Pervious Pavement TC-13

Design Considerations
■ Accumulation of Metals
■ Clogged Soil Outlet Structures

Targeted Constituent	Removal
Sediment	High
Nutrients	Low
Trash	High
Metals	High
Bacteria	Med
Oil and Grease	Med
Organics	Low
Flow Control	Med

CASQA
CALIFORNIA STORMWATER QUALITY ASSOCIATION®

Description

Pervious (Permeable) Pavement describes a system which combines a load-bearing, durable surface with an underlying layered storage structure. Stormwater is temporarily stored prior to infiltration or discharge through an underdrain to a controlled outlet. The system can infiltrate water across the entire surface or through the spaces between impermeable blocks. Pervious paving may permit groundwater recharge where appropriate, or if unsuitable may be lined to discharge to an underdrain.

California Experience

Pervious pavement has been widely implemented across California in a variety of configurations to meet a full suite of regulatory requirements including in the Los Angeles Zoo parking lot (image above), incorporated in a green street in San Diego (Figure 1), and to create permeable plazas in San Francisco (Figure 2).

Figure 1. Pervious concrete parking lane in San Diego

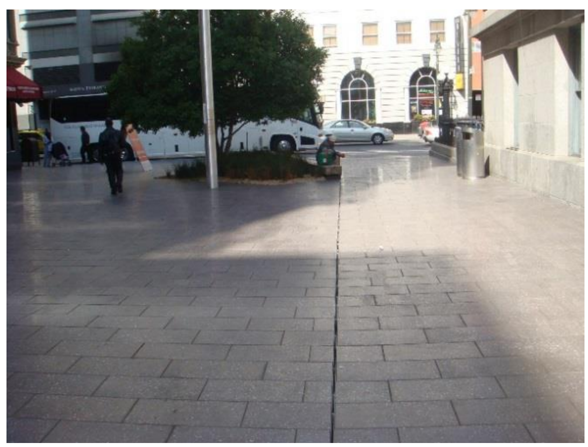


Figure 2. PICP plaza in San Francisco.

Advantages

- Offers a valuable stormwater management solution in spatially constrained urban areas which also serves as transportation infrastructure.

Limitations

- Permeable pavement can become clogged if improperly installed or maintained.
- Limited to paved areas with low traffic volumes, axle loads and speeds.

Performance

Attenuation of flow is provided by the storage within the underlying structure of the pavement. Volume reduction primarily depends on the drainage configuration and subsoil infiltration capacities. Systems installed without underdrains in highly permeable soils can achieve practically 100% volume reduction efficiency (Bean et al. 2007). Systems installed in restrictive clay soils can still give significant volume reduction (Tyner et al. 2009; Fassman and Blackbourn 2010). The volume reduction can be further enhanced by treating the subgrade with scarification, ripping, or trenching (Tyner et al. 2009; Brown and Hunt 2010), by omitting underdrains (where practicable), or by incorporating an internal water storage layer by upturning underdrain inverts to create a sump (Wardynski et al. 2013). Materials should create neutral or slightly alkaline conditions and they should provide favorable sites for colonization by microbial populations.

Peak flow can be also effectively attenuated by permeable pavement systems by reducing overall runoff volumes, promoting infiltration, and increasing the lag time to peak discharge (Collins et al. 2008). Table 1 details expected effluent concentrations and removal processes for each pollutant constituent.

Table 1. Typical pollutant removal for constituents and removal processes

Pollutant	Typical Removal	Median Effluent Concentration[1]	Removal Processes	References
Sediment	High[2] (32% to 96%)	24.9 mg/L	Settling on surface and in reservoir layer.	Bean et al. 2007; CWP 2007; Fassman and Blackbourn 2011; Gilbert and Clausen 2006; MWCOG 1983; Pagotto et al. 2000; Roseen et al. 2009, 2011; Rushton 2001; Schueler 1987; Toronto and Region Conservation Authority 2007; Scholes, 2007; Geosyntec Consultants and Wright Water Engineering 2012

