (3.8 inches/hour) for a 20-25 year initial pavement design life.

Infiltration Capacity of Pavers

The other area of permeability that needs to be considered is the runoff potential of the permeable pavement itself. In most practical situations, water is not expected to runoff the surface of the SF Rima permeable pavement systems. Testing has shown that a long term surface infiltration rate of permeability for SF Rima permeable pavements can exceed 270 L/s/hectare (3.8 in/hour). This rate will accept the total volume for many small storms, however peak storm intensity of low frequency storms should be examined to prevent short term surface pooling.

To ensure that the water can be readily absorbed, the site should be designed to prevent steep slopes. Other factors to consider in maintaining high levels of infiltration are ensuring that the pavement surface is kept clean and clear of debris. It is also important that the subsurface layers be designed with adequate capacity and drainage to prevent them from refusing additional water.

5.3 Storage Capacity of Granular Materials

In larger storm events, the water is expected to arrive faster than it is likely to infiltrate into the subgrade. As a method to control the water during the peak inflow period, it is often temporarily stored in the pore space between the base and subbase aggregates. This water is then drained into the subgrade and groundwater table over time. The storage available, and time that it takes to drain are governed by the porosity and permeability of the layers (Figure 7).

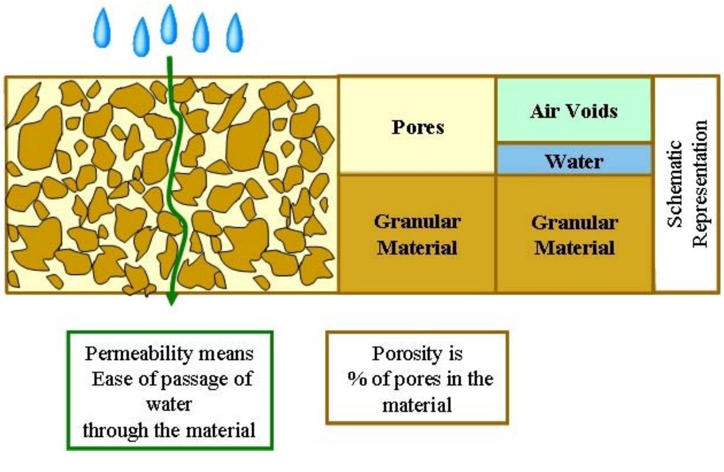


Figure 7. Porosity and Permeability.

The storage capacity of the granular layers is equivalent to the amount of void space in the granular base and subbase. These materials have very little fine material which allows the pore spaces between aggregates to fill easily and completely. The void space for any granular material is defined by the porosity (n).

$$n = 1 - \frac{\gamma_D}{(\gamma_W \times G_S)}$$

Porosity (n): The *n* value is the calculated percentage of the material volume that is comprised of the voids between aggregate particles.

Dry Unit Weight (γ_D): The *Unit Weight* represents the bulk density of the granular material. This value is determined in a laboratory as the mass of the material over the compacted volume (including air voids). Most mineral soils have dry unit weights between 1,000 and 2,000 kg/m^3 (62 and 125 pcf).

Aggregate Specific Gravity (G_S): The G_S value is the density of the aggregate particles relative to the density of water. The particle density is the mass of the particles without considering the volume of the voids between the particles. These values are a unit less ratio.

Unit Weight of Water (γ_W): The *Unit Weight of Water* is a constant value that represents the density of water at standard temperature and pressure. This value is 1,000 kg/m^3 (62.4 pcf).

5.4 Rate of Groundwater Recharge

As water is absorbed into the granular layers, it will begin to infiltrate into the subgrade and back into the groundwater. The rate of groundwater recharge is very important in the design of permeable pavements because a faster recharge will allow rapid drainage allowing the permeable pavement to accommodate larger rain storms. It is also important to ensure that there is adequate time to drain between storm events.

The main factors to consider with groundwater recharge are the depth from the bottom of the pavement granular layers to the water table and the permeability of the subgrade materials. Ideally having a depth of 1.2 m (4 feet) or more of non saturated subgrade will ensure that groundwater table will be able to withstand all inflow from the pavement structure.

