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## Section 1. GENERAL INFORMATION

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### Section 1.01 WHAT ARE POROUS PAVERS?

Porous pavers, such as the EGRA™ Stone, are pre-cast unit block pavers that have openings or large crevices (expanded joints). The EGRA™ Stone crevice (or expanded joint) is created through tabs or spacers that are cast onto the concrete unit block paver. The cast on tabs or spacers lock into each other. They allow the EGRA™ Stone to be installed with a stack or running bond. The width of the crevices measures 1<sup>1</sup>/<sub>16</sub>-inches for the EGRA™ Stone. This constitutes a ratio of 18% openings per square foot. The crevices are filled with an open graded permeable material to allow water to infiltrate through the pavement. The gradation and permeability of the material will ultimately determine how much water can be infiltrated through the EGRA™ Stone pavement.



Figure 1 EGRA™ Stone

### Section 1.02 PURPOSE AND CONCEPTS OF POROUS PAVEMENTS

The purpose and concept behind porous unit block pavers, such as the EGRA™ Stone, is to offer a decentralized stormwater management tool. It allows for stormwater infiltration through the pavement wearing course, base, and subbase. This principle results in reduced runoff and subsequently helps to reduce the risk of flooding in downstream areas<sup>1</sup>. It maintains the natural water cycle in that infiltration sustains groundwater levels, recharges our aquifers and supports groundwater driven base flows into our streams and other water bodies. Another benefit is stormwater treatment through infiltration and a reduction in runoff temperatures, both resulting in improved water quality<sup>2</sup>.

### Section 1.03 PRINCIPALS OF FLEXIBLE PAVEMENT DESIGN

Porous paver-surfaced pavements behave as flexible pavements<sup>3</sup>. The surface is composed of tightly placed high-strength concrete pavers. The tight placement in combination with appropriate edge restraint, the laying pattern, and granular fill in the crevices allows the pavers to interact and function as a unified structure rather than individual units. This flexible pavement behavior mandates a flexible pavement design. Components of flexible pavement design are as follows:

Unit block pavers such as the EGRA™ Stone constitute a high strength, long-lived wearing course set into a setting bed. The purpose of the setting bed is to provide an accurate leveling course that allows the paver to be set at the specified elevations. The base and subbase course are the major load-carrying element. They distribute the loads to the level where it can be tolerated by the subgrade without failure. An additional

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function of the subbase in porous pavement systems is to laterally drain the water that is infiltrated through the pavement surface. It should also perform as a capillary barrier. This prevents water from moving upwards into the pavement base. It helps to secure the pavement's structural integrity and prevents ice lenses from forming in the pavement. The subbase may be followed by a layer of improved or stabilized subgrade if the structural properties of the soil prove insufficient (see also Section 3.01 (A)).

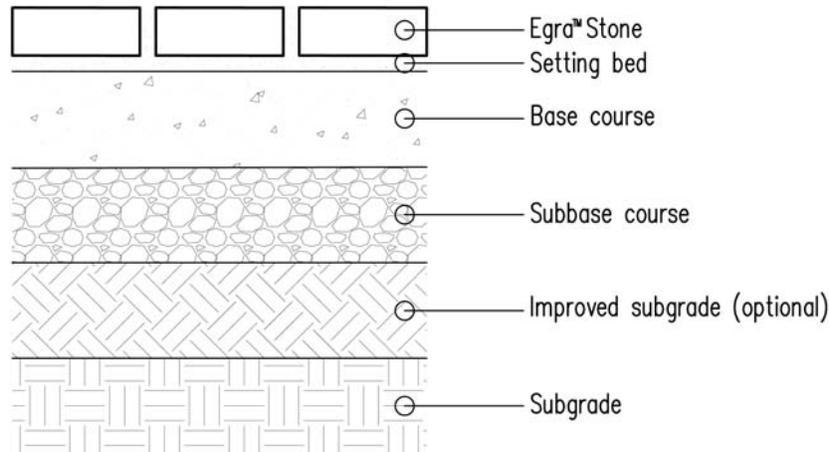


Figure 2 Schematic representation of the different pavement layers and courses

The principle of porous unit pavers, such as the EGRA™ Stone, is to allow stormwater to infiltrate into the base, subbase, and exfiltrate (soak away) into the subgrade. This may appear to be in conflict with 'conventional' pavement design where the intent is to prevent water from entering into the pavement<sup>4</sup>. It is, however, practically impossible to prevent water from eventually entering into the pavement base. This may happen through cracks and fissures in the pavement and lateral subsurface water movement<sup>5</sup>. Design for porous paving has to reconcile structural and drainage objectives. To assure structural integrity of the pavement and prevent frost heave damage, a properly designed subbase with the appropriate drainage characteristics is of critical importance<sup>6</sup>. Good pavement design for porous unit pavers, such as the EGRA™ Stone, results in water infiltration and particle filtration combined with structural strength.

If these basic pavement drainage design principles are followed, the concept of stormwater infiltration through a porous pavement is a compatible objective<sup>7</sup>. The porous pavement design process constitutes evaluation of the inherent subgrade characteristics and use of open-graded aggregates. These should contain no or a limited percentage of fines, and must be specified for crevice fill, setting layer, base, and subbase in porous pavements (see also Section 3.03). The open graded material assures effective infiltration through the pavement surface, adequate drainage of the base, and at the same time attenuation of peak runoff rates and time for infiltration into the subgrade (where appropriate). It also reduces the risk for frost heave damage (see also Section 3.01 (D)).

#### **Section 1.04 BEST MANAGEMENT PRACTICE (BMP) AND APPLICABLE LEGISLATION**

Several federal, state and local laws control stormwater runoff, runoff quality, and amount of impervious surfaces. The National Pollution Discharge Elimination System

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(NPDES) Phase II stormwater regulation calls for states to define and require Best Management Practices (BMP's)<sup>8</sup>.

- Municipalities with separated storm sewer systems (MS4s) and under 100,000 in population are required to develop, implement, and enforce BMP stormwater control programs for new and redevelopment projects.
- National rules require municipalities to have stormwater control plans that apply to developments larger than one acre.
- As a result, some municipalities have restrictions on the amount of impervious cover.
- Furthermore, many local stormwater codes require BMP's that improve stormwater quality through reduction of total suspended solids.

Porous pavers, such as the EGRA™ Stone, can help to meet these mandated requirements. The EGRA™ Stone should be built over an open-graded base that offers infiltration, retention and partial stormwater treatment. This allows the EGRA™ Stone to be treated as a structural BMP, as mandated by the Environmental Protection Agency (EPA) and many regional and local governments.

### Section 1.05 DOES THE EGRA™ STONE FULFILL POROUS PAVER REQUIREMENTS?

The EGRA™ Stone crevices measure 1<sup>1</sup>/<sub>16</sub>-inches and constitute 18% openings per square foot. The openings filled with a 1/4- to 3/8-inch open graded, freely draining aggregate will allow for an infiltration capacity of up to 8<sup>1</sup>/<sub>2</sub>-inches per hour after installation<sup>9</sup>. This infiltration rate will decrease over a period of several years and should level out to between 1- and 5-inches per hour<sup>10</sup> provided the paving is protected from construction site runoff and other sedimentations. With this capacity, 70-80% or more of the storms in North America can be absorbed by a porous paver installation<sup>11</sup> such as the EGRA™ Stone.

The spacers cast into the EGRA™ Stone cause interlocking, improving structural properties relative to non-interlocking pavers. The size and placement of the cast spacers allow the EGRA™ Stone to be installed in a stack bond or the more structurally sound running bond. These structural provisions allow it to function as a flexible pavement.

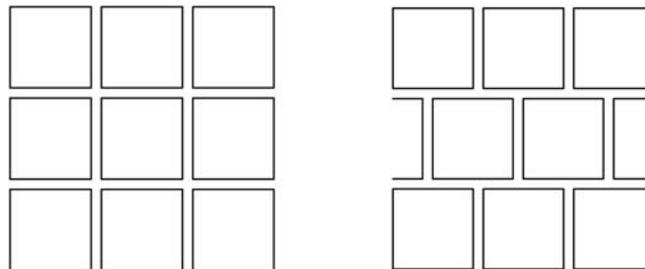


Figure 3 Stack bond (left) and running bond (right)

The EGRA™ Stone complies with the ASTM C936. It exceeds the requirements of a maximum 5% water absorption and minimum 8,000 psi compressive strength. The EGRA™ Stone is ICPI (Interlocking Concrete Pavement Institute) certified and complies with CSA (Canadian Standards Association), which mandates a maximum loss of 200g/meter square during 25 freeze and thaw cycles. These values are typically all greater than that of cast-in-place concrete and asphaltic concrete. The EGRA™ Stone has a higher abrasive resistance and superior longevity.