Pollutant	Typical Removal	Median Effluent Concentration[1]	Removal Processes	References
Metals	High (65% to 84%)	TAs: 2.50 µg/L, TCd: 0.25 µg/L, TCr: 3.89 µg/L, TCu: 7.52 µg/L, TPb: 0.40 µg/L, TNi: 1.71 µg/L, TZn: 10.5 µg/L	Removal with sediment and possible sorption to aggregate base course.	Bean et al. 2007; Brattebo and Booth 2003; CWP 2007; Dierkes et al. 2002; Fassman and Blackbourn 2011; Gilbert and Clausen 2006;MWCOG 1983; Pagotto et al. 2000; Roseen et al. 2009, 2011; Rushton 2001; Schueler 1987; Toronto and Region Conservation Authority 2007; Geosyntec Consultants and Wright Water Engineering 2012
Hydro-carbons	High (92% to 99%)	N/A	Removal in surface course and aggregate layer.	Roseen et al. 2009, 2011
Total phosphorus	Low (20% to 78%)	0.100 mg/L	Settling with sediment, possible sorption to aggregate, and sorption to underlying soils.	Bean et al. 2007; CWP 2007; Gilbert and Clausen 2006; MWCOG 1983; Roseen et al. 2009, 2011; Rushton 2001; Schueler 1987; Toronto and Region Conservation Authority 2007; Geosyntec Consultants and Wright Water Engineering 2012; Yong et al. 2011
Total nitrogen	Low (-40% to 88%)	TKN: 1.00 mg/L *$NO_{2,3}$-N: 1.35 mg/L*	Settling, possible denitrification in IWS, sorption in underlying soils (TKN).	Collins et al. 2010; CWP 2007; MWCOG 1983; Schueler 1987; Geosyntec Consultants and Wright Water Engineering 2012
Bacteria	Medium	N/A	Sedimentation, filtration, sorption, desiccation, and predation in surface course and reservoir layer.	Myers et al. 2009; Tota-Maharaj and Scholz 2010;
Thermal load	Medium	58–73 °F	Heat transfer at depth, thermal buffering through profile, and thermal load reduction by volume reduction (infiltration). IWS enhances thermal load reduction.	Wardynski et al. 2013

[1] Underlined effluent concentrations were (statistically) significantly lower than influent concentrations, as determined by statistical hypothesis testing on the available sampled data. Effluent concentrations displayed in *italics* were (statistically) significantly higher than influent concentrations.

[2] Run-on from adjacent surfaces with high sediment yield can cause premature clogging of the surface course or subsurface interface. Permeable pavement should not be used to treat runoff from pervious surfaces or other areas with high sediment yield

Suitability and Design

If the grades, drainage characteristics, and traffic conditions are suitable, permeable paving may be substituted for conventional pavement on parking lots or other areas with light traffic. Car parking areas along residential streets, parking lots, and other lightly trafficked or non-trafficked areas are appropriate siting locations. The suitability of a pervious system should also consider loading criteria required of the pavement; if the area is to be used by heavy vehicles (e.g. garbage truck on residential street), there is a need to increase structural design. Fundamental design components are as follows:

- Geotechnical investigation required to identify soil infiltration rate and to design the subgrade to support the anticipated traffic load. If known soil contamination is present, infiltration is not allowed.
- When infiltrating, 10 feet of separation between bottom of bed and seasonal high water table.
- Materials should be able to sustain traffic loading without excessive deformation or cracking.
- Contain sufficient void space for storage of sediments to limit the period between maintenance.
- The sub-base and capping will be in contact with water, the strength and durability of the aggregate particles when saturated and subjected to wetting and drying should be assessed.

Pervious pavement design is highly dependent on the constraints of the considered site and local regulations. Permeable pavement is often considered self-treating with no run-on allowed while some municipalities do allow consideration of run-on from surrounding areas for treatment purposes. Costs will vary in accordance with the design. Table 2 details a number of core construction components and corresponding design considerations.

Table 2. Cost of design components and associated considerations

Component	Cost	Design Consideration
Excavation	$1.10–$2.25/ft^2	Underdrain required if subsoil infiltration rate < 0.5 in/hr. Provide orifice at underdrain outlet sized to release water quality volume over 2–5 days. Surface ponding should be provided (by curb and gutter) to capture design storm
Surface Course Pervious asphalt Pervious concrete PICP Plastic grid pavers	 $2.00/ft^2 $6.00/ft^2 $3.00/ft^2 $2.50/ft^2	Pervious concrete, porous asphalt, and permeable interlocking concrete pavers (PICP) are the preferred types of permeable pavement because detailed industry standards and certified installers are available.
Underdrain Pipe Includes drainage stone, assumes 5-foot spacing	$3.60/ft^2	4-inch diameter minimum, schedule 40 PVC pipe with perforations (slots or holes) every 6 inches at 0.5% slope. Provide cleanout ports/observation wells for each underdrain pipe.
Bedding/Reservoir Layer No. 8 aggregate (min. 2 in. thick) No. 57 stone (min. 6 in. thick)	 $0.22/ft^2 $0.83–$1.67/ft^2	Use a 2-inch bedding course of ASTM No. 8 stone on top a base layer of washed ASTM No. 57 stone (washed

Component	Cost	Design Consideration
		ASTM No. 2 may be used as a subbase layer for additional storage).
Hydraulic Restriction Layer 30-mil liner Concrete barrier	 $0.35/ft² $12.00/ft²	Subgrade slope should be 0.5% or flatter. Baffles should be used to ensure water quality volume is retained. Use hydraulic restriction layer on vertical surfaces to restrict lateral flows to adjacent subgrades, foundations, or utilities; also prevents soils from entering aggregate voids.

