Permeable Pavement

[STRATEGY]

Brief Description

Permeable pavement systems, also referred to as pervious or porous paving, allow stormwater runoff to filter through the pavement section and infiltrate into the soil below. By allowing the water to infiltrate into the ground, the water undergoes absorption, filtration and microbiological degradation; in turn, reducing pollutants entering downstream water bodies. Permeable pavements also reduce the volume and velocity of stormwater runoff off site. There are four types of permeable pavement systems: pervious concrete (PC), porous asphalt (PA), reinforced turf or gravel (RT or RG), and permeable interlocking concrete pavers (PICP). All four variations include a surface pavement layer, aggregate bedding and base layers, filter fabric, and an underdrain if required.

By allowing stormwater runoff to infiltrate the pavement surface, permeable pavements reduce runoff and filter sediments and pollutants prior to entering underlying soils or discharging to the stormwater conveyance system via underdrain.

Applications

- Parking Lots
- Roadways, Residential Streets
- Driveways
- Sidewalks
- Recreation Facilities: Playgrounds, Tennis Courts, Trails
- Emergency Access Roads and Fire Lanes
- Maintenance Drives
- Overflow Parking Areas

(a) (b) (c) (d) (e)

(a) Reinforced Turf Concrete Grid Paver Driveway (Source: www.buildinggreentv.com)
(b) Porous Asphalt Roadway/Path (Source: creativeconcrete4you.com)
(c) Concrete Permeable Paver Plaza (Source: http://www.uni-groupusa.org/)
(d) Reinforced GravelTrail (Source: http:// www.ia.nrcs.usda.gov)
(e) Concrete Permeable Paver Patio (Source: http://www.uni-groupusa.org/)

Design Notes

Design Considerations for all Permeable Pavement

- Consider traffic volume and loading criteria in project area.
- Pavement design engineer and stormwater design engineer must coordinate

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to ensure the pavement meets both the structural pavement design criteria and the stormwater management requirements.

- Permeable pavement requires regular maintenance to maintain porosity (See Operations and Maintenance section).
- Permeable pavement should be sited at least 2-5 feet above the seasonally high ground water table, and at least 100 feet away from drinking water wells.
- Materials can be specified with recycled content.
- Permeable pavements should not be used in "hot spots" (fuel areas, industrial storage, vehicle maintenance, etc.) where there is potential to contaminate underlying soils.

Code Restrictions

- State and/or local stormwater management regulations may control the hydrologic design.
- Structural design of the pavement section must comply with applicable pavement design criteria. Consult pavement design engineer.

Pervious Concrete

- Similar to conventional concrete, though smaller amounts of fines, larger pea gravel, and a lower water-to-cement ratio are used to achieve more voids and an open surface.
- Care must be taken during placement to avoid removing the voids and smoothing the surface, which could reduce porosity.
- Since the concrete mix has more voids, the concrete strength is typically less than conventional concrete. Pavement designer should take this into account.

Reinforced Turf or Gravel

- Reinforced turf or gravel consists of interlocking concrete grid or plastic geogrid units that contain voids for grass growth or open-graded gravel fill. The pervious surface performs similar to the hydrology of a traditional lawn area but can support traffic loads and parking.
- The reinforced turf is underlain by a stone and/or sand layer to filter pollutants and temporarily store runoff.
- 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.
- Reinforced turf applications work well for fire access roads, overflow

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parking, and occasional use parking. The reinforced turf grids provide a support structure for heavy vehicles, and prevent erosion.

Permeable Concrete Pavers

- Permeable pavers consist of interlocking concrete pavers with pea gravel filling the spaces between pavers.
- Runoff passes through the pervious spaces between pavers to the open-graded aggregate layers and infiltrates into the underlying soils below.
- Permeable pavers are most often used for driveways, parking areas, entrance drives, walkways, plazas, patios or terraces to achieve a more aesthetically pleasing appearance.