The permeability rate of the subgrade materials can greatly affect the design. Higher permeable materials such as sand subgrade will allow water to drain quickly. Finer materials such as silts and clays have much lower permeability and it may take days or even weeks to drain the pavement. Typical subgrade permeability rates are shown in Figure 8.

Based on the subgrade permeability, the quantity of water that can enter the groundwater can be estimated by Darcy's Law [9]. Since the water table is safe distance below the base/subbase layer, the hydraulic gradient can be assumed to be 1.0 as the drop in elevation is the main cause of the flow. It is also assumed that the drainage will be taking place uniformly across the bottom of the pavement as the base/subbase becomes saturated.

$$Q_{Groundwater} = k_{Subgrade} \times \frac{Depth\ of\ Water\ in\ Pavement}{Thickness\ of\ Pavement} \times Subgrade\ Infiltration\ Factor$$

Where:

$Q_{Groundwater}$: Flow rate of water into groundwater recharge (m/day, ft/day)

$k_{Subgrade}$: Hydraulic conductivity of the subgrade material (m/day, ft/day)

Subgrade Infiltration Factor: Expected reduction in subgrade permeability due to clogging

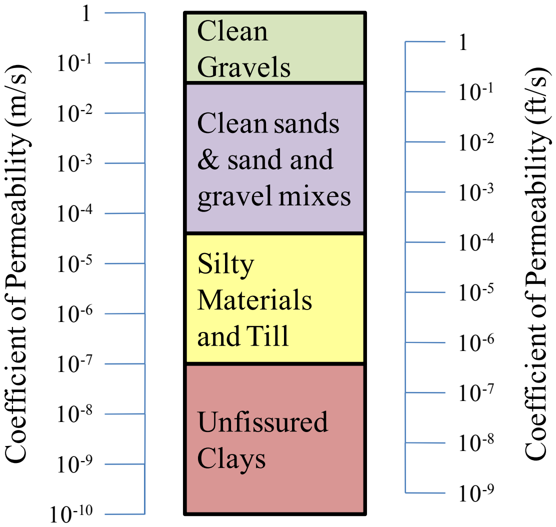


Figure 8. Permeability Rates of Subgrade Materials

The subgrade infiltration reduction factor is used in this calculation to account for less than saturated conditions and potential clogging due to movement of fine particles into the subgrade. The factor is expected to have a typical value of 0.5. This factor effectively reduces the expected subgrade permeability by 50 percent.

The water depth in the pavement is calculated for every time step due to the changing depth of water in the pavement materials. As the depth increases, the static pressure is expected to increase which will directly affect the rate of drainage.

Design of Permeable Pavements on Fine Grained Soils

There are many potential benefits to using permeable pavement systems. When a site is located that has primarily fine grained soils, the low level of permeability often makes ground water recharge more difficult. The lower permeability for silts and clays will mean that other drainage facilities will be necessary to drain the structure. There are still benefits of reducing peak water flows that are provided by permeable pavements.

The timing of water infiltration is often as important as the volume when developing storm water management plans. Most traditional urban developments have a negative impact on flood areas because they allow more water to flow at a much faster pace into streams and rivers. This creates a large peak in the inflow which cannot be adequately drained and can cause flooding. The effect of these improvements over large watersheds can be cumulative and cause significant problems downstream.

Permeable pavement systems, with properly designed subdrains systems, will actually delay the water inflow and slow down the rate the water will reach the surface water outlets. During the peak of the storm, the water will enter the permeable pavement system and percolate into the open graded material. By using the placed granular materials to temporarily store the storm water, the subdrains can be designed to allow a metered outflow that will reduce the risk of flooding. This process is accomplished while still encouraging as much groundwater recharge as the allowed by the natural soils.

5.5 Geotextiles in Permeable Pavement Systems

Geotextiles may be used with permeable pavement systems to prevent movement of fine subgrade materials into the large pores of the base and subbase materials. It is important that the proper geotextile is selected for each project. The apparent opening size (AOS) of the geotextile needs to be small enough to prevent the movement of the subgrade into the subbase while being large enough to allow water to easily drain through the fabric.