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## **Section 2. APPLICATION OF POROUS PAVERS**

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### **Section 2.01 WHEN AND WHERE TO USE POROUS PAVERS**

The EGRATM Stone serves as an important and cost effective structural BMP tool and valuable alternative to conventional pavements. The EGRATM Stone is a particularly important stormwater management tool on projects that are subject to any of the following considerations:

#### Regulatory Considerations

- National Pollution Discharge Elimination System (NPDES) construction site permits are required for all construction activities greater than 1 acre within municipalities with separated storm sewer systems (MS4s). Under these permits both construction site runoff and post-construction runoff (stormwater) must be addressed. Detention and infiltration practices are both accepted methods of controlling stormwater runoff. Porous pavement systems can provide both detention and infiltration, depending on the design.
- Municipalities within census designated urban areas are covered under NPDES Phase II. Under Phase II, municipalities are required to develop and implement a stormwater control plan. Porous pavement is ideal for small urban sites where other BMPs such as stormwater detention ponds are not feasible due to space constraints.
- Many municipalities and/or counties have stormwater regulations that limit the rate of stormwater discharge from new development and redevelopment. Some also regulate the volume of runoff. Many have standards for water quality as well, including capture of a percentage of the total suspended solids generated by the site.

#### Ecological Considerations

- Thermal impacts (high temperature) of runoff can be reduced due to increased groundwater recharge and reduced surface detention subject to solar radiation (heat accumulation).
- Increased groundwater recharge reduces surface runoff volumes responsible for increased flooding, stream bank erosion, and transmission of urban stormwater pollutants that collect on impervious surfaces.
- LEED rating (Leadership in Energy & Environmental Design) and other sustainable design strategy are part of the project/client's objectives.

#### Physical Factors

- Porous pavement systems are ideal for small sites where surface detention is not feasible due to space constraints.
- Porous pavement systems may be used on sites where no or limited discharge systems or areas to connect to are available.
- Porous pavement and other infiltration systems may be used where municipalities are seeking to limit or reduce discharge to combined sewer systems or storm sewer systems with little remaining capacity.
- On sites where property values are high, porous pavement allows paved areas to double as stormwater management.

The EGRATM Stone can be used for its environmental and stormwater benefits or for its aesthetic properties in many different residential, commercial, institutional and recreational applications:

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- Paths, sidewalks, and walkways.
- Patios, terraces and plazas.
- Driveways.
- Parking lots.
- Main and service drives.
- Emergency access areas.
- Small subdivision roads and alleyways.
- Non-commercial boat ramps and landings.

Use of porous pavers such as the EGRA™ Stone is NOT recommended in areas with land uses such as:

- Gas stations, recycling facilities, salvaging yards, vehicle storage, service and cleaning facilities and other uses with risk of contamination through industrial/commercial activities.
- Parking with risk of industrial/hazardous material contamination.
- Commercial marina services with risk of industrial/hazardous contamination.
- Outdoor loading facilities with risk of industrial/hazardous contamination.
- Any roadways that exceed the Average Daily Traffic (ADT) of 2000 and the speed limit of 30 miles/hour (i.e. Collector roads, Arterial roads, Freeways).
- Well fields (see also Section 3.01(C)).
- Land uses within the recharge zone of sensitive wetlands, such as fens and other areas where the impact of potential increased volumes of groundwater recharge is not analyzed.
- Locations where construction site runoff that could clog the system and other risks of sedimentation cannot be controlled.
- Land uses that drain contaminated runoff (e.g. pesticides, fertilizers, sediments) into the pavement.

## **Section 2.02 WHAT ARE THE BENEFITS OF THE EGRA™ STONE?**

### **(A) Stormwater runoff reduction (flow attenuation)**

The EGRA™ Stone has the pavement openings filled with a 1/4- to 3/8-inch open graded and freely draining aggregate. It will allow for 1- to 5-inches per hour of infiltration, even years after installation<sup>12</sup>. With this infiltration capacity, 70-80% or more of the storms in North America can be infiltrated through the surface of a porous paver installation without generating any surface runoff<sup>13</sup> (see also Section 1.05).

The infiltrated stormwater is stored in the subbase of the pavement and exfiltrated into the subgrade. This effect leads to a substantial reduction in the volume of runoff on moderate to high permeability soils. In other words, the amount of rainwater that drains from a porous pavement is reduced when the pavement is built over moderate to freely draining soils. Modeling performed by Conservation Design Forum has shown that even with a compacted subgrade infiltration capacity as low as 0.1-inch/hour, annual surface runoff volumes can be reduced by 60% or more. This is consistent with modeling by the Northeastern Illinois Planning Commission that showed a 50% reduction in annual surface runoff volumes with as little as 0.5-inch of infiltration storage<sup>14</sup>. In essence, small amounts of stormwater storage can achieve significant runoff reductions.

If the pavement is built on soils with limited infiltration capacities, excess water that cannot be exfiltrated into the subgrade is slowly released through the pavement's drainage system, which reduces the peak discharge rate and the need for detention. Based on the drainage characteristics of the aggregate recommended for the porous

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pavement base and subbase (see also Section 3.03), the time of concentration for a typical small parking lot can be increased from minutes to hours. In other words, infiltrated runoff into the pavement is retained in the structure and released very slowly over a given period of time.

### **(B) Aquifer recharge**

Conventional (impervious) pavements drain and surface discharge almost all stormwater they receive. This process disrupts the natural water cycle in that a large percentage of precipitation is prevented from infiltrating into the ground. Porous pavements, on the other hand, detain stormwater and allow it to slowly exfiltrate it into the subgrade. This mechanism mimics the natural water cycle and allows for aquifer recharge. Water that is slowly recharging aquifers sustains base flows for streams, wetlands, and rivers. The constant flow of water they receive sustains water levels and contributes to the health of the aquatic environment and natural resources. Depending on the nature of the subgrade soils, groundwater recharge may actually be increased relative to existing conditions by porous pavement systems. This is caused by the reduction in evaporation (transpiration) of soil moisture due to the elimination of vegetation.

### **(C) Stormwater runoff pollution control**

Paved surfaces, particularly those subject to vehicular traffic, accumulate pollutants that are washed off by stormwater runoff and cause water quality problems in receiving water bodies. The highest concentration of pollutants in stormwater runoff is found in the first flush – the first generated runoff in a storm event. Another water quality problem is the generally high runoff temperatures caused by heated up pavement. The concentration of pollutants in the first flush combined with the high runoff temperatures impose significant stress on downstream ecosystems that are exposed to these conditions.

These pollution effects can be reduced by porous pavements. As stated earlier, 70-80% or more of storms in North America can be entirely absorbed by a porous paver installation<sup>15</sup> such as the EGRA™ Stone. Generally, the entire first flush infiltrates and filters through the crushed stone base and reduces pollutants like suspended solids (SS), nutrients, and metals<sup>16</sup>. It further provides for the biological decomposition of hydrocarbon contaminants<sup>17</sup>. In many instances, a primary concern is groundwater contamination.

A study in Tokyo with an Experimental Sewer System (ESS) utilized porous pavement, infiltration trenches, and dry wells<sup>18</sup>. This system has reduced surface runoff volumes by 50% in a 3300 acre portion of the city that is built upon very permeable soils. Despite the very porous soils, ten years of monitoring has identified no groundwater contamination problems.

Several unpublished studies have been performed by graduate students at the University of Guelph<sup>19</sup> and Coventry University<sup>20</sup>. These studies indicate that impacts from thermal pollution and petroleum-based hydrocarbons can be significantly reduced, even for non-infiltration porous pavement installations (installations on non-permeable soils). Thermal pollution is reduced due to the lower temperatures of the pavement base relative to the pavement surface. The large thermal mass steadily reduces the runoff temperature to healthier levels throughout the infiltration and discharge process. Petroleum based hydrocarbons have been found to be removed by microbes living on the aggregate substrate in a manner similar to bio-remediation.

For metals and nutrients, the surface runoff load can be significantly reduced due to the reduction in surface runoff for porous pavement systems. When drainage from the base and subbase are considered, one study indicated that little attenuation of pollutants occurs through the base. However, to the degree that the subgrade soils include at least a modest level of clay soils, it is likely that most metals will be adsorbed<sup>21</sup>. An exception is soluble chlorides that are likely to continue to the groundwater, and eventually to the local stream, lake, or wetland. Because chlorides are not removed using any conventional stormwater BMP's, the levels of these pollutants reaching local waterbodies will be similar for all stormwater management systems.

Even modest amounts of infiltration can capture a significant portion of the pollutant load. Modeling performed by the Northeastern Illinois Planning Commission showed that by infiltrating as little as 0.5-inches of runoff, total suspended solids loads can be reduced by 80% and total phosphorous load can be reduced by nearly 60%<sup>22</sup>.

#### **(D) Effective snow melt and reduced surface ice formation**

Experiences with porous unit block pavers such as the EGRA™ Stone suggest that snow and ice melt faster on these surfaces. Thawing of porous pavement occurs more rapidly than in impervious pavement due to the air in the pavement that releases heat to the surface<sup>23</sup>. Another added benefit is that functioning porous unit block surfaces are rarely subject to ice or black ice formation. Depressions in conventional pavements accumulate snow melt water that may freeze when temperatures drop below freezing. Porous pavements, on the other hand, effectively drain all snow melt water into the pavement and reduce the risk of ice formation (see also Section 3.01(D)).