Porous Asphalt

- UFC 3-201-01 Civil Engineering does not allow porous asphalt on DoD facilities.
- Similar to conventional asphalt, except that the fines (sand and finer material) from parent asphalt mix are removed.
- Bituminous mix design critical to the porous asphalt performance.

Figure 1 Permeable Concrete Pavers (Source: Fort George G. Meade Department of Public Works)

Related Technologies **Low Impact Development**

References/Useful Resources:
[1] Army Low Impact Development Technical User guide
http://www.usace.army.mil/Portals/2/docs/Sustainability/Hydrology_LID
[2] UFC 3-201-01, Civil Engineering, www.wbdg.org

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Environmental Impacts

Stormwater Management (Quality and Quantity Control)

- Permeable pavement filters pollutants which enhances downstream water quality.
- Permeable pavement reduces stormwater quantity by infiltrating runoff across the pavement surface instead of concentrating flow to stormwater conveyance systemsover impervious pavement.

Guiding Principles[1]

Protect & Conserve Water

- Employ low impact development design and construction strategies that reduce stormwater runoff and pollutant discharges offsite.
- Per the Energy Independence and Security Act (EISA) Section 438, to the maximum extent technically feasible, maintain or restore the predevelopment hydrology of the site with regard to temperature, rate, volume, and duration of flow using site planning, design, construction, and maintenance strategies.

Associated LEED Credits (NC 2009)[2]

SS Credit 6.1: Stormwater Design- Quantity Control

- Stormwater runoff is infiltrated on site by the permeable pavement system, reducing the peak discharge rate and volume.
- The area of permeable pavement acts like a pervious surface rather than an impervious surface, thereby reducing impervious cover.

SS Credit 6.2: Stormwater Design- Quality Control

- Open-graded aggregate base and subbase layers in a permeable pavement section filter pollutants from stormwater runoff, especially total suspended solids (TSS).
- To earn this credit, the permeable pavement design must comply with state and/or local stormwater management performance standards, OR field performance monitoring data can demonstrate compliance with the performance standards listed in the LEED Reference Guide.

SS Credit 7.1: SHeat Island Reduction- Nonroof

- Pervious concrete, reinforced turf or gravel, and permeable concrete pavers have high solar reflectivity to help achieve this credit.

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[1] Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings www.wbdg.org/pdfs/hpsb_guidance.pdf

[2] USGBC LEED Reference Guide for Green Building Design and Construction, 2009 Edition

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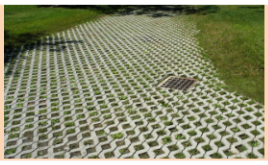
Type	Product	Vendors	Material Cost per Square Foot	Estimated Strength (psi)	Primary Applications	Product Image
PA	Permeable Asphalt	Various	$0.50 - $1.00	500 - 4,000	Roadway, Parking Lots, Paths	
PC	Permeable Concrete	NRMCA PCA	$2.00 - $7.00	500 - 4,000	Roadway, Parking Lots, Paths	
PG With Grass	Checkerblock	Hastings Pavement Co.	$3.00 - $4.00	2,000 - 5,500	Emergency Access Areas, Driveways, Plazas	
	Geoblock®	Presto Products, Inc.	$1.00 - $2.00	2,000 - 5,500	Emergency Access Areas, Driveways, Plazas	
PG With Gravel	Geoweb®	Presto Products, Inc	$2.00 - $3.00	5,500	Roadway, Parking Lots, Yards, Paths	
	Gravelpave™	Invisible Structures, Inc	$1.00 - $2.00	5,700	Roadway, Parking Lots, Yards, Paths	
CGP	Turfstone	UNILOCK®	$2.00 - $3.00	≥ 5,000 psi	Roadway, Driveways, Patios, Boat Ramps	
PICP	UNI-Eco-stone	Uni-Group USA	$4.00 - $8.00	> 8,000 psi	Roadway, Parking lots, Ports, Airports	