The US Federal Highway Administration (FHWA) has recommended criteria for selecting the geotextile [10]:

For fine grained soils (>50% passing the 0.075mm (No. 200) sieve)

Woven Geotextiles: $AOS \leq D_{85}$

Non-Woven Geotextiles: $AOS \leq 1.8 \cdot D_{85}$

For coarse grained soils (<50% passing the 0.075mm (No. 200) sieve)

$AOS \leq B \cdot D_{85}$

Where:

$B = 1$ for $2 \geq C_U \geq 8$
$B = 0.5$ for $2 < C_U < 4$
$B = 1$ for $4 < C_U < 8$
$C_U = D_{60}/D_{10}$

Permeability Criteria: $k_{Fabirc} \geq k_{Soil}$

5.6 Design and Use of Subdrains

In many cases, supplementary drainage such as a subdrain system is not necessary in permeable pavement systems. If the subgrade soil does not drain the system in a reasonable amount of time, subdrains can be used. These drains assist in handling peak water flow which cannot effectively be drained into the subgrade.

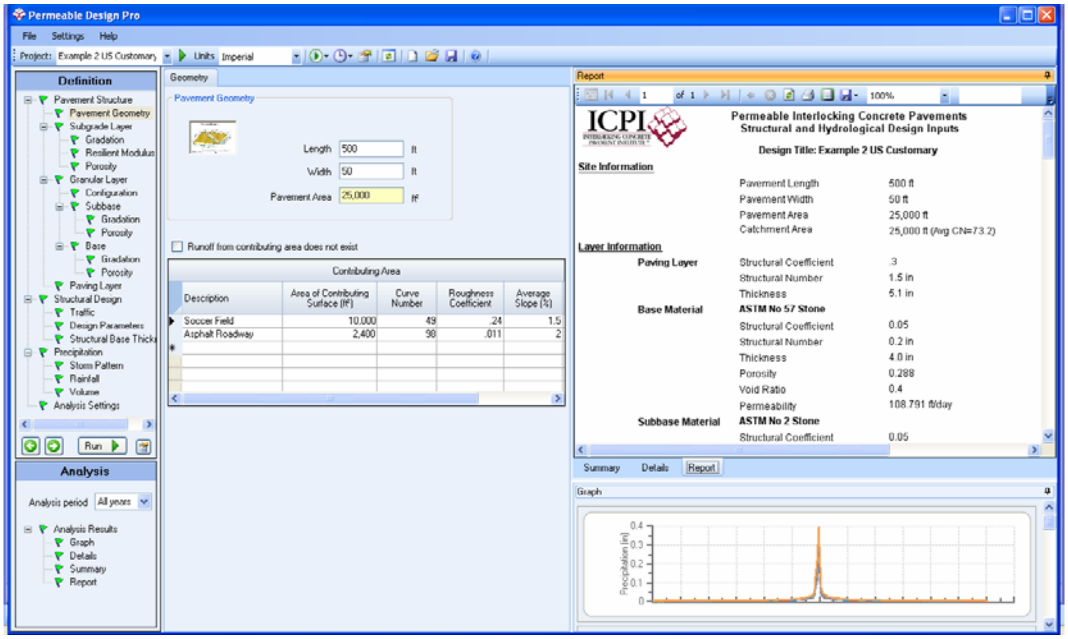
In most traditional pavement systems, subdrains are placed at the bottom of the subbase layer so that all water entering the system can be drained quickly and effectively. However, in permeable pavement systems, the purpose of subdrains is to prevent over-saturation of the pavement during high intensity rain events. To accomplish this, the subdrains are typically placed above the subgrade so that they are only used during storm events when a substantial portion of the base material has become saturated. This will allow the water from the majority of storm events to infiltrate into the subgrade.

Subdrains to be installed are typically 100-150 mm (4-6 in) perforated plastic pipes. They are typically placed in a uniformly graded filter material in order to prevent fines from entering into the subdrain system. It is important that the subdrains are correctly installed and that they do not become clogged over time. In the case of fine graded systems or pavements with geotextiles, these subdrains may be the only significant source of water removal.

