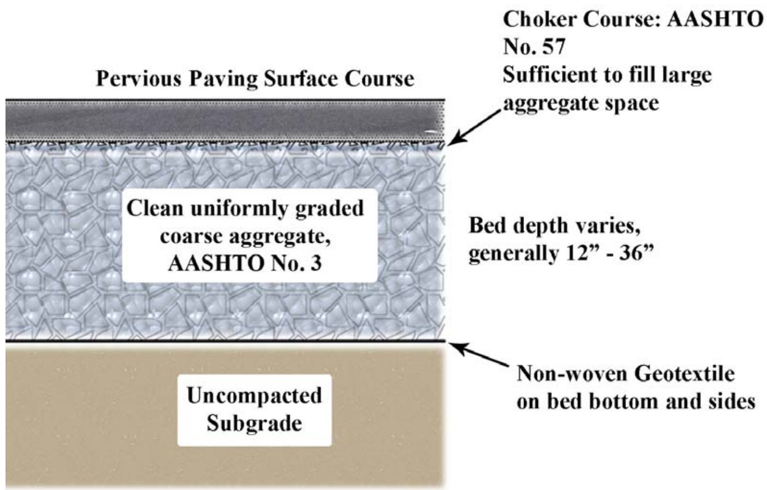
Structural BMP Criteria

BMP #: Porous Pavement with Infiltration Bed



Porous pavement consists of a permeable surface course underlain by an open-graded stone subbase which provides stormwater management. The surface course may consist of porous asphalt, porous concrete, or various porous structural pavers.

Key Design Elements

- Surface with significant permeability (> 20” per hr)
- Open-graded sub-base with minimum 40% void space
- Surface and sub-base suitable for design traffic loads
- Uncompacted sub-base
- Underlain by non-woven geotextile
- Level bed bottoms
- Generally not recommended for traffic surfaces with slope >5%.
- Provide positive stormwater overflow from beds
- Do not place bed bottom on compacted fill; fill with stone, as needed
- Protect from sedimentation during construction
- Line bed with non-woven geotextile
- Provide perforated pipe network along bed bottom for distribution
- Allow 3ft buffer between bed bottom and seasonal high ground water table and 2ft for bed rock
- When possible, place infiltration beds on upland soils

Potential Applications

Residential Subdivision:	**YES***
Commercial:	**YES**
Ultra Urban:	**YES**
Industrial:	**YES***
Retrofit:	**YES***
Highway/Road:	**YES***

**Applicable with specific considerations to design*

Stormwater Functions

Volume Reduction:	**High**
Recharge:	**Med/High**
Peak Rate Control:	**High**
Water Quality:	**High**

Pollutant Removal

Total Suspended Solids:	**x**
Nutrients:	**x**
Metals:	**x**
Pathogens:	**x**

Other Considerations

- Percolation testing required

Description

Porous pavement bed consists of a porous surface course underlain by a stone bed of uniformly graded and clean-washed course aggregate, 1-1/2 to 2-1/2 inches in size, with a void space of at least 40%. The porous pavement may consist of porous asphalt, porous concrete, or pervious pavement units. Stormwater drains through the surface, is temporarily held in the voids of the stone bed, and then slowly exfiltrates into the underlying, uncompacted soil mantle. The stone bed is designed with an overflow control structure so that during large storm events peak rates are controlled, and at no time does the water level rise to the pavement level. A layer of non-woven geotextile filter fabric separates the aggregate from the underlying soil, preventing the migration of fines into the bed. The bed bottoms should be level and uncompacted. If fill is required, it should consist of additional stone and not compacted soil.

Figure 1. Porous pavement at the Morris Arboretum, photo taken during Hurricane Floyd, (1983)

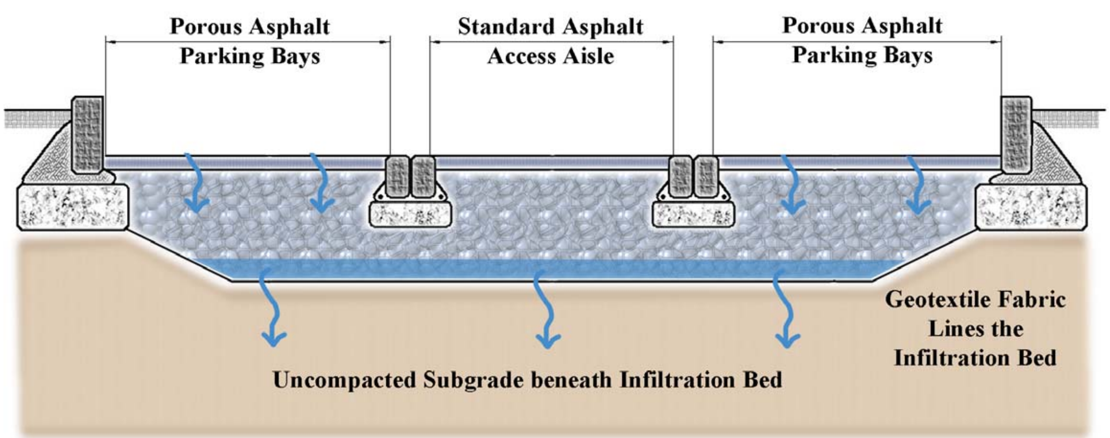


Figure 2. Cross-section through the Morris Arboretum parking lot

Porous pavement is well suited for parking lots, walking paths, sidewalks, playgrounds, plazas, tennis courts, and other similar uses. Porous pavement can be used in driveways if the home-owner is aware of the stormwater functions of the pavement. Porous pavement roadways have seen wider application in Europe and Japan than in the U.S., although some U.S. systems have been constructed.