#### **(E) Cost savings**

Installation costs (or first costs) for porous unit pavers are often higher than asphalt and concrete pavements. This simplified comparison, however, is misleading in that it does not account for factors such as maintenance or rehabilitation<sup>24</sup>. Extensive maintenance cost studies show that unit pavers have maintenance costs that are 30% or less of asphalt surfaces.

Life-cycle cost analysis of large scale interlocking paver installations at Main Street, North Bay, Ontario, Canada and container terminals in the Port of New Orleans show that interlocking pavements are more cost effective than Portland cement concrete pavements and asphaltic concrete. The study was based on a 40-year life cycle and included aspects such as maintenance, rehabilitation, inflation and interests. The latter two are converted into a 'discount rate'. The total life cycle cost per square foot for the interlocking paver installation at a discount rate of 4% was \$2.95 at North Bay and \$4.31 at New Orleans at the time of the study (03/08/2000). This compares to total life cycle cost for asphalt at North Bay of \$3.15 and \$5.04 for concrete pavement at New Orleans<sup>25</sup>.

Another cost saving aspect is the typically superior pavement structure of porous unit block pavers, due to the pavement depth, quality of materials, and drainage provisions. This increase in first costs translates into greater longevity of the pavement. Some transportation departments allow for an average life cycle of 20 years for asphalt and concrete pavements. A properly installed porous pavement installation outlives most asphalt and concrete pavements. A typical applied life cycle for interlocking pavers is 40 years<sup>26</sup>. This number is based on experiences with installations that date back to the 1960s.

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In some instances, the installation of porous unit block pavers is more economic than an impervious (asphalt or concrete) pavement. For example, some projects may have limited space on site for detention. On other projects, high land prices make conventional detention facilities very expensive. A porous pavement installation allows for dual land-use, parking and retention, and provides a cost effective stormwater treatment and pavement surface (see also Section 2.01). It may also save costs due to a reduction in conventional stormwater infrastructure.

**(F) Architectural, aesthetic and greening effects**

The EGRA™ Stone has numerous valuable architectural and aesthetic properties besides the above-listed engineering and environmental benefits. Its square shape and distinct linear crevices combined with the running and stack bond laying pattern provide a simple, but strong geometric pattern at the ground plain – an architectural look that is required and desired by many clients. The dimensions of the EGRA™ Stone allow it to be easily combined with the Double Holland and Holland Stone.

Some designers and clients wish to reduce the visual impact of a paved surface through vegetation. This objective has been achieved through vegetation of the EGRA™ Stone crevices with grass. The crevices can be filled with a free draining growing medium and seeded with drought and mowing tolerant vegetation. It is important to note, however, that this greening method significantly reduces the infiltration capacity of the pavement.

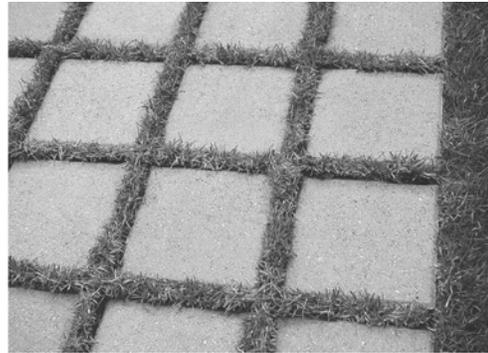


Figure 4 Egra™ Stone with vegetated crevices

### Section 3. INSTALLATION DATA

Porous pavement design considerations include soil/subgrade properties, base and subbase design, traffic type and loading, appropriate aggregate material selection, and provisions for excess water collection and disposal. Table 1 provides characteristics typical of various soils that may be encountered at the subgrade depth.

USCS Soil Classification	Typ. CBR range	Compressibility	Shear strength when compacted	Typ. permeability in inches/hour	Relative permeability when compacted and saturated
GW - Well graded gravels	30-80	Negligible	Excellent	1.3 to 137	Pervious
GP - Poorly graded gravels	20-60	Negligible	Good	6.8 to 137	Very pervious
GM - Silty gravels	20-60	Negligible	Good	1.3x10 <sup>-4</sup> to 13.5	Semi-pervious to impervious
GC - Clayey gravels	20-40	Very low	Good to fair	1.3x10 <sup>-4</sup> to 1.3x10 <sup>-2</sup>	Impervious
SW - Well graded sands	10-40	Negligible	Excellent	0.7 to 68	Pervious
SP - Poorly graded sands	10-40	Very low	Good	0.07 to 0.7	Pervious to semi-pervious
SM - Silty sands	10-40	Low	Good	1.3x10 <sup>-4</sup> to 0.7	Impervious
SC - Clayey sands	5-20	Low	Good to fair	1.3x10 <sup>-5</sup> to 0.7	Impervious
ML - Inorganic silts of low plasticity	2-15	Medium	Fair	1.3x10 <sup>-5</sup> to 0.07	Impervious
CL - Inorganic clays of low plasticity	2-5	Medium	Fair	1.3x10 <sup>-5</sup> to 1.3x10 <sup>-3</sup>	Impervious
OL - Organic silts of high plasticity	2-5	Medium	Poor	1.3x10 <sup>-5</sup> to 1.3x10 <sup>-2</sup>	Impervious
MH - Inorganic silts of high plasticity	2-10	High	Fair to poor	1.3x10 <sup>-6</sup> to 1.3x10 <sup>-5</sup>	Very impervious
CH - Inorganic clays of high plasticity	2-5	High	Poor	1.3x10 <sup>-7</sup> to 1.3x10 <sup>-5</sup>	Very impervious
OH - Organic clays of high plasticity	Not appropriate under porous block pavements				
PT - Peat, mulch, soils with high organic content	Not appropriate under porous block pavements				

Table 1 Suitability of USCS classified soils for bearing capacity and infiltration of stormwater<sup>27</sup>. Use this table for general guidance only. Soil testing and evaluation is recommended.

The indicated permeability rates in Table 1 may, in many instances, appear low compared to values that are likely to be found in local County Soil Surveys. It is recommended to perform a percolation test on site to establish the site-specific

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permeability rate. Instructions on how to conduct a permeability test are included in Section 6 Appendix A.

### **Section 3.01 SOILS AND WATER**

Critical factors in the porous pavement design process are the inherent soil characteristics. The existing subgrade has to be analyzed for:

- its load bearing strength under wet conditions (see also Table 1),
- its infiltration capacity (see also Table 1 and Table 2),
- seasonal high groundwater table elevation, and
- depth of frost penetration.

These factors will ultimately influence the pavement design.

#### **(A) Load bearing strength**

The subgrade strength is a dominant factor in flexible pavement design<sup>28</sup>. Soil, or subgrade strength, is sometimes expressed by the Modulus of Elasticity (E), but more typically by the California Bearing Ratio (CBR) and defined in the ASTM D 1883 specification. The CBR of soils, particularly those that are finer graded, varies with moisture content. This is important in porous pavement design, where the subgrade is expected to be wet. Soils with permeability lower than 0.77-inch/hour can be used for exfiltration as long as the subgrade remains stable while saturated. The saturated subgrade CBR in porous pavement must be at least 5% after a minimum of 96-hours of soaking if used for vehicular traffic<sup>29</sup>. Other empirical design specifications require for vehicular traffic a 6,550 psi Modulus of Elasticity in porous pavement design<sup>30</sup>, which translates into 4.3% CBR for relatively soft, fine grained soils<sup>31</sup>.

Most subgrades will require some compaction or other stabilization treatment to assure sufficient load bearing capacity. This may greatly reduce or eliminate the infiltration capacity on finer graded soils. In some instances, the use of a geotextile can help to balance structural with infiltration objectives. The use of a Woven-Monofilament geotextile will spread loads over a wider area and allows for bridging of weak spots in the subgrade. An increase in depth of the base or subbase is an alternative to the use of a geotextile. The increased depth of base or subbase also spreads the load over a larger area. By using these methods, the need for compaction on finer graded soils can be reduced or eliminated to preserve infiltration rates. It is recommended to consult a geotechnical engineer to evaluate soils for their CBR and suitability under porous pavements.

#### **(B) Infiltration capacity**

The infiltration capacity will determine the volume of runoff that can be exfiltrated from the pavement into the ground over a given time (typically measured in inch/hour). This factor influences the site drainage design and will determine the potential amount of runoff reduction. The infiltration capacity also determines the level of drainage required in the pavement base and subbase. A freely draining soil may be able to exfiltrate almost all the stormwater within a few hours.

As outlined above, poorly drained soils often have a reduced load bearing strength under wet conditions; thus, it is necessary to keep them free of excess water. They may only infiltrate small storm events and require drainage at the pavement edge to maintain structural integrity (see also Section 3.04(B) and Figure 5 and Figure 6). Soils on bed rock with very high infiltration rates may be unsuitable for porous pavement installations.