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Typical Permeable Pavement Cross Section

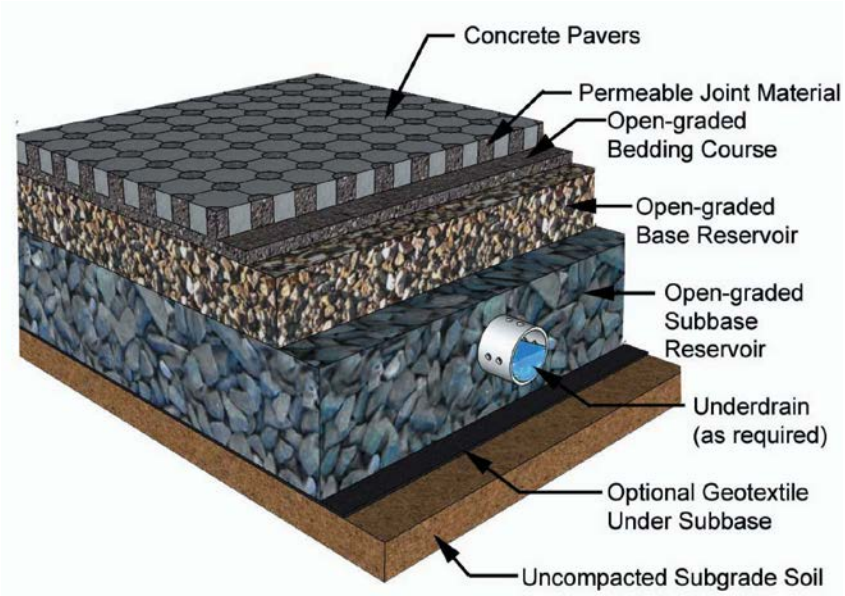

Figure 2 Permeable Pavement Cross Section

(Source: Interlocking Concrete Pavement Institute http://www.icpi.org/)

Component	Specification
Concrete Pavers	3⅛ inch Uni-Ecoloc® in conjunction with solid 3⅛ inch UNI-Anchorlock®
Permeable Joint Material	ASTM No. 8 Pea Gravel
Open-Graded Bedding Course	2 inches thick (ASTM No. 8 Pea Gravel)
Open-Graded Base Aggregate	4 inches thick (ASTM No. 57 Stone)
Open-Graded Subbase Aggregate	12-24 inches thick (ASTM No. 2 Stone)
Underdrain	As required stormwater management design
Geotextile	As required to prevent migration of soil into the aggregate base layers
Subgrade	Consult geotechnical engineer, subgrade should only be compacted enough to support pavement section but not prevent infiltration

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Sample Specifications[3]

1.0 QUALITY ASSURANCE

A. Paver Manufacturer's Qualifications
The manufacturer shall demonstrate a minimum of 5 years successful experience in the manufacture of the applicable permeable pavement type.

B. Paver Installer's Qualifications
Pavers installers shall demonstrate a minimum of 5 years experience in the installation of permeable pavement system similar in size and nature to the project.

2.0 MATERIALS

A. Pavement
1. Permeability: Not less than 1 inch/hour.
2. Permeable Concrete Paver: The permeable concrete paver shall conform to ASTM C 936, and shall be minimum 3-1/8 inch thick, with minimum 8% surface area open. Pigmentation shall conform to ASTM C 979. Spacers shall be formed into paver for interlock integrity and joints shall meet ADA guidelines. Concrete grid paver units shall comply with ASTM C1319. Average compressive strength of 8,000 psi with no individual paver under 7,200 psi. Maximum 1% loss in dry mass per unit in minimum 50 freeze-thaw cycles when tested in accordance with ASTM C 67.
3. Pervious Concrete: Minimum **Solar Reflectance of 0.3, Solar Reflectance Index (SRI) of 29**. Minimum permeability rate **[60] [xxxx]** percent or not less than an infiltration rate of 1.1 in/hr for a 20-year design life. Determine the permeability rate of in place pervious concrete in accordance with ASTM C1701. Determine the density and void content of freshly mixed pervious concrete in accordance with ASTM C1688. Verify that mixture proportions are as designed.
4. Reinforced Turf or Gravel: Interlocking plastic geogrid shall have minimum compressive strength of 5720 psi. Soil and seed mixture shall meet manufacturer instructions.