Properly installed and maintained porous pavement has a significant lifespan, and existing systems that are more than twenty years in age continue to function. Because water drains through the surface course and into the subsurface bed, freeze-thaw cycles do not adversely affect porous pavement.

Porous pavement is most susceptible to failure difficulties during construction, and therefore it is important that the construction be undertaken in such as way as to prevent:

- Compaction of underlying soil
- Contamination of stone sub-base with sediment and fines
- Tracking of sediment onto pavement
- Drainage of sediment laden waters onto porous surface or into constructed bed

Staging, construction practices, and erosion and sediment control must all be taken into consideration when using porous pavements.

Studies have shown that porous systems have been very effective in reducing contaminants such as total suspended solids, metals, and oil and grease (*need good ref list*). When designed, constructed, and maintained according to the following guidelines, porous pavement with underlying infiltration systems can dramatically reduce both the rate and volume of runoff, recharge the groundwater, and improve water quality.

In northern climates, porous pavements have less of a tendency to form black ice and often require less plowing. Sand and gravel should never be used on porous pavements, although salt may be used on porous asphalt, and commercial deicers may be used on porous concrete. Porous asphalt and concrete surfaces provide better traction for walking paths in rain or snow conditions.

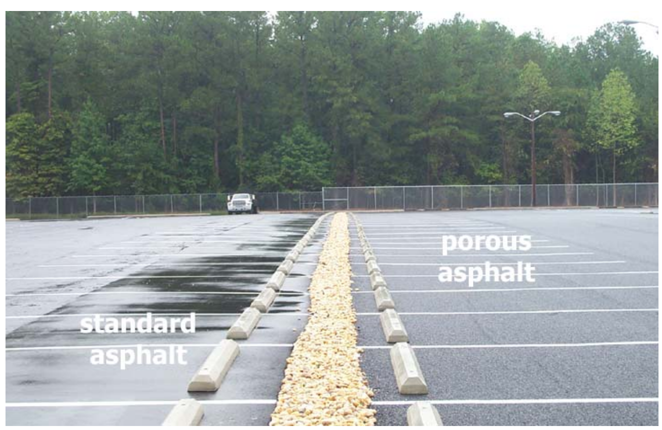


Figure 3. Standard pavement and porous pavement look very similar

Variations

Porous Bituminous Asphalt

Porous asphalt pavement was first developed in the 1970's and consists of standard bituminous asphalt in which the fines have been screened and reduced, allowing water to pass through very small voids. Porous asphalt is placed directly on the stone sub-base in a single 3 ½ inch lift that is lightly rolled to a finish depth of 2 ½ inches.

Because porous asphalt is standard asphalt with reduced fines, it is similar in appearance to standard asphalt. Recent research in open-graded mixes for highway application has led to additional improvements in porous asphalt through the use of additives and binders. Porous asphalt is suitable for use in any climate where standard asphalt is appropriate.

Figure 4. Porous asphalt parking lot at the Hockessin Library, Delaware (1991)

Figure 5. Porous asphalt parking lot at the University of North Carolina, Chapel Hill (2001)

Porous Concrete

Porous Portland Cement Concrete, or porous concrete, was developed by the Florida Concrete Association and has seen the most widespread application in Florida and southern areas. Like porous asphalt, porous concrete is produced by substantially reducing the number of fines in the mix in order to establish voids for drainage. In northern and mid-Atlantic climates such as Pennsylvania, porous concrete should always be underlain by a stone sub-base designed for stormwater management and should never be placed directly onto a soil sub-base.

While porous asphalt is very similar in appearance to standard asphalt, porous concrete has a coarser appearance than its conventional counterpart. Care must be taken during placement to avoid working the surface and creating an impervious layer. Porous concrete has been proven to be an effective a stormwater management mechanism. Additional information pertaining to porous concrete, including specifications, is available from the Florida Concrete Association.

Figure 6. Porous concrete parking lot (www.chargerconcrete.com/perviousconcrete.htm)

Figure 7. Porous concrete parking lot at the University of North Carolina, Chapel Hill

Figure 8. The edge of this plaza at Villanova University is porous concrete (R. Traver).

Porous Paver Blocks

Figure 9. Porous paver block

Porous Paver Blocks consist of interlocking units (often concrete) that provide some portion of surface area that may be filled with a pervious material such as gravel. These units are often very attractive and are especially well suited to plazas, patios, small parking areas, etc. There are also products available that provide a fully permeable surface through the used of plastic rings grids filled with gravel. A number of manufactured products are available, including (but not limited to):

- Turfstone; UNI Eco-stone; Checkerblock; GravelPave

As products are always being developed, the designer is encouraged to evaluate the benefits of various products with respect to the specific application.

Reinforced Turf

Reinforced Turf consists of interlocking structural units that contain voids or areas for turf grass growth and are suitable for traffic loads and parking. Reinforced turf units may consist of concrete or plastic and are underlain by a stone and/or sand drainage system for stormwater management.

Reinforced Turf applications are excellent for applications such as Fire Access Roads, overflow parking, occasional use parking (such as at religious facilities and athletic facilities). Reinforced turf is also an excellent application to reduce the required standard pavement width of paths and driveways that must occasionally provide for emergency vehicle access.

While both plastic and concrete units perform well for stormwater management and traffic needs, plastic units tend to provide better turf establishment and longevity, largely because the plastic will not absorb water and diminish soil moisture conditions. A number of products are available and the designer is encouraged to evaluate and select a product suitable to the design in question.