Infiltration under such conditions may lead to sink holes and potential groundwater contamination.

The National Resource Conservation Service (NRCS) divides soils into four hydrologic soil groups (HSG) with different infiltration rates (see Table 2). The soils in group A generally have very good infiltration characteristics and are suitable for porous pavement installations. Soils in categories B and C have lower infiltration capacity. Porous pavements on these soils can often infiltrate a significant proportion of the annual runoff volume but may require some degree of subsurface drainage to insure the structural integrity of the pavement. Excess water in the base and subbase should be collected and discharged in a controlled manner. Soils in category D have very low infiltration capacity and are only suitable for porous pavement when adequate drainage of the subgrade is provided. Although porous pavement on D soils detains runoff, reducing peak flows<sup>32</sup>, it is unlikely to provide significant runoff volume reduction benefits.

Highly expansive clay soils are unsuitable for porous pavement installation, except where their volume stability can be insured<sup>33</sup>. An appropriate drainage system is necessary to collect and dispose of excess stormwater in a controlled manner. It is recommended that field tests be conducted to verify the specific infiltration characteristics of the subgrade (see also Section 6 Appendix A).

HSG Group	Soil Description	Transmission
A	Sandy, loamy sand, or sandy loam	>0.3-inch/hour
B	Silt loam or loam	0.15- to 0.3-inch/hour
C	Sandy clay loam	0.05- to 0.15-inch/hour
D	Clay loam, silty clay loam, sandy clay, silt clay, or clay	0- to 0.05-inch/hour

Table 2 – Hydrologic Soil Groups (HGS) by the National Resource Conservation Service (NRCS). This table provides general guidance only. Testing and evaluation of soils are recommended.

### (C) Ground water table elevation / minimum filter strata depth

Part of the porous paver design process is identification of the seasonal high ground water table. On installations where the main objective is to exfiltrate stormwater into the ground, the bottom of the pavement must be a minimum of two-feet<sup>34</sup>, but more typically three-feet<sup>35</sup> above the seasonal high groundwater table. Some States have issued guidance to the minimum separation distance required, which may be as much as 10-feet<sup>36</sup>. This distance provides a filter to remove pollutants from the runoff and to prevent ground water contamination.

Staying a minimum required distance above the seasonal high ground water table also has a structural rationale. It prevents groundwater from entering into the pavement and allows for efficient subsurface drainage and exfiltration during storm events. Controlling the moisture content of the subgrade allows for improved load bearing capacity and reduces the potential for frost heave.

Porous pavement systems should not be used in the immediate proximity of a well or a well field. Depending on state regulation, the minimum required buffer between any porous pavement and water supply wells is 100-feet up to 500-feet<sup>37</sup>. The State of Illinois, for instance, requires a minimum setback of 200-feet for potential primary or potential

secondary sources of contamination to any existing or permitted community water supply wells<sup>38</sup>.

#### **(D) Freezing considerations and frost depth**

Porous unit block pavers are a suitable pavement surface in areas that are subject to severe frost and frequent freeze-thaw cycles. Like any pavement, its success relies on proper pavement design, including adequate drainage provisions.

Research on porous pavement in cold climates shows that porous pavement is more resistant to freezing, frost penetration, and frost action than impervious pavement<sup>39</sup>. The increased resistance to freezing is attributed to higher water content in the underlying soil, which increases the latent ground heat<sup>40</sup>. In other words, water in the subgrade increases the thermal mass and delays the freezing process. Another contributing factor to the delay of subgrade freezing is the insulating affect of air in the porous pavement<sup>41</sup>.

The depth of frost penetration is an important factor in porous pavement design on soils with high silt content. Design frost depth is typically specified by local code. Silty soils should adequately drain before frost penetrates through the pavement to their depth. This is to minimize the potential for frost heave. Frost heave in porous pavement is, however, not necessarily a failure-causing factor. Research shows that porous pavement is less susceptible to irregular frost heave than impervious pavement<sup>42</sup>. Measured frost heave in two similarly designed sections was  $\frac{3}{8}$ -to  $\frac{3}{4}$ -inch in porous versus  $2\frac{3}{4}$ - to  $3\frac{1}{8}$ -inches in the impervious pavement. These findings show that porous pavement reduces the risk of frost damage. The unit block pavement is able to withstand modest amounts of frost heave without damage because of its flexible nature.

Research further shows that subgrade soils thaw faster in porous pavements than impervious pavements<sup>43</sup>, reinstating the soils infiltration capacity. Thawing of porous pavement itself also occurs more rapidly than in impervious pavement. The cause was found in the air in the pavement that released heat to the surface<sup>44</sup>.

### **Section 3.02 PAVEMENT DESIGN**

#### **(A) Edge restraints**

A rigid, stationary edge restraint is of critical importance to a porous block pavement installation due to the modular nature of the block system. The edge restraint prevents lateral creep, holds the pavers tightly together and provides load transfer between blocks. Modular pavements without an edge restraint will move laterally, fail along the edges and cease to provide load transfer between blocks, which compromises the structural integrity of the pavement.

Methods of edge restraint include abutting existing structures, cast in place concrete curbs or slabs, pre-cast concrete curbs, or soldier courses set into concrete with aesthetically matching pavers to the EGRA™ Stone such as the Double Holland or Holland Stones. The more structurally sound the edge (i.e. concrete products), the less the opportunity for pavement failure at the edges. No matter what edge restraint is used, it must remain stationary under stress or it is of no value to the porous block pavement.

## **(B) Laying pattern**

The EGRA™ Stone can be installed in two different laying patterns: running bond and stack bond. The running bond is structurally superior to the stack bond and is recommended for installations subject to vehicular traffic flow (parking lot aisles etc.). The stack bond laying pattern is appropriate for pedestrian applications and areas with low vehicular traffic flow, such as parking bays. An added advantage of the stack bond laying pattern is that it can be installed mechanically.

## **(C) Traffic categories**

General roadway classification as defined in the AASHTO 'A Policy on Geometric Design of Highways and Streets; also know as the "Green Book", distinguishes between:

- Local roads
- Collector roads
- Arterial roads
- Freeways

For the purpose of these guidelines, categories are created that reflect additional uses and traffic types at lower traffic volumes, loads and repetitions than those of 'local roads', including:

- Paths + patios (pedestrian and bicycle applications)
- Driveways + small parking (personal automobiles)
- Large parking (personal automobiles and some truck and bus traffic)
- Local roads

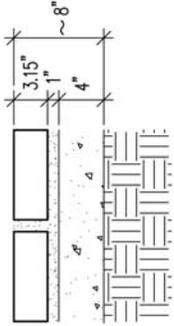
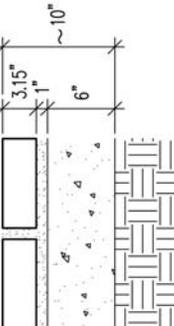
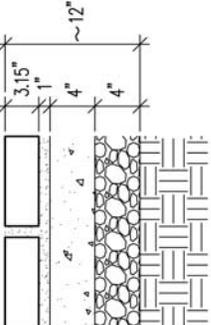
As described in Section 2.01, porous pavement applications are suitable for traffic volumes up to those defined in the 'local road' category (ADT 2000 or less) and where the posted speed limit does not exceed 30 miles/hour. Typical examples for the 'local road' category are alleyways and small subdivision roads. The foremost rationale behind the 'local road' restriction is concerns over stormwater runoff quality and pollution. It also attempts to reduce the most common cause of pavement failure - heavy and repetitive loads. The occasional school bus, garbage truck, or fire engine represents an acceptable load at acceptable repetitions. Higher and more repetitive loads will require consultation of a qualified civil engineer.

## **(D) Typical cross sections**

Table 3, Table 4, Table 5, and Table 6 show recommended cross section designs for different porous paver applications, such as the EGRA™ Stone. Porous pavement installations on subgrades with an infiltration capacity less than 0.1-inch/hour should be designed and evaluated by a qualified civil engineer.

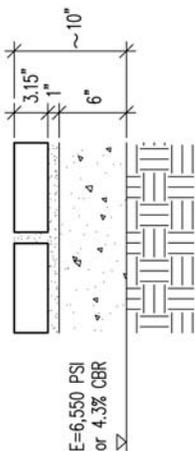
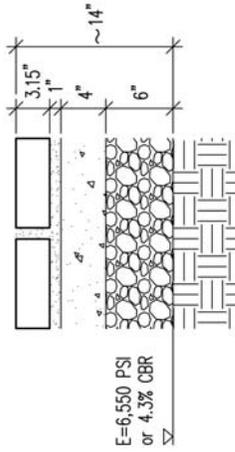
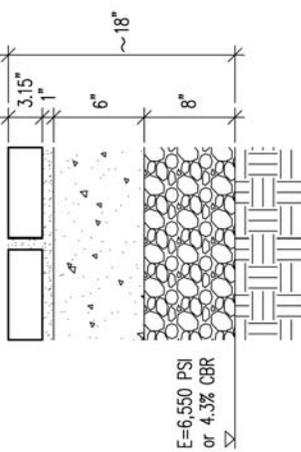
The indicated depths of the subbase in Table 3, Table 4, Table 5, and Table 6 may be increased if additional storage and detention of runoff is required. The indicated infiltration rates must be based on the subgrade at the depth of the subbase-subgrade interface after compaction or soil treatment. It is highly recommended that a qualified civil engineer with porous paving experience be consulted if conditions vary from those represented below.