Subdrains can be connected to drainage ditches, storm sewers and supplementary storm water features such as local ponds. By adjusting the depth of the subdrains the discharge rates can be controlled to prevent flooding and reduce treatment costs when possible. Subdrains should also be equipped with rodent screens to prevent rodents from building nests and clogging the outlets.

5.7 Design Examples

Example structural and hydrological permeable pavement designs are given in Appendix A. The Interlocking Concrete Pavement Institute has released the Permeable Design Pro software application, Figure 9, to allow users to develop permeable pavement designs in a user friendly format. The design software provides guidance on material selection and includes a database of storm events for most North American cities.



Project: Example 2 US Customary
Units: Imperial

Length 500 ft
Width 50 ft
Pavement Area 25,000 ft^2

☐ Runoff from contributing area does not exist

Contributing Area

Description	Area of Contributing Surface (ft^2)	Curve Number	Roughness Coefficient	Average Slope (%)
Soccer Field	10,000	49	.24	1.5
Asphalt Roadway	2,400	98	.011	2

Analysis period: All years

ICPI INTERLOCKING CONCRETE PAVEMENT INSTITUTE

Permeable Interlocking Concrete Pavements
Structural and Hydrological Design Inputs

Design Title: Example 2 US Customary

Site Information

	Pavement Length	500 ft
	Pavement Width	50 ft
	Pavement Area	25,000 ft
	Catchment Area	25,000 ft (Avg CN=73.2)

Layer Information

Paving Layer	Structural Coefficient	.3
	Structural Number	1.5 in
	Thickness	5.1 in
Base Material	**ASTM No 57 Stone**	
	Structural Coefficient	0.05
	Structural Number	0.2 in
	Thickness	4.0 in
	Porosity	0.288
	Void Ratio	0.4
	Permeability	108.791 ft/day
Subbase Material	**ASTM No 2 Stone**	
	Structural Coefficient	0.05

Figure 9. Permeable Design Pro Software from ICPI.

6.0 OTHER DESIGN CONSIDERATIONS

6.1 Designing Permeable Pavements for Cold Weather Environments

In colder climates, there are some additional factors which often need to be addressed by designers.

Freeze-Thaw Resistance

The water enters the pavement through designed open spaces (joints) between SF-Rima™ paving stones and drains in to underlying open graded layers and will not be retained in pavement's surface structure and thus demonstrates good freeze-thaw resistance.

Water ideally drains to the subgrade layer or to lateral drainage pipes relatively quickly without freezing in place. For slow draining systems, it is important that adequate protection is provided to allow the pavement system to drain before any suspended water is allowed to freeze.

The coldest temperature is near the pavement surface. Freezing gradually progresses into the base layers and subgrade where the frost remains for only a short time. The depth of frost penetration into a pavement and its subgrade depends on temperature, the nature and moisture content of the material. Generally, nominal frost depth is determined on local experiences and is available from local agencies.

Fine grained soil is particularly susceptible to heave upon freezing, because moisture suspended in small pores can migrate toward growing ice crystals. This kind of ice formation does not occur in well-drained, coarse-grained aggregates such as gravel with a void space of about 30 percent. The typical placed material, open-graded crushed stone without fine particles, is non-frost-susceptible.

The natural subgrade soils however may have the potential to cause frost issues if the frost depth is sufficiently deep. As water freezes in isolated grains in fine soils, the system can expand causing localized heave areas. To protect the subgrade from frost completely, a sufficient thickness of non-frost-susceptible base and subbase material should be provided.

Winter Maintenance

In cold weather climates, the temperatures and precipitation can cause a variety of hazards and obstacles for permeable pavement systems. Most of the problems are caused by the frozen precipitation. As snow accumulates, it also can become contaminated with chlorides and road abrasives (sand). When the snow and ice then melt, they can provide a large influx of water into a permeable pavement system over a relatively short time frame. This can cause flooding of the pavement as well as contaminants entering the groundwater through the permeable pavement system.