- Grasspave; Geoblock; Grassy Pave; Geoweb

Figure 10. This 7-acre parking area at Reliant Stadium in Houston,Texas is completely paved with Grasspave. (www.invisiblestructures.com)

Figure 11. Standard asphalt pathway with 2ft. reinforced turf edges at Pennsylvania State University, Berks Campus

Applications

- **Parking**

Figure 12. Porous pavement at Pennsylvania State University, Berks Campus

Figure 13. Porous pavement parking lot in Radnor Township, 2003

- **Walkways**

Porous Pavement Walkways (Concrete and Asphalt)
Porous pavement, both as asphalt and concrete, has also been used in walkways and sidewalks. These installations typically consist of a shallow (12in minimum) aggregate trench that is sloped to follow the surface slope of the path. In the case of relatively mild surface slopes, the aggregate infiltration trench may be "terraced" into level reaches in order to maximize the infiltration capacity, at the expense of additional aggregate.

Figure 14. This pathway at Swarthmore College is made of porous asphalt, with subsurface infiltration bed beneath, 2002

Figure 15. The Visitor Center at Pennsylvania State University Main Campus used porous concrete to construct the sidewalks, 2000

- **Playgrounds**

Figure 16. Porous asphalt playground at the Alexander-Penn-Partnership School in West Philadelphia

- **Alleys**

- **Roof drainage; Direct connection of roof leaders and/or inlets**

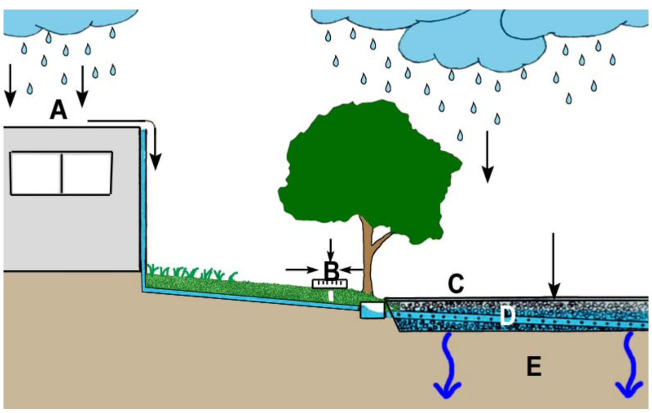


Figure 17. Conceptual schematic showing roof drains tied directly into infiltration bed below porous pavement

Figure 18. Roof drains tie directly into the infiltration beds at DuPont

- **Limited use for roads and highways**

Figure 19. Porous asphalt pavement on this road in Chandler, Arizona

Figure 20. Porous asphalt highway (standard asphalt shoulder) in Japan, courtesy of Infrastructure Development Institute of Japan.

Design Considerations

1. Soil Investigation and Percolation Testing Required (see Section x/x)

2. Guidelines for Infiltration Systems must be met (i.e., depth to water table, setbacks, Loading Rates, etc. See Section x/x).

3. The overall site shall be evaluated for potential porous pavement / infiltration areas early in the design process, as effective porous pavement design requires consideration of grading.

4. Orientation of the parking bays along the existing contours will significantly reduce the need for cut and fill.

5. Porous Pavement and Infiltration Beds **shall not be placed on areas of fill** or compacted fill. Any grade adjust requiring fill shall be done using the stone sub-base material.

6. The bed bottom is not compacted, however the stone sub-base is placed in lifts and lightly rolled according to the specifications.

7. During construction, the excavated bed may serve as a Temporary Sediment Basin or Trap. This will reduce overall site disturbance. The bed shall be excavated to within six (6) inches of the final bed bottom elevation for use as a sediment trap or basin. Following construction and site stabilization, sediment shall be removed and final grades established.

8. **Bed Bottoms must be level**. Sloping bed bottoms will lead to areas of ponding and reduced distribution.

9. **All systems shall be designed with an overflow system**. Water within the sub-surface stone bed should never rise to the level of the pavement surface. Inlet boxes can be used for cost-effective overflow structures.

10. While infiltration beds are typically sized to handle the increased volume from a 2-yr design storm, they must also be able to convey and mitigate the peak of the less-frequent, more intense storms (such as the 100-yr). Control in the beds is usually provided in the form of an outlet control structure. A modified inlet box with an internal concrete weir and low-flow orifice is a common type of control structure. The specific design of these structures may vary, depending on factors such as rate and storage requirements, but it always must include positive overflow from the system.

11. The sub-surface bed and overflow may be designed and evaluated in the same manner as a detention basin to demonstrate the mitigation of peak flow rates. In this manner, the detention basin may be eliminated or significantly reduced in size.

12. A weir plate or weir within an inlet or overflow control structure may be used to maximize the water level in the stone bed while providing sufficient cover for overflow pipes.

13. Perforated pipes along the bottom of the bed are necessary to evenly distribute runoff over the entire bed bottom. Continuously perforated pipes shall connect structures (such as cleanouts and inlet boxes). Pipes shall lay flat along the bed bottom and provide for uniform distribution of water. Depending on size, these pipes may provide additional storage volume.

14. Roof leaders and area inlets may be connected to convey runoff water to the bed. Water Quality Inserts or Sump Inlets shall be used to prevent the conveyance of sediment and debris into the bed.

15. Infiltration areas should be located within the immediate project area in order to control runoff at its source. Expected use and traffic demands shall also be considered in porous pavement placement.