B. Aggregate

[3] Specification language provided is a combination of the Whole Building Design Guide's *Federal Green Construction Guide for Specifiers,* Section 1 32 12 43 (02795) - POROUS PAVING (Accessed August 2012 at http://www.wbdg.org/ccb/browse_org.php?o=84) and specification language from U.S. Army Corps of Engineers, Baltimore District (August 2015).

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1. Bedding Course and Joint Filler: The bedding course and void filler (joint filler) aggregate shall conform to ASTM C 33, Class 5S, size designation No. 8.
2. Base Course Aggregate: Base Course aggregate shall conform to ASTM C 33, Class 5S, size designation No. 57.
3. Subbase Course Aggregate: Subbase aggregate shall conform to ASTM C 33, Class 5S, size designation No. 357 or No. 2 per designer of record.

C. Geotextile fabric: Comply with AASHTO M288 based on application and installation conditions. Verify compatibility between geotextile and adjacent soils for filtration, clogging and permeability.

3.0 INSTALLATION

A. Subgrade
The subgrade shall be constructed to the specified grade and cross section prior to placement of the subbase. To ensure a permeable subgrade, the in-situ soils (i.e. subrade) in fill and cut areas shall NOT be compacted prior to placing the non-woven geotextile and/or subbase course.

B. Fill Material
Where fill is required to meet finished grades beneath the pavers, fill shall consist of Subbase Course placed and compacted as indicated in paragraph PLACEMENT OF SUBBASE COURSE.

C. Placement Of Subbase Course
Subbase shall be placed in lifts not exceeding 6 inches in loose thickness and compacted with a minimum of 6 passes using a vibratory 10-15 ton smooth drum roller. The completed subbase shall then be proof-rolled with a 10 ton tandem dump truck to identify any areas requiring additional compaction.

D. Placement Of Base Course
Base course shall be placed in one lift not exceeding 6 inches in loose thickness and compacted with a minimum of 6 passes using a vibratory 10-15 ton smooth drum roller.

E. Placement Of Bedding Course
Bedding course shall be placed in one lift not exceeding 6 inches in loose thickness and compacted with a minimum of 6 passes using a vibratory 10-15 ton smooth drum roller. Contractor shall screed the bedding course using either an approved mechanical screed or by use of screed guides and boards to produce a smooth level course. The screeded bedding aggregate shall not be subjected to any traffic (mechanical or pedestrian) prior to installation of the paver units. Voids left after the removal of the screed rails shall be filled with aggregate as the paver bedding course proceeds.

F. Placement of Permeable Pavement (refer to designer of record and manufacturer for instructions for applicable type of permeable pavement).

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4.0 MAINTENANCE
Contractor shall provide O&M plan to owner at the completion of the work. Provide 5 percent pavers or reinforced turf geogrid matching those used in the project. Provide copy of mix design for pervious concrete or porous asphalt to owner for future repairs.

5.0 CLEANUP
Sweep the entire pavement surface and remove all excess sand, blocks and debris from the project area.

Maintenance Requirements

The primary goal of permeable pavement maintenance is to prevent the pavement surface and the underlying infiltration-bed from becoming clogged with fine sediments. The pavement surface should be swept and vacuumed with a commercial vacuum sweeper unit annually at a minimum. Designer of record may recommend sweeping/vacuuming more frequently depending on pavement use and sediment loading. Use of conventional power washing is not recommended; compression systems can push sediments deeper in the pavement section.