(i) Paths and patios

Table 3 Cross section design for <b>PATHS</b> and <b>PATIOS</b> (pedestrian and bicycle applications)		Subgrade infiltration rate (after compaction or soil treatment)	Subgrade infiltration rate (after compaction or soil treatment)	Subgrade infiltration rate (after compaction or soil treatment)	Subgrade infiltration rate (after compaction or soil treatment)
		<b>&gt;7.65-inches/hour</b>	<b>from 7.65- to 0.77- inches/hour</b>	<b>from 0.77- to 0.1-inches/hour</b>	
Block		3.15-inches	3.15-inches	3.15-inches	
Setting		1-inch	1-inch	1-inch	
Base		4-inches	6-inches	4-inches	
Subbase		n/a	n/a	4-inches	
Total		~ 8-inches	~ 10-inches	~ 12-inches	
					
Drainage		No drainage required	No drainage required	Allow for pavement base to drain within 24-hours , may require drainage at pavement edge (see Figure 5 and Figure 6)	

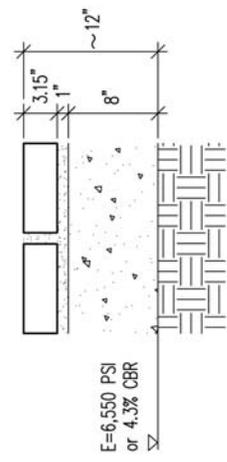
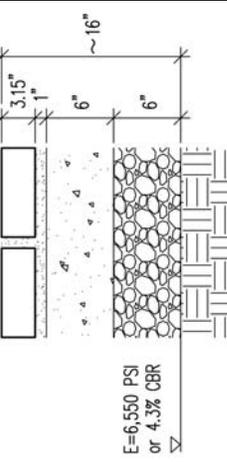
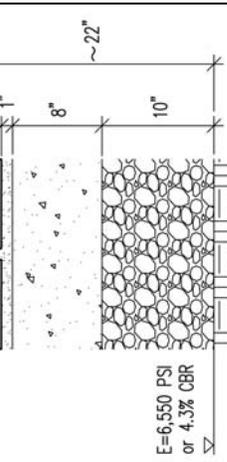
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(ii) Driveways and small parking

Table 4 Cross section design for <b>DRIVEWAYS</b> and <b>SMALL PARKING</b> (personal automobiles)			
	Subgrade infiltration rate (after compaction or soil treatment) <b>&gt;7.65-inches/hour</b>	Subgrade infiltration rate (after compaction or soil treatment) <b>from 7.65- to 0.77- inches/hour</b>	Subgrade infiltration rate (after compaction or soil treatment) <b>from 0.77- to 0.1-inches/hour</b>
Block	3.15-inches	3.15-inches	3.15-inches
Setting	1-inch	1-inch	1-inch
Base	6-inches	4-inches	6-inches
Subbase	n/a	6-inches	8-inches
Total	~ 10-inches	~ 14-inches	~ 18-inches
			
Drainage	No drainage required	Allow for pavement base to drain within 24-hours , may require drainage at pavement edge (see Figure 5 and Figure 6)	Allow for pavement base to drain within 24-hours , may require drainage at pavement edge (see Figure 5 and Figure 6)
CBR = California Bearing Ration in % (soaked) E = Modulus of Elasticity (in psi) on soaked subgrade for relatively soft, fine grained soils			

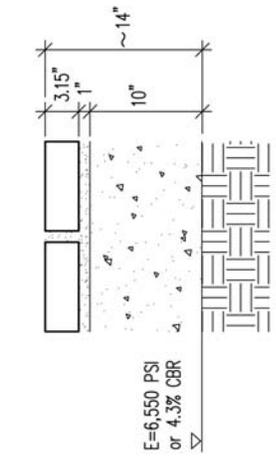
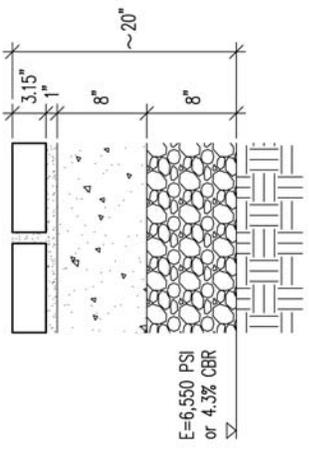
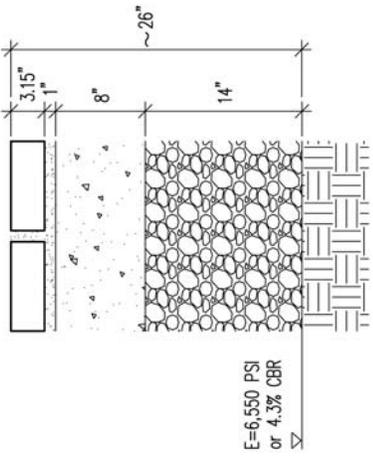
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(iii) Large parking

Table 5 Cross section design for <b>LARGE PARKING</b> (personal automobiles and some truck and bus traffic)			
	Subgrade infiltration rate (after compaction or soil treatment) <b>&gt;7.65-inches/hour</b>	Subgrade infiltration rate (after compaction or soil treatment) <b>from 7.65-to 0.77- inches/hour</b>	Subgrade infiltration rate (after compaction or soil treatment) <b>from 0.77- to 0.1-inches/hour</b>
Block	3.15-inches	3.15-inches	3.15-inches
Setting	1-inch	1-inch	1-inch
Base	8-inches	6-inches	8-inches
Subbase	n/a	6-inches	10-inches
Total	~ 12-inches	~ 16-inches	~ 22-inches
			
Drainage	No drainage required	Allow for pavement base to drain within 24-hours, include drainage at pavement edge (see Figure 5 and Figure 6)	Allow for pavement base to drain within 24-hours, include drainage at pavement edge (see Figure 5 and Figure 6)
CBR = California Bearing Ratio in % (soaked) E = Modulus of Elasticity (in psi) on soaked subgrade for relatively soft, fine grained soils			

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(iv) Local Roads

Table 6 Cross section design for LOCAL ROADS		Subgrade infiltration rate (after compaction or soil treatment) <b>&gt;7.65-inches/hour</b>	Subgrade infiltration rate (after compaction or soil treatment) <b>from 7.65- to 0.77- inches/hour</b>	Subgrade infiltration rate (after compaction or soil treatment) <b>from 0.77- to 0.1-inches/hour</b>
Block	3.15-inches	3.15-inches	3.15-inches	3.15-inches
Setting	1-inch	1-inch	1-inch	1-inch
Base	10-inches	8-inches	8-inches	8-inches
Subbase	n/a	8-inches	8-inches	14-inches
Total	~ 14-inches	~ 20-inches	~ 20-inches	~ 26-inches
				
Drainage	No drainage required	Allow for pavement base to drain within 24-hours, include drainage at pavement edge (see Figure 5 and Figure 6)	Allow for pavement base to drain within 24-hours, include drainage at pavement edge (see Figure 5 and Figure 6)	Allow for pavement base to drain within 24-hours, include drainage at pavement edge (see Figure 5 and Figure 6)
CBR = California Bearing Ratio in % (soaked) E = Modulus of Elasticity (in psi) on soaked subgrade for relatively soft, fine grained soils				

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### **Section 3.03 MATERIAL/AGGREGATE SELECTION, FUNCTION AND PERFORMANCE**

A porous unit block paver system must be designed and constructed with open graded materials in the paver crevices or openings, the bedding layer, the base, and subbase to ensure and sustain good drainage and infiltration characteristics.

Typical road construction aggregates (including sharp sands) are unsuitable due to their percentage of fines (Sieve No. 16 to 200). These aggregates have small voids and tend to trap fine dust particles that wash into the pavement. This will lead to clogging and formation of an impervious “pan” over time. Infiltrated runoff will accumulate on the pan, which compromises the stormwater objectives of the porous pavement. A reduction in permeability in the base or subbase will also compromise structural objectives. Trapped water in the base can cause high pore-water pressure and result in pumping under dynamic traffic loads<sup>45</sup>. Only non-plastic, open-graded aggregates (plasticity index of 0) that sustain their strength in the presence of water should be used in porous pavement installations<sup>46</sup>.

Open graded materials for porous pavements should originate from a hard, durable crushed rock with 90% fractured face and a Los Angeles (LA) Abrasion of <40. A design CBR of 80% is recommended<sup>47</sup>.