16. **Control of Sediment is critical**. Rigorous installation and maintenance of erosion and sediment control measures is required to prevent sediment deposition on the pavement surface or within the stone bed. Non-woven geotextile may be folded over the edge of the pavement until the site is stabilized. The Designer should consider the placement of Porous Pavement to reduce the likelihood of sediment deposition. **Surface sediment shall be removed by a vacuum sweeper and shall not be power-washed into the bed.**

17. **Infiltration Beds may be place on a slope by benching or terracing parking bays.** Orienting parking bays along existing contours will reduce site disturbance and cut/fill requirements.

Figure 21. Terraced infiltration beds below porous pavement at a steep site

18. The underlying infiltration bed is typically 12-36in deep and comprised of clean, uniformly-graded aggregate with approximately 40% void space. AASHTO No.3, which ranges 1.5-2.5in in gradation, is often used. Depending on local aggregate availability, both larger and smaller size aggregate has been used. The critical requirements are that the aggregate be **uniformly-graded**, **clean washed**, and contain **40% void space**. The depth of the bed is a function of stormwater storage requirements, frost depth considerations, and site grading. Infiltration beds are typically sized to mitigate the increased runoff volume from a 2-yr design storm.

19. While most porous pavement installations are underlain by an aggregate bed, alternative subsurface storage products may also be employed. These include a variety of proprietary, interlocking plastic units that contain much greater storage capacity than aggregate, at an increased cost.

20. All Porous Pavement installations must have a backup method for water to enter the stone storage bed in the event that the pavement fails or is altered. In uncurbed lots, this backup drainage may consist of an unpaved 2ft wide stone edge drain connected directly to the bed between the wheel stop. In curbed lots, inlets with 12in sediment traps may be required at low spots. Backup drainage elements will ensure the functionality of the infiltration system even if the porous pavement is ever compromised.

Figure 22. Porous parking lot w/ stone edge drain at the Morris Arboretum

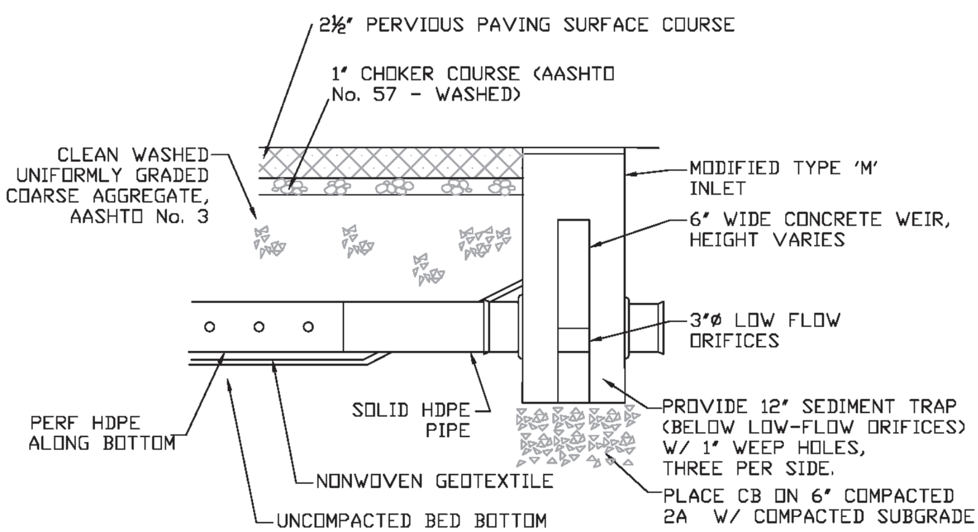


Figure 23. Detail showing typical outlet control structure

21. In areas with poorly-draining soils, infiltration beds below porous pavement may be designed to slowly discharge to adjacent wetlands or bioretention areas. In only extreme cases (i.e. industrial sites with contaminated soils) may the aggregate bed be lined to prevent infiltration.

22. In those areas where the threat of spills and groundwater contamination is quite likely, pretreatment systems, such as filters and wetlands, may be required before any infiltration occurs. In Hot Spot areas, such as truck stops, fueling stations the appropriateness of Porous Pavement must be carefully considered. A stone Infiltration Bed located beneath standard pavement, preceded by spill control and water quality treatment, may be more appropriate.

23. The use of porous pavement must be carefully considered in areas where the pavement may be seal coated or paved over due to lack of awareness, such as individual home driveways. In those situations, a system that is not easily altered by the property owner may be more appropriate. An example would include an infiltration system constructed under a conventional driveway. Educational signage at porous pavement installations may guarantee its prolonged use in some areas.

24. Proper construction, as outlined below, and long-term maintenance of the porous pavement system are critical to ensure its functionality for well over 20 years.

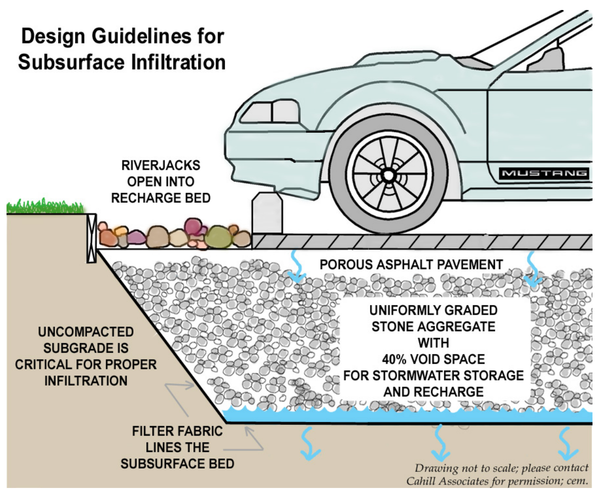


Figure 24. Design guidelines for porous pavement with subsurface infiltration

Detailed Stormwater Functions

Infiltration Area (If needed):

For non-carbonate geologic areas, the minimum infiltration area shall be based on the following equation:

Minimum Infiltration Area =
Contributing Impervious Area (including infiltration area under porous pavement) / 6

For carbonate geologic areas, the minimum infiltration area shall be based on the following equation:

Minimum Infiltration Area =

Contributing Impervious Area (including infiltration area under porous pavement) / 4

Volume Reduction Calculations:

Peak Rate Mitigation:

See Section z/z in Section 8 for Peak Rate Mitigation methodology which addresses link between volume reduction and peak rate control.