If salts are used for deicing, then the groundwater should be monitored for chlorides. This can be done through sampling water in observation wells located in the pavement base and soil. Chloride levels in the samples should be compared to local criteria for the particular use of the water in the receiving lake, stream or river.

When the frost depth exceeds 1 m (3 ft), all permeable parking lots should be set back from the subgrade of adjacent roads by at least 6 m (20 ft). This will reduce the potential for frost lenses and heaving of soil under the roadway.

The most ecological alternative to using deicing salts is the use of a gravel material, the same or similar aggregate used in the joints of a SF-Rima pavement. This material can be spread over the pavement surface and will reduce slippery conditions on the concrete paving stones. Winter sand should not be applied to avoid clogging of the pavement joints.

Snow Melt

Snow melt in the spring can provide large quantities of water to a permeable pavement system that may still be frozen. Snow piles and snow melt should not be directed to a permeable concrete pavement if groundwater contamination from chlorides is a concern. However, this may not be avoidable in some situations. If high chloride concentrations in the runoff and groundwater are anticipated, then consideration should be given to using one or two design options:

1. Runoff from snow melt can be diverted from the pavement during the winter. The diversion of runoff away from the pavement is typically through channels or pipes. Pipe valves must be operated each winter and spring. Snowmelt, however, is not treated but diverted elsewhere.

2. Oversized drainage pipes can be used to remove the runoff during snowmelt, and then be closed for the remainder of the year.

6.2 Construction

The proper design of permeable pavements systems will ensure that they have the ability to accommodate the expected storm events and the traffic driving on the surface. However it is important that the system be constructed properly to ensure the expected design life will be reached.

During construction it is important that all layers be placed carefully and compacted to prevent any secondary consolidation due to traffic. This process starts with the excavation, grading, and compaction of the subgrade materials. For permeable pavements, high levels of compaction in the subgrade are not desirable. As compaction and density increase, the permeability of the subgrade decreases.

The use of geotextiles is common in permeable pavement systems. With large size aggregates in placed granular layers and fine materials in the subgrade, the geotextile can prevent the migration of fines materials which may clog the granular layers or subgrade.

Each layer must be placed carefully on top of underlying layers to prevent the mixing of materials and reducing the filling of voids. Care needs to be taken in placement of the layers, specifically for vehicular applications, to prevent tearing or puncture of the fabric by coarse, angular aggregates.

Placement of the open graded aggregate bases also must be completed with strict compaction controls. The base materials are compacted with a minimum 5,000 lbf (22 kN) plate compactor. The compactor force on the pavers pushes the bedding layer into the upper portion of the base materials. Upon completion of the base materials, the bedding material should be levelled. It is important to have this layer placed properly as it will reflect the final grade of the travelled surface upon completion.

The paving stones are placed on top of the compacted bedding material manually or using mechanized devices as shown in Figure 10. At pavement edges, stones should be cut to fill any remainder spaces. Cut stones should be larger than one third of initial stone size on sections expecting vehicular traffic.

Once placement of the paving stones is completed in the area, the surface is swept clean and the system compacted using a plate compactor with a minimum force of 22 kN (5,000 lbs) at 75 to 90 kHz vibration. After initial compaction, the joints or openings are filled with additional bedding material to fill the joints flush with the pavement surface and prevent shifting of the surface.

Figure 10. Mechanical Paver Placement Equipment

7.0 CONCLUSION

SF-Rima™ permeable paver systems are actively being implemented across North America because of their aesthetic beauty, engineered quality, and positive environmental contribution. If properly designed and constructed, these pavements can meet and greatly exceed their expected design lives. The VS 5 Eco and VS 5 Drain products can be effectively used on a large range of projects and should be considered when designing a permeable pavement system.

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APPENDIX A

DESIGN EXAMPLE

Permeable Parking Lot in Chicago, Illinois

The following example outlines the procedure followed to design a permeable pavement system for a parking area pavement in Chicago, Illinois. The parking area, designed primarily for passenger vehicles, is part of commercial plaza. The goals of the design are to provide a pavement structurally capable of accommodating the relatively light traffic and delay the inflow of water into the local storm water system.