#### **(A) Crevice fill**

An ASTM C33 No. 8 crushed stone should be used to fill the paver openings and crevices. The ASTM C33 No. 8 is also commonly referred to as <sup>3</sup>/<sub>8</sub>-inch stone chips. The size and porosity of this material allows accumulated dust particles to flush out during heavier storm events. This helps to prevent clogging and sustain good infiltration rates over time. The infiltration rate of the ASTM C33 No. 8 should be at least 1,000-inches/hour<sup>48</sup>.

#### **(B) Bedding layer**

Besides filling the paver openings and crevices, the ASTM C33 No. 8 crushed stone should be used for the bedding layer. As with the paver openings and crevices, the size and porosity of this material allows accumulated dust particles to flush out during heavier storm events. The infiltration rate of the ASTM C33 No. 8 should be at least 1,000-inches/hour<sup>49</sup>.

It is not recommended to use sand for the setting layer in porous block paver systems. The sand may trap fine dust particles that wash into the pavement. This leads to clogging and pan formation, which can only be repaired through costly removal and reinstallation of the bedding layer and paver course.

#### **(C) Base course**

This structural/load bearing component of the pavement should be constructed using an ASTM C33 No. 57 crushed stone. The infiltration rate of the ASTM C33 No. 57 should be at least 1,000-inches/hour<sup>50</sup>.

#### **(D) Subbase course**

This pavement component has several objectives: capillary break, structural support of the pavement, and storage and drainage. The latter is essential, although a drainage rate (hydraulic conductivity) greater than necessary will reduce detention time and amount of runoff infiltrated. Numerous types of open-graded materials can be used, depending on the priority of the above outlined objectives.

**(i) Storage – drainage – capillary break**

A washed, open-graded, round gravel will provide the best porosity, excellent drainage, and capillary break. It has, however, limited structural capacity.

**(ii) Structural – storage – drainage – capillary break**

A crushed rock, such as the ASTM C33 No. 57 or larger (ASTM C33 No. 2), also has good porosity, although less so than the open-graded, washed, round gravel. It has, however, superior structural characteristics and provides both excellent drainage and an effective capillary barrier.

The open graded subbase and base course must be installed in lifts that do not exceed 12-inches to assure sufficient compaction. Compaction equipment should be approved by the consulting engineer. Depending on the size of the installation, a Steel Drum Compactor (min. 60-inch drum) or Vibratory Plate Compactor (min. 42-inch plate), both capable of controlled frequency, can be used. Full particle interlock of the open-graded material must be achieved, which requires three passes with an approved compactor. More than three passes may lead to over compaction, which may result in particle abrasion. The process of particle abrasion will add undesired fine matter to the open graded material.

The bedding layer is typically not compacted until after the paver installation. A plate compactor with 3000 to 5000 lbs of centrifugal compaction force that operates at 80-90 Hz should be used across the installed pavement<sup>51</sup>. This operation sets the pavers firmly into place and also compacts the underlying bedding layer.

Gradation specifications and available aggregates vary from state to state. The given ASTM gradations shown below should be matched to local DOT specifications in the selection process of the appropriate aggregates for the porous pavement.

Sieve Size		% Passing	Sieve Size		% Passing	Sieve Size		% Passing
½ in.	12.5 mm	100	1 ½ in.	37.5 mm	100	3 in.	75 mm	100
¾ in.	9.5 mm	85 to 100	1 in.	25.0 mm	95 to 100	2 ½ in.	63 mm	90 to 100
No. 4	4.75 mm	10 to 30	½ in.	12.5 mm	25 to 60	2 in.	50 mm	35 to 70
No. 8	2.36 mm	0 to 10	No. 4	4.75 mm	0 to 10	1 ½ in.	37.5 mm	0 to 15
No. 16	1.18 mm	0 to 5	No. 8	2.36 mm	0 to 5	¾ in.	12.5 mm	0 to 5

Table 7 ASTM C33 No. 8 gradation    Table 8 ASTM C33 No. 57 gradation    Table 9 ASTM C33 No. 2 gradation

“A poorly ‘designed’ pavement that uses good material and that is well constructed will always out-perform a properly ‘designed’ pavement that uses inferior materials and that is poorly constructed”<sup>52</sup>.

**(E) Filter criteria**

It is of critical importance to specify and use materials that are resistant to erosion within the pavement and thus meet the filter criteria. Finer-graded materials that wash out (migrate) and erode into underlying coarser graded materials do not meet the filter criteria and cause slumping and pavement failure. The installation of an ASTM C33 No. 8 (bedding layer) over an ASTM C33 No. 57 (base course) installed over an ASTM C33 No. 2 (subbase course) meets the filter criteria.

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If materials are used that differ from the above stated ASTM gradations, it is recommended to check their filter criteria. The following method is commonly applied in geotechnical analysis<sup>53</sup>:

$$\frac{D_{15}}{d_{85}} \leq 5$$

Another method, recommended by the International Concrete Pavement Institute (ICPI) is as follows<sup>54</sup>:

$$\frac{D_{15}}{d_{50}} < 5 \text{ and } \frac{D_{50}}{d_{50}} > 2$$

Where:

D = coarser aggregate (open graded stone)

d = finer aggregate (choke stone)

How to read D<sub>x</sub> or d<sub>x</sub> ?:

For example, at D<sub>15</sub>, 15% of the aggregate gradation is smaller and 85% is coarser.

A coarse, open-graded subbase placed over a subgrade of fine material may not meet the filter criteria. In this case, the subgrade may choke the subbase course. Wet subgrade (that is expected in porous pavement systems) in combination with dynamic traffic loads (causing vibration) can lead to pumping, which would compromise the stormwater and structural performance of the pavement. Pumping can be prevented and the filter criteria met by placing an appropriate geotextile between the subbase and subgrade. Both woven monofilament and non-woven, needle-punched fabrics will provide an adequate filter. Standard woven (tape) filter fabrics should not be used as they are insufficiently permeable and do not pass sufficient volumes of water.

Aggregates must be kept clean and protected from soil contamination throughout the construction process. This is to preserve their porosity and drainage characteristics. All installed porous block paver systems must be protected from siltation during and post construction. Eroding soils that wash onto the pavement will clog the crevices and effectively eliminate the infiltration capacity.

### **Section 3.04 DRAINAGE DESIGN**

The drainage design process requires analysis of rainfall intensity and stormwater runoff rates. Surface runoff as well as runoff that enters the pavement through the crevices must be considered and adequate drainage provided. Drainage design for porous unit block pavements can be divided into two components: surface drainage and subsurface drainage.

#### **(A) Surface drainage**

When planning a porous pavement installation, all areas that drain onto the pavement (contributing watershed) need to be identified in the planning process. It is recommended that the contributing watershed not exceed 20% of the area of the porous pavement installation, or be greater than 5 acres<sup>55</sup>. Runoff from the contributing watershed must be free of sediment, such as construction site runoff to prevent clogging of the subgrade, base, or crevices and loss of infiltration capacity. This requires thorough

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erosion control throughout the installation process, including the re-establishment of the vegetation on disturbed soils in contributing watershed. Porous pavements should be designed and installed in a manner that eliminates or reduces the risk of erosion contamination for the life of the pavement.

The porous unit block pavement in itself is a drainage tool since it transmits water through the pavement surface. The infiltration capacity of the pavement is not determined by the percentage of openings, rather it is determined by the infiltration capacity of the crevice fill material. That fill material must be open-graded with no or a limited amount of fines (see also Section 3.03(A)). Use of the proper fill material will sustain a good infiltration capacity and surface drainage over the lifetime of the pavement and reduce or eliminate the need for catch basins and other drainage structures.

Field test data is available on the infiltration capacity of porous pavements that were constructed similar to the recommendations in these guidelines. One research project shows that virtually all water was infiltrated on permeable parking stalls for a number of monitored storms<sup>56</sup>. In another instance, two and five year old installations were tested. The two year old installation infiltrated 2.8-inches/hour after 60-minutes of constant sprinkling, whereas the five year old installation infiltrated 5.7-inches/hour after the same loading. The lower infiltration capacity of the more recent installation (two years of age) is explained with a higher percentage of organic substances and fine particles in the crevice fill<sup>57</sup>. This data illustrates the importance of clean and open-grade materials in porous pavement construction. Although 2.5-inches/hour is an adequate design infiltration capacity for mature systems, more conservative approaches recommend using an infiltration capacity of 1-inch/hour over a 20-year life for porous pavements<sup>58</sup>.

As with most pavements, it is recommended that the porous unit block pavers be installed with at least 1% slope<sup>59</sup>. Because a properly installed porous pavement will only generate surface runoff during very heavy storms, conventional catch basin and stormwater pipe installations can be reduced in number, substituted by infiltration swales or bioswales (see also Figure 5 and Figure 6) or eliminated<sup>60</sup>. The use of swales instead of catch basins reduces costs relative to conventional drainage infrastructure. Bioswales have the added advantage of treating and filtering the surface runoff. Provisions for frequent curb cuts should be made if the pavement edge is a raised curb. These curb cuts can be as frequent as one for every parking stall; this frequency allows any excess surface water to drain into adjacent swales without causing scour and erosion.