Planted areas adjacent to pervious pavement should be well maintained and fully stabilized to prevent mulch and soil washout onto the pavement surface. If washout does occur, it should be cleaned off the pavement immediately to prevent clogging of the system. Replant or reseed bare spots and eroded areas as needed. Debris and trash observed during routine inspections should be removed. Prevent construction vehicles from tracking and spilling sediment onto the permeable pavement.

Snow removal for permeable pavement is less intensive than for conventional pavement. Permeable pavement with subsurface aggregate has superior snow melting characteristics compared to standard pavements. The underlying stone bed tends to absorb and retain heat, so snow and ice melt faster on pervious surfaces. For accumulated snow, set plow blades approximately 1 inch above the pavement surface. Salt is acceptable for use as a deicer on the pervious surface; though nontoxic, organic deicers, applied either as blended, magnesium chloride-based liquid products or as pre-treated salt, are preferable. Sand should never be used.

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Maintenance contracts should clearly specify permeable pavement maintenance activities. See table below for suggested maintenance activities and frequencies.

Suggested Maintenance Activities for Permeable Pavement

Task	Frequency	Maintenance Notes
Sweep and Vacuum Pavement	Semi-annually	Commercial sweeper/vacuum unit.
Clean Inlets, Drainage Pipe, Stone Edge Drains	Semi-annually	Remove sediment and debris.
Water Reinforced Turf and Grass-filled Open Grid Pavement	Regularly	Reseed as needed.
Clean Up Sediment Deposited on Pavement	As Needed	Inspect after heavy rains.
Maintain Planted Areas adjacent to Permeable Pavement	Regularly	Prevent mulch and soil washout onto pavement surface.
Snow Removal	As Needed	Raise plow blade 1 inch higher. Do not use sand

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Emergency Services Center[4]

Fort Detrick, Maryland

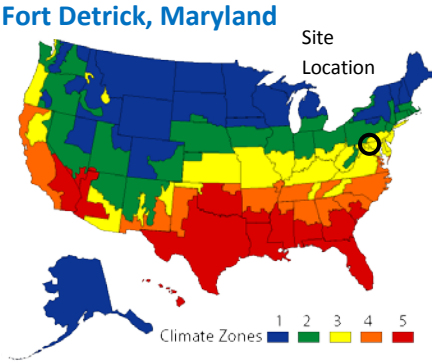

Figure 3 Parking Lot Permeable Concrete Pavers
(Source: USACE, Baltimore District)

Facility

- This project consisted of the design and construction of a new emergency services center and associated parking lot at Fort Detrick in Frederick, Maryland. The site limit of disturbance was approximately 3 acres.
- The parking lot included permeable concrete pavers in the POV parking stalls.

Approach

- The permeable pavers section includes 3-1/8" thick concrete blocks meeting ASTM C 936. Below the pavers, there is a 2" pea gravel bedding layer, followed by 4" No. 57 stone. The subbase layer is 12" No. 2 stone. Concrete edge restraints provide a transition between the pavers and adjacent pavement and turf areas.
- A 2" perforated PVC overdrain is set higher in the subbase to allow infiltration to the subgrade. As the infiltration slows, the overdrain will drain the section.
- The parking lot does not have curb and gutter, to allow sheet flow into adjacent swales during heavy storms.
- The pavers were installed after adjacent areas were stabilized in order to prevent sediment loading to the section.