Water Quality Improvement:

See Section a/a in Section 8 for Water Quality Improvement methodology which addresses pollutant removal effectiveness of this BMP.

Construction Sequence

1. Due to the nature of construction sites, porous pavement and other infiltration measures should by installed toward the end of the construction period, if possible. Infiltration beds under porous pavement may be used as temporary sediment basins or traps provided they are excavated to within 6-12in of the designated bed bottom elevation. Once the site is stabilized and sediment storage is no longer required, the bed is excavated to the its final grade and the porous pavement system is installed.

2. The existing subgrade under the bed areas shall <u>NOT</u> be compacted or subject to excessive construction equipment traffic prior to geotextile and stone bed placement.

3. Where erosion of subgrade has caused accumulation of fine materials and/or surface ponding, this material shall be removed with light equipment and the underlying soils scarified to a minimum depth of 6 inches with a York rake (or equivalent) and light tractor. All fine grading shall be done by hand. All bed bottoms are level grade.

4. Earthen berms (if used) between infiltration beds shall be left in place during excavation. These berms do not require compaction if proven stable during construction.

Figure 25. Unexcavated earthen berms between terraced bed bottoms

5. Geotextile and bed aggregate shall be placed immediately after approval of subgrade preparation. Geotextile is to be placed in accordance with manufacturer's standards and recommendations. Adjacent strips of geotextile shall overlap a minimum of 16in. It shall also be secured at least 4ft outside of bed in order to prevent any runoff or sediment from entering the storage bed. This edge strip shall remain in place until all bare soils contiguous to beds are stabilized and vegetated. As the site is fully stabilized, excess geotextile along bed edges can be cut back to gravel edge.

6. Clean (washed) uniformly-graded aggregate is placed in the bed in maximum 8in lifts. Each layer shall be lightly compacted, with the construction equipment kept off the bed bottom as much as possible. Once bed aggregate is installed to the desired grade, a 1in layer of choker base course (AASHTO #57) aggregate shall be installed uniformly over the surface in order to provide an even surface for paving.

Figure 26. Aggregate is placed in the infiltration bed

Figure 27. Close-up view of stone for the infiltration bed

7. The porous bituminous asphalt is installed just like standard bituminous asphalt. Porous pavement shall be laid in one lift directly over the storage bed and stone base course to a 2.5in thickness. It shall not be installed on wet surfaces or when the ambient temperature is 60 degrees Fahrenheit or lower. Compaction of the surface course shall take place when the surface is cool enough to resist a 10-ton roller. One or two passes is all that is required for proper compaction. More rolling could cause a reduction in the surface course porosity.

Prior to installation, the porous pavement mix shall not be stored in excess of 90 minutes. Transporting of the mix to the site shall be in vehicles with smooth, clean dump beds that have been sprayed with a non-petroleum release agent. The mix shall be covered during transport to control cooling.

After final rolling, no vehicular traffic of any kind shall be permitted on the surface until cooling and hardening has taken place, and in no case within the first 48 hours.

The full permeability of the pavement surface shall be tested by application of clean water at the rate of at least 5 gpm over the surface, using a hose or other distribution devise. All applied water shall infiltrate directly without puddle formation or surface runoff.

Maintenance Issues

The primary goal of porous pavement maintenance is to prevent the pavement surface and/or underlying infiltration bed from being clogged with fine sediments. To keep the system clean throughout the year and prolong its lifespan, the pavement surface should be vacuumed biannually with a commercial cleaning unit**. Pavement washing systems or compressed air units are not recommended.** All inlet structures within or draining to the infiltration beds should also be cleaned out on a biannual basis.

Planted areas adjacent to porous pavement should be well maintained to prevent soil washout onto the pavement. If any washout does occur it should be cleaned off the pavement immediately to prevent further clogging of the pores. Furthermore, if any bare spots or eroded areas are observed within the planted areas, they should be replanted and/or stabilized at once. Planted areas should be inspected on a semi-annual basis. All trash and other litter that is observed during these inspections should be removed.

Superficial dirt does not necessarily clog the pavement voids. However, dirt that is ground in repeatedly by tires can lead to clogging. Therefore, trucks or other heavy vehicles should be prevented from tracking or spilling dirt onto the pavement. Furthermore, all construction or hazardous materials carriers should be prohibited from entering a porous pavement lot.