## **(B) Subsurface drainage**

The subsurface drainage design of porous pavements is largely determined by the infiltration capacity of the subgrade soils. As outlined in Section 1.03, a porous pavement installation can tolerate temporary storage of runoff in the base and subbase without compromising its structural integrity. Maintaining structural integrity under periodic wet conditions is contingent on subgrade strength, sufficient base and subbase depth, and the use of appropriate aggregates and geotextiles<sup>61</sup> (see also Section 3.03). The stored runoff will ultimately be exfiltrated into the ground, or collected and discharged through a drainage system.

Porous pavements on freely draining soils with an infiltration capacity that equals or exceeds 7.65-inches/hour and have adequate depth to groundwater do not require any additional drainage infrastructure (see also Section 3.02(D) and Section 3.01(C)). The soil permeability should be measured at the proposed depth of the subgrade and under compacted conditions.

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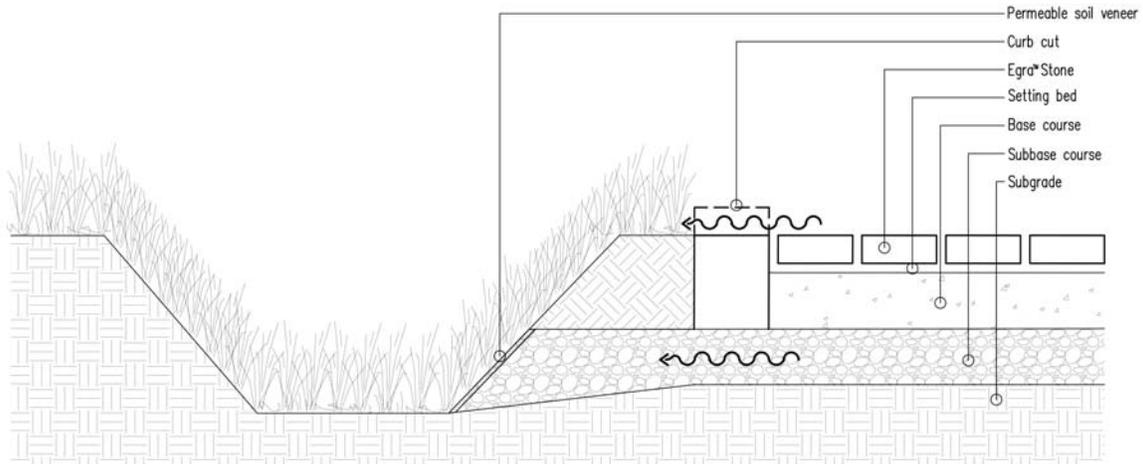


Figure 5 Drainage of porous pavement into Bioswale

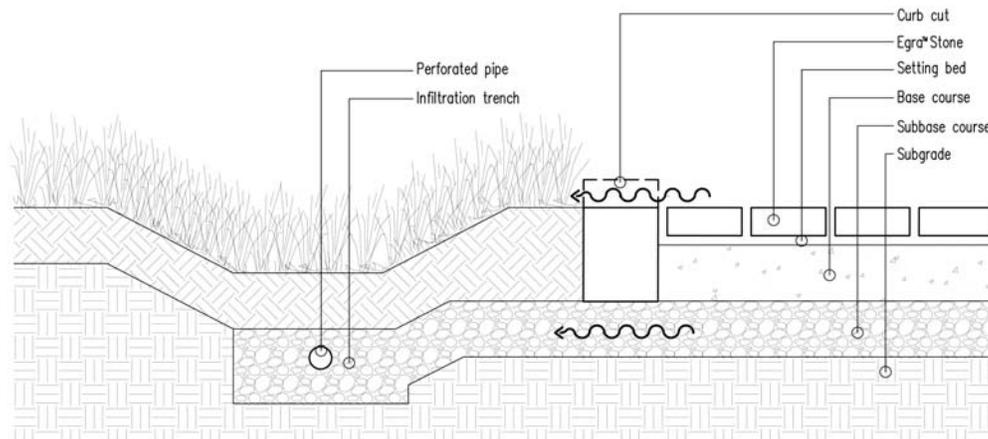


Figure 6 Drainage of porous pavement into Bioswale with Infiltration Trench

The same also applies to paths, patios, driveways and small parking installations on soils with infiltration capacities between 7.65- and 0.77-inches/hour. However, it is important to ensure that the water in the pavement base is drained within 24-hours (see also Table 3 and Table 4). To meet the 24-hour requirement, subsurface drainage may be necessary in some cases. For large parking lots and local roads, the same standard applies and, at a minimum, has to include subsurface drainage at the pavement edge (see also Table 5, Table 6, Figure 5 and Figure 6). This requires that the subgrade of the installation is graded with a minimum of 1% slope towards the pavement edge.

Soils with an infiltration rate of 0.77- to 0.1-inch/hour may exhibit a reduction in their structural capacity when saturated for extended periods. The pavement base of paths, patios, driveways, and small parking installed on such soils should drain within 24-hours (see also Table 3 and Table 4). To meet the 24-hour requirement, subsurface drainage may be necessary in some cases, particularly at the low end of the permeability range. The same 24-hour drain time applies to porous pavement on large parking lots and local road installations. The traffic load on the latter two further necessitates subsurface drainage at the pavement edge (see also Table 5, Table 6, Figure 5 and Figure 6), which requires that the subgrade of the installation is graded with a minimum of 1% towards the edge and other locations of subsurface drainage.

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Porous pavement installations should be a minimum of ten-feet downslope from building foundations and 100-feet upslope. The building foundation should further have a drainage system<sup>62</sup> (footing drain).

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## **Section 4. ANSWERS TO FREQUENTLY ASKED QUESTIONS**

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### **(1) Can the EGRA™ Stone be installed where it is subject to severe frost conditions, and many freeze-thaw cycles?**

Yes. Like any pavement, its success relies on proper pavement design, including adequate drainage provisions. Thorough subgrade evaluation, proper selection of open graded aggregates, good base and subbase design, and appropriate provisions for excess water collection and drainage will make porous pavements into one of the most reliable and long-lived pavement surfaces, even under severe frost conditions. Although conditions that will lead to frost heave should be avoided, porous unit block pavement is able to withstand modest amounts of frost heave without damage because of its flexible nature (for more details refer to Section 3.01 (D)).

### **(2) Can EGRA™ Stone surfaces be snow plowed?**

Yes. Experience with installations in North America, Scandinavia and Switzerland show that porous pavements can be snow plowed. Like with any pavement, a steel-edge snow plow run reckless or at an excessive speed will ultimately cause damage. A snow plow operated with reason and care over an EGRA™ Stone surface will allow smooth plowing operation. Snowplows should not catch the crevices of the EGRA™ Stone unless the plow is set to the same angle as a continuous paving crevice. The EGRA™ Stone is typically installed in the driving/plowing direction. The snow plow is typically set at an angle. Thus, it is very unlikely that the blade will align with the pavement crevices.

Properly installed unit block pavements provide a smooth surface that eliminates the potential for the snow plow to catch a displaced paver. Furthermore, the superior compressive strength of the paver (see also Section 1.05) makes it more resistant to abrasion than conventional concrete and asphalt pavement. Research has shown that interlocking unit block pavers interact and function as a unified structure rather than individual units (see also Section 1.03). Should a snow plow catch a paver, it is virtually impossible to scrape it out of the pavement due to its interlocking nature. For the protection of the driver, it is recommended that the steel edge of the plow be replaced with a rubber edge for all jointed pavements, included poured concrete.

### **(3) Is the EGRA™ Stone subject to rutting and subsequent trip hazards?**

Rutting and trip hazards are caused by improper pavement design and/or installation. Investigations have shown that rutting and trip hazards are due to non-compliance with project specification<sup>63</sup>. Proper pavement design and installation minimizes the occurrence of ruts and potential trip hazards.

### **(4) Are porous unit pavers, such as the EGRA™ Stone suitable for high heel shoes?**

Investigations have shown that a heel cannot get stuck when stepping on a fully and properly filled drainage opening<sup>64</sup>.

### **(5) Are porous unit pavers, such as the EGRA™ Stone ADA compliant?**

The Federal Accessibility Standards, Section 4.5 (Ground and Floor Surfaces) states that surfaces must be stable, firm, and slip resistant. The EGRA™ Stone meets these three requirements, given that the crevices are fully filled with stone chips. The EGRA™ Stone has good traction and provides road safety when wet. Unit block pavers can be easily installed with great precision meeting the surface evenness requirements.

Other investigations on comfort and ease with reference to wheelchair traffic show that porous unit pavers provide a suitable trafficking surface. Some vibration can be felt by the wheelchair user, which is most noticeable if the joints are not filled completely<sup>65</sup>.