[4] Case Study courtesy of U.S. Army Corps of Engineers, Baltimore District

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Construction Details	
Pavers	$3^{1}/_{8}$" thick paver
Bedding & Joints	2" AASHTO No. 8 Stone
Base	4" AASHTO No. 57 Stone
Subbase	12" AASHTO No. 2 Stone
Subgrade	Silty Clay

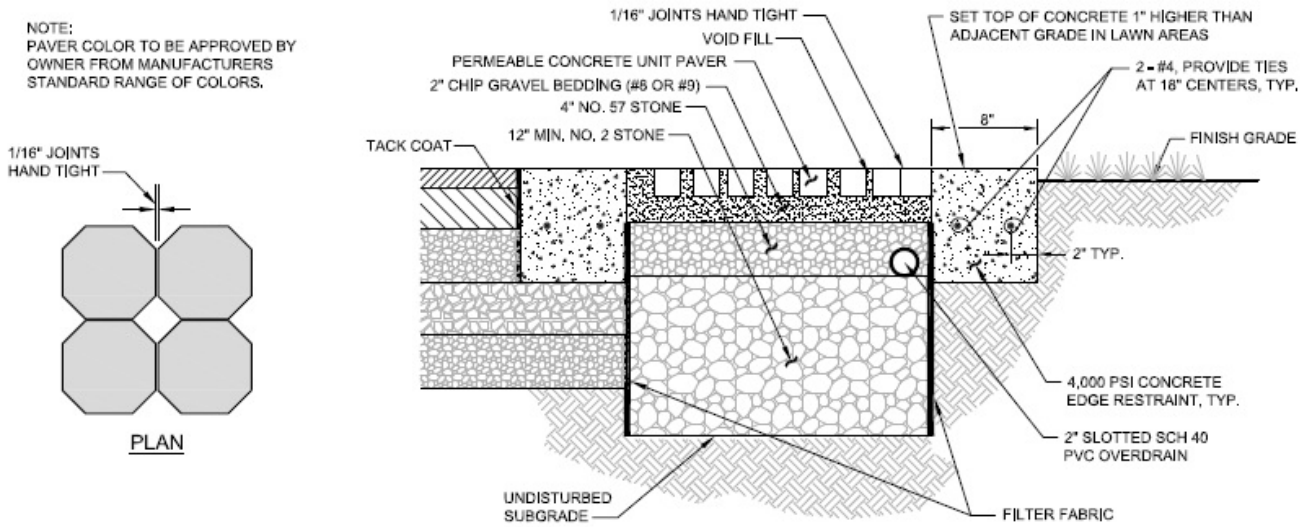

Figure 4 Permeable Paver Detail from Contract Drawing

(Source: USACE, Baltimore District)

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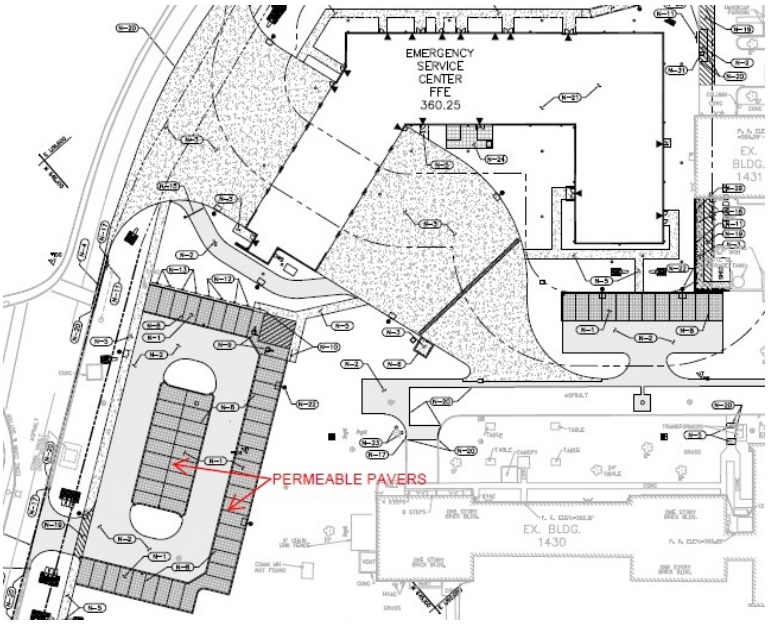

Figure 5 Site Plan

(Source: USACE, Baltimore District)

Results

- The contract drawings provided a maintenance instructions including annual sweeping using a commercial sweeping/vacuum truck. Lost pea gravel in the paver voids should be replaced after the vacuuming operation. Snow plow blades should be set 1" above grade to prevent damage to the pavers. Deicing agents that are non-toxic and organic can be applied, such as calcium magnesium acetate and pretreated deicing salt.
- In addition to bioswales on site and the building's green roof, the permeable pavers contribute to the project's compliance with the Maryland Department of the Environment (MDE) stormwater management requirements.