Special Maintenance Considerations:

- Prevent Clogging of Pavement Surface with Sediment
    - Vacuum pavement twice per year
    - Maintain planted areas adjacent to pavement
    - Immediately clean any soil deposited on pavement
    - Do not allow construction staging, soil/mulch storage, etc. on unprotected pavement surface
    - Clean inlets draining to the subsurface bed twice per year

- Snow/Ice Removal
    - Porous pavement systems generally perform better and require less treatment than standard pavements
    - Do not apply abrasives such as sand or cinders on or adjacent to porous pavement
    - Snow plowing is fine but should be done carefully (i.e. set the blade slightly higher than usual)
    - Salt application is acceptable, although more environmentally-benign deicers are preferable

- Repairs
    - Surface should never be seal-coated
    - Damaged areas less than 50 square feet can be patched with porous or standard asphalt
    - Larger areas should be patched with an approved porous asphalt

Winter Maintenance

Winter maintenance for a porous parking lot may be necessary but is usually less intensive than that required for a standard asphalt lot. By its very nature, a porous pavement system with subsurface aggregate bed has superior snow melting characteristics than standard pavement. The underlying stone bed tends to absorb and retain heat so that freezing rain and snow melt faster on porous pavement. Therefore, ice and light snow accumulation are generally not as problematic. However, snow will accumulate during heavier storms. Abrasives such as sand or cinders should not be applied on or adjacent to the porous pavement. Snow plowing is fine, provided it is done carefully (i.e. by setting the blade slightly higher than usual, about an inch). Salt is acceptable for use as a deicer on the porous pavement, though non-toxic, organic deicers, applied either as blended, magnesium chloride-based liquid products or as pretreated salt, are preferable.

Repairs

Potholes in the porous pavement are extremely unlikely; though settling might occur if a soft spot in the subgrade is not removed during construction. For damaged areas of less than 50 square feet, a declivity could be patched by any means suitable with standard pavement, with the loss of porosity of that area being insignificant. The declivity can also be filled with porous mix. If an area greater than 50 SF is in need of repair, approval of patch type must be sought from either the engineer or owner. Under no circumstance is the pavement surface to ever be seal coated.

Any required repair of drainage structures should be done promptly to ensure continued proper functioning of the system.

Cost Issues

Porous Asphalt, with additives, is generally 10% to 20% higher in cost than standard asphalt on a unit area basis.

Porous Concrete as a material is generally more expensive than asphalt and requires more labor and experience for installation due to specific material constraints.

Porous Paver Blocks vary in cost depending on type and manufacturer.

The added cost of a porous pavement/infiltration system lies in the underlying stone bed, which is generally deeper than a conventional sub-base and wrapped in geotextile. However, this additional cost is often offset by the significant reduction in the required number of inlets and pipes. Also, since porous pavement areas are often incorporated into the natural topography of a site, there generally is less earthwork and/or deep excavations involved. Furthermore, porous pavement areas with subsurface infiltration beds often eliminate the need (and associated costs, space, etc.) for detention basins. When all of these factors are considered, porous pavement with infiltration has proven itself less expensive than the traditional approach. Recent installations have averaged between $2000 and $2500 per parking space, for the pavement and stormwater management.

Specifications

The following specifications are provided for information purposes only. These specifications include information on acceptable materials for typical applications, but are by no means exclusive or limiting. The designer is responsible for developing detailed specifications for individual design projects in accordance with the project conditions.

1. **Stone** for infiltration beds shall be 2-inch to 1-inch uniformly graded coarse aggregate, with a wash loss of no more than 0.5%, AASHTO size number 3 per AASHTO Specifications, Part I, 19th Ed., 1998, or later and shall have voids ^{3} 35% as measured by ASTM-C29. Choker base course aggregate for beds shall be 3/8 inch to 3/4 inch uniformly graded coarse aggregate AASHTO size number 57 per Table 4, AASHTO Specifications, Part I, 13th Ed., 1998 (p. 47).

2. **Non-Woven Geotextile** shall consist of needled non-woven polypropylene fibers and meet the following properties:

a. Grab Tensile Strength (ASTM-D4632)	≥ 120 lbs
b. Mullen Burst Strength (ASTM-D3786)	≥ 225 psi
c. Flow Rate (ASTM-D4491)	≥ 95 gal/min/ft^2
d. UV Resistance after 500 hrs (ASTM-D4355)	≥ 70%
e. Heat-set or heat-calendared fabrics are not permitted.	

Acceptable types include Mirafi 140N, Amoco 4547, and Geotex 451.

3. **Pipe** shall be continuously perforated, smooth interior, with a minimum inside diameter of 8-inches. High-density polyethylene (HDPE) pipe shall meet AASHTO M252, Type S or AASHTO M294, Type S.

4. **Storm Drain Inlets and Structures**

a. Concrete Construction: Concrete construction shall be in accordance with Section 1001, PennDOT Specifications, 1990 or latest edition.

b. Precast Concrete Inlets and Manholes: Precast concrete inlets may be substituted for cast-in-place structures and shall be constructed as specified for cast-in-place. Precast structures may be used in only those areas where there is no conflict with existing underground structures which may necessitate revision of inverts. Precast structures shall be placed on a 6 inch bed of compacted coarse aggregate Size No. 2A. Reinforcement steel, if required for handling, shall have a minimum of 2-inch cover. Handling devices, if used, shall be removable and the holes filled with concrete. Type M standard PennDOT inlet boxes will be modified to provide minimum 12" sump storage and bottom leaching basins, open to gravel sumps in sub-grade, when situated in the recharge bed.

c. All PVC Catch Basins/Cleanouts/Inline Drains shall have H-10 or H-20 rated grates, depending on their placement (H-20 if vehicular loading).

d. Steel reinforcing bars over the top of the outlet structure shall conform to ASTM A615, grades 60 and 40.

e. HDPE Flared End Section shall be installed according to manufacturers' specifications.

f. Permanent turf reinforcement matting shall be installed according to manufacturers' specifications.

5. **Porous Bituminous Asphalt**

Bituminous surface course for **porous paving** shall be two and one-half (2.5) inches thick with a bituminous mix of 5.75% to 6% by weight dry aggregate. In accordance with ASTM D6390, drain down of the binder shall be no greater than 0.3%. If more absorptive aggregates, such as limestone, are used in the mix, then the amount of bitumen is to be based on the testing procedures outlined in the National Asphalt Pavement Association's Information Series 131 – "Porous Asphalt Pavements" (2003) or PennDOT equivalent.