The parking area is rectangular in shape and is 100 by 75 m (320 x 240 ft^2) in size. The parking area is not expected to receive additional runoff from any adjacent property and is to be constructed in an area with poorly draining silt subgrade.

Structural Capacity

The structural capacity for a parking area is expected to be minimal. Since primarily cars are expected to be using the parking area, with a chance of some light trucks used for deliveries, a design traffic level of 30,000 ESALs was used. Since it is parking area, a reliability of 75 percent can be used for the design. The resilient modulus for the silt subgrade is assumed to be 20 MPa (2,900 psi).

Using the 1993, AASHTO Guide for Design of Pavement Structures formula, a recommended structural number of 64 mm (2.5 in). The thickness of the subbase is determined to ensure that the required structural number is met. The following design meets the structural requirements:

80 mm	SF Rima Paving Stones
25 mm (1 in)	ASTM No. 8 Bedding Stone
100 mm (4 in)	ASTM No. 57 Open Graded Base
475 mm (19 in)	ASTM No. 2 Open Graded Subbase

Using this cross-section will provide the necessary structural protection of the subgrade materials, but it is necessary to now check if it meets the hydrologic requirements.

Hydrologic Capacity

Since the site is only expected to absorb the water that arrives as precipitation over it's area. In the Chicago, IL area, the rainfall expected for a range of 24 hour storm periods can be seen below:

Storm (years)	Intensity, mm (in)
2	76 (3)
5	99 (3.9)
10	115 (4.5)
25	138 (5.4)
50	156 (6.1)
100	173 (6.8)

In order for the pavement to be designed to with stand a 50 year design storm, it must be capable of storing the 156 mm (6.1 in) that would be expected. For the entire 7,500 m^2 (77,280 ft^2) pavement area, this represents a total of 1,170 m^3 (38,700 ft^3) of water.

Although the pavement cross-section has 575 mm (22.6 in) of open graded base and subbase and the depth of the water is only 156 mm (6.1 in), the amount of water that can be held by the pavement is controlled by the amount of void space within the open graded materials. Assuming typical open graded aggregate materials with a density of 2.65 and a compacted bulk density of 2,100 kg/m^3 (131 lb/ft^3) the void space available would be 20.8 percent.

$$n = 1 - \frac{\gamma_D}{(\gamma_W \cdot G_S)}$$

$$n = 1 - \frac{2{,}100m^3}{(1{,}000m^3 \cdot 2.65)}$$

$$n = 20.8\%$$

This means that for the parking area, there will be the storage capacity equivalent to the volume of the volume of the pores in the open graded base:

Q = Area · Open Graded Thickness · Porosity

Q = 7,500 m^2 · 0.475 m · 20.8%

Q = 897 m^3 (29,670 ft^3)

Since the volume of water expected for a 50-year storm is higher than the capacity of the pavement, the thickness of the subbase should be increased to allow for the additional storage. The required thickness is:

Q = Area · Open Graded Thickness · Porosity

1,170 m^3 = 7,500 m^2 · Open Graded Thickness · 20.8 percent

Open Graded Thickness = 750 mm (29.5 in)

This thickness assumes that all water will arrive at the site and be stored simultaneously. While this is not practical in the field, this allows for a factor of safety to account for factors not considered in the analysis. To accommodate the 50-year design storm, the following final design cross-section would be necessary:

80 mm	SF Rima Paving Stones
25 mm (1in)	ASTM No. 8 Bedding Stone
100 mm (4 in)	ASTM No. 57 Open Graded Base
650 mm (25.5in)	ASTM No. 2 Open Graded Subbase

Due to the fine grained nature of the silt subgrade material, subdrains will be required to drain the pavement in a reasonable time frame. Based on the size of the site, it is recommended that 100 mm (4 in) subdrains be installed at the bottom of the subbase to allow the water to be removed in a controlled fashion. The permeable pavement system will act as a storage and slow release system to eliminate extreme peaks and better manage the stormwater.