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HEADQUARTERS COMPLEX[5]

Fort Meade, Maryland

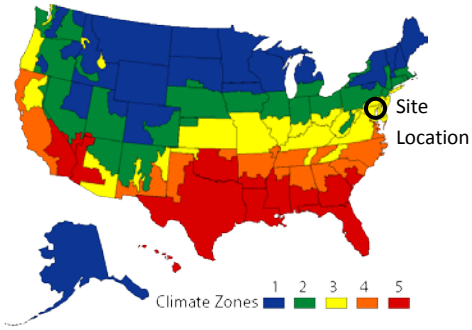

Figure 6 Concrete Permeable Pavers
(Source: USACE, Baltimore District)

Facility

- This project included the design and construction of a new headquarters complex including an administration building, visitor control center (VCC), parking lots, and supporting facilities at Fort Meade, Maryland. The site limit of disturbance was approximately 9 acres.

Approach

- The stormwater management plan implemented a combination of low impact development practices. The VCC parking lot and front entrance drop off circle are concrete permeable pavers. Curb cuts provided allow runoff during heavy rains to drain to adjacent grass areas.

Construction Details	
Pavers	$3^1/_8$" thick Belgard®
Square Footage	13,000
Bedding & Joints	2" AASHTO No. 8 Stone
Base	4" AASHTO No. 57 Stone
Subbase	12" AASHTO No. 357 Stone
Subgrade	Silty Sand

[5] Case Study courtesy of U.S. Army Corps of Engineers, Baltimore District

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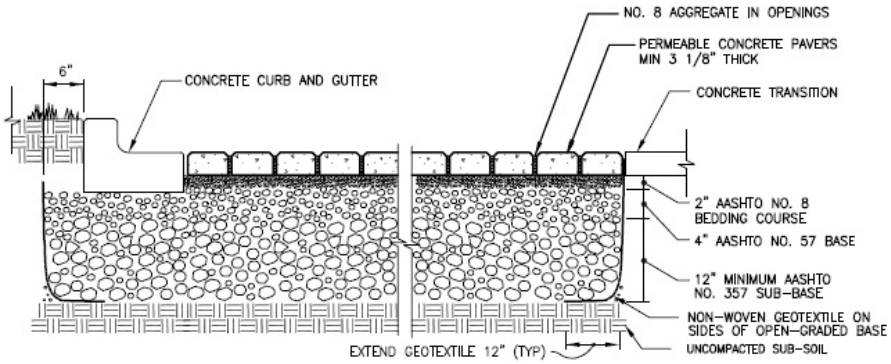

Figure 7 Permeable Paver Detail from Contract Drawings
(Source: USACE, Baltimore District)

Figure 8 Site Plan
(Source: USACE, Baltimore District)

Results

- The permeable pavement implemented, in addition to the site's grass swales, bioretention cells, and infiltration trenches, contributed to the project's to compliance with the Maryland Department of the Environment Environmental Site Design (ESD) stormwater management regulations for water quality and quantity. The design resulted in the post-development project site's hydrology mimicking a pre-development "woods in good condition" site.
- The in situ soils were sandy and classified as Hydrologic Soil Groups (HSG) A and B, with infiltration rates up to 100 in/hr, so no underdrain was required.
- The total construction contract cost of the permeable pavers was approximately $20 per square foot.

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