Use neat asphalt binder modified with an elastomeric polymer to produce a binder meeting the requirements of PG 76-22 as specified in AASHTO MP-1. The elastomer polymer shall be styrene-butadiene-styrene (SBS), or approved equal, applied at a rate of 3% by weight of the total binder. The composite materials shall be thoroughly blended at the asphalt refinery or terminal prior to being loaded into the transport vehicle. The polymer modified asphalt binder shall be heat and storage stable.

Aggregate shall be minimum 90% crushed material and have a gradation of:

U.S. Standard Sieve Size	Percent Passing
½ (12.5 mm)	100
3/8 (9.5 mm)	92-98
4 (4.75 mm)	34-40
8 (2.36 mm)	14-20
16 (1.18 mm)	7-13
30 (0.60 mm)	0-4
200 (0.075mm)	0-2

Add hydrated lime at a dosage rate of 1.0% by weight of the total dry aggregate to mixes containing granite. Hydrated lime shall meet the requirements of ASTM C 977. The additive must be able to prevent the separation of the asphalt binder from the aggregate and achieve a required tensile strength ratio (TSR) of at least 80% on the asphalt mix when tested in accordance with AASHTO T 283. The asphaltic mix shall be tested for its resistance to stripping by water in accordance with ASTM D-1664. If the estimated coating area is not above 95 percent, anti-stripping agents shall be added to the asphalt.

Porous pavement shall not be installed on wet surfaces or when the ambient air temperature is 60 degrees Fahrenheit or lower. The temperature of the bituminous mix shall be between 300 degrees Fahrenheit and 350 degrees Fahrenheit (based on the recommendations of the asphalt supplier).

6. <u>Porous Concrete</u>

GENERAL

Weather Limitations:
Do not place Portland cement pervious pavement mixtures when the ambient temperature is 40 degrees Fahrenheit or lower, unless otherwise permitted in writing by the Engineer.

Test Panels: Regardless of qualification, Contractor is to place, joint and cure two test panels, each to be a minimum of 225 sq. ft. at the required project thickness to demonstrate to the Engineer's satisfaction that in-place unit weights can be achieved and a satisfactory pavement can be installed at the site location.

Test panels may be placed at any of the specified Portland Cement pervious locations. Test panels shall be tested for thickness in accordance with ASTM C 42; void structure in accordance with ASTM C 138; and for core unit weight in accordance with ASTM C 140, paragraph 6.3. Satisfactory performance of the test panels will be determined by:

Compacted thickness no less than ¼” of specified thickness.

Void Structure: 12% minimum; 21% maximum.
Unit weight plus or minus 5 pcf of the design unit weight.
If measured void structure falls below 15% or if measured thickness is greater than ¼” less than the specified thickness of if measured weight falls less than 5 pcf below unit weight, the test panel shall be removed at the contractor’s expense and disposed of in an approved landfill.
If the test panel meets the above-mentioned requirements, it can be left in-place and included in the completed work.

CONCRETE MIX DESIGN
Contractor shall furnish a proposed mix design with proportions of materials to the Engineer prior to commencement of work. The data shall include unit weights determined in accordance with ASTM C29 paragraph 11, jigging procedure.

MATERIALS
Cement: Portland Cement Type I or II conforming to ASTM C 150 or Portland Cement Type IP or IS conforming to ASTM C 595.

Aggregate: Use No 8 coarse aggregate (3/8 to No. 16) per ASTM C 33 or No. 89 coarse aggregate (3/8 to No. 50) per ASTM D 448. If other gradation of aggregate is to be used, submit data on proposed material to owner for approval.

Air Entraining Agent: Shall comply with ASTM C 260 and shall be used to improve resistance to freeze/thaw cycles.

Admixtures: The following admixtures shall be used:
Type D Water Reducing/Retarding – ASTM C 494.
A hydration stabilizer that also meets the requirements of ASTM C 494 Type B Retarding or Type D Water Reducing/Retarding admixtures. This stabilizer suspends cement hydration by forming a protective barrier around the cementitious particles, which delays the particles from achieving initial set.

Water: Potable shall be used.

Proportions:
Cement Content: For pavements subjected to vehicular traffic loading, the total cementitious material shall not be less than 600 lbs. Per cu.yd.
Aggregate Content: the volume of aggregate per cu. yd. shall be equal to 27 cu.ft. when calculated as a function of the unit weight determined in accordance with ASTM C 29 jigging procedure. Fine aggregate, if used, should not exceed 3 cu. ft. and shall be included in the total aggregate volume.
Admixtures: Shall be used in accordance with the manufacturer’s instructions and recommendations.

Mix Water: Mix water shall be such that the cement paste displays a wet metallic sheen without causing the paste to flow from the aggregate. (Mix water yielding a cement paste with a dull-dry appearance has insufficient water for hydration).

- Insufficient water results in inconsistency in the mix and poor bond strength.
- High water content results in the paste sealing the void system primarily at the bottom and poor surface bond.

An aggregate/cement (A/C) ratio range of 4:1 to 4.5:1 and a water/cement (W/C) ratio range of 0.34 to 0.40 should produce pervious pavement of satisfactory properties in regard to permeability, load carrying capacity, and durability characteristics.

INSTALLATION
Portland Cement Pervious Pavement Concrete Mixing, Hauling and Placing:
Mix Time: Truck mixers shall be operated at the speed designated as mixing speed by the manufacturer for 75 to 100 revolutions of the drum.