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- <sup>1</sup> Borgwardt *et al.* (2000)
  - <sup>2</sup> Smith (2001); Smith (2003)
  - <sup>3</sup> Rollings *et al.* (1992)
  - <sup>4</sup> Rollings *et al.* (1993)
  - <sup>5</sup> Rollings *et al.* (1992); Rollings *et al.* (1993)
  - <sup>6</sup> Borgwardt *et al.* (2000); Rollings *et al.* (1992); Yoder *et al.* (1975)
  - <sup>7</sup> Rollings *et al.* (1993)
  - <sup>8</sup> EPA (1999)
  - <sup>9</sup> Shackel *et al.* (1996)
  - <sup>10</sup> Borgwardt (1994); Borgwardt *et al.* (2000); and Smith (2001)
  - <sup>11</sup> Smith (2001)
  - <sup>12</sup> Borgwardt (1994); Borgwardt *et al.* (2000); and Smith (2001)
  - <sup>13</sup> Smith (2001)
  - <sup>14</sup> Price *et al.* (2000)
  - <sup>15</sup> Smith (2001)
  - <sup>16</sup> Smith (2003)
  - <sup>17</sup> Shackel *et al.* (1996)
  - <sup>18</sup> Pitt *et al.* (2000)
  - <sup>19</sup> Verspagen (1995); Thompson (1995)
  - <sup>20</sup> Newman *et al.* (undated)
  - <sup>21</sup> Leeper (1978)
  - <sup>22</sup> Price *et al.* (2000)
  - <sup>23</sup> Pratt (1997)
  - <sup>24</sup> JEGEL (2000)
  - <sup>25</sup> JEGEL (2000)
  - <sup>26</sup> JEGEL (2000)
  - <sup>27</sup> Smith (2001)
  - <sup>28</sup> Rollings *et al.* (1993)
  - <sup>29</sup> Smith (2001)
  - <sup>30</sup> Borgwardt *et al.* (2000)
  - <sup>31</sup> Dorman *et al.* (1964)
  - <sup>32</sup> Smith (2001)
  - <sup>33</sup> Rollings *et al.* (1993)
  - <sup>34</sup> EPA (1998); Smith (2003)
  - <sup>35</sup> Schueler (1987); Horner *et al.* (1994)
  - <sup>36</sup> EPA (1998)
  - <sup>37</sup> EPA (1998)
  - <sup>38</sup> IEPA (1996)
  - <sup>39</sup> Backstrom (1999)
  - <sup>40</sup> Backstrom (1987)
  - <sup>41</sup> Hogland *et al.* (1988)
  - <sup>42</sup> Stenmark (1995)
  - <sup>43</sup> Backstrom (1999)
  - <sup>44</sup> Pratt (1997)
  - <sup>45</sup> Borgwardt *et al.* (2000)
  - <sup>46</sup> Rollings *et al.* (1993)
  - <sup>47</sup> Smith (2001)

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- 48 Smith (2001)
  - 49 Smith (2001)
  - 50 Smith (2001)
  - 51 Rollings *et al.* (1992)
  - 52 Rollings *et al.* (1992)
  - 53 Dunn *et al.* (1980); Rollings *et al.* (1992); Borgwardt *et al.* (2000)
  - 54 Smith (2001)
  - 55 Smith (2001); Smith (2003)
  - 56 Brattebo (in print)
  - 57 Borgwardt (1994)
  - 58 Smith (2001)
  - 59 Smith (2003); Borgwardt *et al.* (2000)
  - 60 Backstrom (2000)
  - 61 Hansen *et al.* (1997)
  - 62 Smith (2001); Smith (2003)
  - 63 JEGEL (2000)
  - 64 Bretschneider (1992a)
  - 65 Bretschneider (1992b)

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## Section 6. APPENDIX A

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Design Manual – Onsite Wastewater Treatment and Disposal System, EPA, 1980

### Falling Head Percolation Test Procedure

#### Number and Location of Tests

Commonly a minimum of three percolation tests are performed within the area proposed for an absorption system. They are spaced uniformly throughout the area. If soil conditions are highly variable, more tests may be required.

#### Preparation of Test Hole

The diameter of each test hole is 6-inches, dug or bored to the proposed depths at the absorption systems or to the most limiting soil horizon. To expose a natural soil surface, the sides of the hole are scratched with a sharp pointed instrument and the loose material is removed from the bottom of the test hole. Two-inches of ½- to ¾-inch gravel are placed in the hole to protect the bottom for scouring action when the water is added.

#### Soaking Period

The hole is carefully filled with at least 12-inches of clear water. This depth of water should be maintained for at least 4-hours and preferably overnight if clay soils are present. A funnel with an attached hose or similar device may be used to prevent water from washing down the sides of the hole. Automatic siphons or float valves may be employed to automatically maintain the water level during the soaking period. It is extremely important that the soil be allowed to soak for a sufficiently long period of time to allow the soil to swell if accurate results are to be obtained.

In sandy soils with little or no clay, soaking is not necessary. If, after filling the hole twice with 12-inches of water, the water seeps completely away in less than ten-minutes, the test can proceed immediately.

#### Measurement of the Percolation Rate

Except for sandy soils, percolation rate measurements are made 15-hours but not more than 30-hours after the soaking period began. Any soil that sloughed into the hole during the soaking period is removed and the water level is adjusted to 6-inches above the gravel (or 8-inches above the bottom of the hole). At no time during the test is the water level allowed to rise more than 6-inches above the gravel.

After each measurement, the water level is readjusted to the 6-inches level. The last water level drop is used to calculate the percolation rate.

In sandy soils or soils in which the first 6-inches of water added after the soaking period seep away in less than 30-minutes, water level measurements are made at 10-minute intervals for a 1-hour period. The last water level drop is used to calculate the percolation rate.

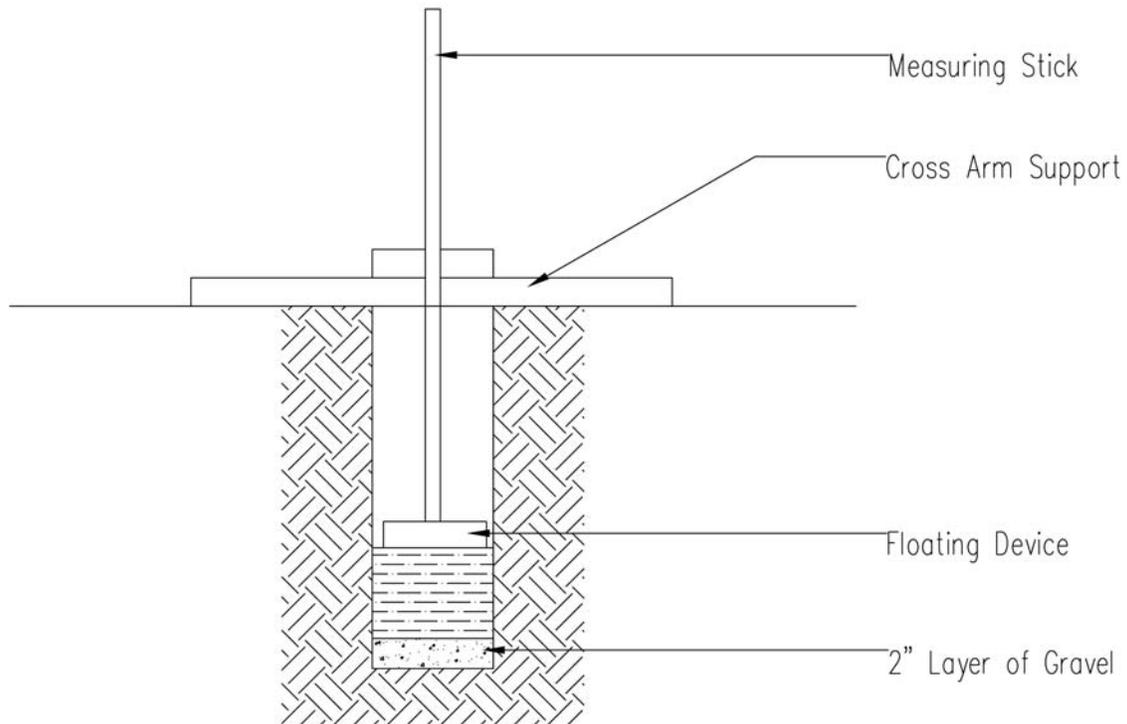
#### Calculation of the Percolation Rate

The percolation rate is calculated for each test hole by dividing the time interval used between measurements by the magnitude of the last water level drop. This calculation results in a percolation rate in terms of minutes/inch. To determine the percolation rate

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for the area, the rates obtained from each hole are averaged. (if tests in the area vary by more than 20-minutes/inch variations in soil type are indicated. Under these circumstances, percolation rates should not be averaged.)

Example: if the last measurement drop in water level after 30-minutes is 5/8-inch the percolation rate = (30-minutes)/(5/8-inch)= 48-minutes/inch.



Construction of a percometer