Transportation: The Portland Cement aggregate mixture may be transported or mixed on site and should be used within one (1) hour of the introduction of mix water, unless otherwise approved by an engineer. This time can be increased to 90 minutes when utilizing the hydration stabilizer specified in Section 2.2.C.4. Each truck should not haul more than two (2) loads before being cycled to another type concrete.
Prior to placing concrete, the subbase shall be moistenened and in a wet condition. Failure to provide a moist subbase will result in a reduction in strength of the pavement.

Discharge: Each mixer truck will be inspected for appearance of concrete uniformity according to Section 2.2.C.6.d. Water may be added to obtain the required mix consistency. A minimum of 20 revolutions at the manufacturer's designated mixing speed shall be required following any addition of water to the mix. Discharge shall be a continuous operation and shall be completed as quickly as possible. Concrete shall be deposited as close to its final position as practicable and such that fresh concrete enters the mass of previously placed concrete. The practice of discharging onto subgrade and pulling or shoveling to final placement is not allowed.

Placing and Finishing Equipment: Unless otherwise approved by the Owner or Engineer in writing, the Contractor shall provide mechanical equipment of either slipform or form riding with a following compactive unit that will provide a minimum of 10 psi vertical force. The pervious concrete pavement will be placed to the required cross section and shall not deviate more than +/- 3/8 inch in 10 feet from profile grade. If placing equipment does not provide the minimum specified vertical force, a full width roller or other full width compaction device that provides sufficient compactive effort shall be used immediately following the strike-off operation. After mechanical or other approved strike-off and compaction operation, no other finishing operation will be allowed. If vibration, internal or surface applied, is used, it shall be shut off immediately when forward progress is halted for any reason. The Contractor will be restricted to pavement placement widths of a maximum of fifteen (15') feet unless the Contractor can demonstrate competence to provide pavement placement widths greater than the maximum specified to the satisfaction of the Engineer.

Curing: Curing procedures shall begin within 20 minutes after the final placement operations. The pavement surface shall be covered with a minimum six-(6) mil thick polyethylene sheet or other approved covering material. Prior to covering, a fog or light mist shall be sprayed above the surface when required due to ambient conditions (high temperature, high wind, and low humidity). The cover shall overlap all exposed edges and shall be secured (without using dirt or stone) to prevent dislocation due to winds or adjacent traffic conditions.

Cure Time:
1. Portland Cement Type I, II, or IS – 7 days minimum.
2. No truck traffic shall be allowed for 10 days (no passenger car/light trucks for 7 days).

Jointing: Control (contraction) joints shall be installed at 20-foot intervals. They shall be installed at a depth of the 1/ 4 the thickness of the pavement. These joints can be installed in the plastic concrete or saw cut. If saw cut, the procedure should begin as soon as the pavement has hardened sufficiently to prevent raveling and uncontrolled cracking (normally after curing). Transverse constructions joints shall be installed whenever placing is suspended a sufficient length of time that concrete may begin to harden. In order to assure aggregate bond at construction joints, a bonding agent suitable for bonding fresh concrete shall be brushed, tolled, or sprayed on the existing pavement surface edge. Isolation (expansion) joints will not be used except when pavement is abutting slabs or other adjoining structures.

TESTING, INSPECTION, AND ACCEPTANCE

Laboratory Testing:

The owner will retain an independent testing laboratory. The testing laboratory shall conform to the applicable requirements of ASTM E 329 “Standard Recommended Practice for Inspection and Testing Agencies for Concrete, Steel, and Bituminous Materials as Used in Construction” and ASTM C 1077 “Standard Practice for Testing Concrete and Concrete Aggregates for use in Construction, and Criteria for Laboratory Evaluation” and shall be inspected and accredited by the Construction Materials Engineering Council, Inc. or by an equivalent recognized national authority. The Agent of the testing laboratory performing field sampling and testing of concrete shall be certified by the American Concrete Institute as a Concrete Field Testing Technician Grade I, or by a recognized state or national authority for an equivalent level of competence.

Testing and Acceptance:

A minimum of 1 gradation test of the subgrade is required every 5000 square feet to determine percent passing the No. 200 sieve per ASTM C 117.

A minimum of one test for each day’s placement of pervious concrete in accordance with ASTM C 172 and ASTM C 29 to verify unit weight shall be conducted. Delivered unit weights are to be determined in accordance with ASTM C 29 using a 0.25 cubic foot cylindrical metal measure. The measure is to be filled and compacted in accordance with ASTM C 29 paragraph 11, jigging procedure. The unit weight of the delivered concrete shall be +/- 5 pcf of the design unit weight.

Test panels shall have two cores taken from each panel in accordance with ASTM 42 at a minimum of seven (7) days after placement of the pervious concrete. The cores shall be measured for thickness, void structure, and unit weight. Untrimmed, hardened core samples shall be used to determine placement thickness. The average of all production cores shall not be less than the specified thickness with no individual core being more than ½ inch less than the specified thickness. After thickness determination, the cores shall be trimmed and measured for unit weight in the saturated condition as described in paragraph 6.3.1 of ‘Saturation’ of ASTM C 140 “Standard Methods of Sampling and Testing Concrete Masonry Units.” The trimmed cores shall be immersed in water for 24 hours, allowed to drain for one (1) minute, surface water removed with a damp cloth, then weighed immediately. Range of satisfactory unit weight values are +/- 5 pcf of the design unit weight.

After a minimum of 7 days following each placement, three cores shall be taken in accordance with ASTM C 42. The cores shall be measured for thickness and unit weight determined as described above for test panels. Core holes shall be filled with concrete meeting the pervious mix design.

References and Additional Sources