Surface Course Types

A number of surface course types are available for implementation. Porous asphalt and pervious concrete are similar in that they utilize the same mixing and application equipment as their traditional (i.e. non-pervious) counterparts. Permeable Interlocking Concrete Pavement (PICP) and grid pavers are other options that allow infiltration in void spaces between impervious components.

Figure 3. Example of porous asphalt.

Porous Asphalt

Porous asphalt is a bituminous-bound pavement composed of fine and coarse aggregate. To offer increased void space (typically 15-20% total) and flow-through of stormwater as compared to traditional asphalt, a gap graded aggregate is used. This layer is placed over a bedding/reservoir layer as described in Table 2. Percolating stormwater is held in the reservoir before infiltration, or if non-infiltrating is directed to the underdrain structure. The particular design specifications of porous asphalt hinge on the materials used and the compaction procedures, should adhere to the National Asphalt Pavement Association (NAPA) Porous Asphalt Pavements for Stormwater Management (NAPA 2008).

Figure 4. Example of pervious concrete.

Pervious Concrete

Pervious concrete is a mixture of Portland cement, fly ash, washed gravel, and water. The water-to cementitious material ratio is typically 0.35–0.45 to 1 such that the mixture displays a wet metallic sheen without the paste flowing from the aggregate (NRMCA 2004). Unlike traditional installations of concrete, permeable concrete usually contains a void content of 15 to 25 percent, which allows water to infiltrate directly through the pavement surface to the subsurface. A fine, washed gravel, less than 13 mm in size (No. 8 or 89 stone), is added to the concrete mixture to increase the void space (GCPA 2006). An admixture improves the bonding and strength of the pavements. The pavements are typically laid with a 4- to 8-inch (10 to 20 cm) thickness over a gravel reservoir (depth varies according to water volume capture requirements), typically a washed No. 57 stone. Pervious concrete is a rigid pavement and therefore does not require an aggregate base course for structural support. Pervious concrete will typically exhibit a coarser surface texture than impervious concrete but is ADA compliant.

Permeable Interlocking Concrete Pavement (PICP)

PICP is available in many different shapes and sizes. When lain, the blocks form patterns that create openings through which rainfall can infiltrate. Orientation of rectangular pavers is important for structural purposes—herringbone patterns tend to provide the most efficient structural design, especially where vehicle stopping and turning are expected. ASTM C936-13 specifications state that the pavers be at least 2.36 inches (60 mm) thick with a compressive strength of 55 MPa (8,000 psi) or greater. Typical installations consist of the pavers and crushed aggregate fill, a 1.5- to 3.0-inch (38 to 76 mm No. 8) fine aggregate bedding layer, and an aggregate base-course, typically a washed No. 57 stone, storage layer (Smith 2011). If greater storage is required, a reservoir subbase layer of No. 2 stone can be included.

Figure 5. Example of PICP.

Grid Pavers

Grid systems, also called geocells, turf pavers, or turf reinforcing grids, consist of flexible-plastic, interlocking units that allow for infiltration through large gaps filled with gravel or topsoil planted with turf grass. Similar to PICP, a 1–2 inch sand bedding layer and gravel base course are often added to increase infiltration and storage. The empty grids are typically 90 to 98 percent open space, so void space depends on the fill media (Ferguson 2005). To date, no uniform standards exist; however, one product specification defines the typical load-bearing capacity of empty grids at approximately 13.8 MPa (2,000 psi)

Figure 6. Example of a grid paver.

(Invisible Structures 2001). That value increases up to 38 MPa (5,500 psi) when filled with various materials (Invisible Structures 2001). If sand is used, a geotextile should be used between the sand course and the reservoir media to prevent the sand from migrating into the stone media.

Maintenance

The maintenance requirements of a pervious surface is determined by its design (i.e., when an underdrain is incorporated, it must be inspected). The chief maintenance concern is prevention of clogging of the pervious surface. The factors to be considered when defining maintenance requirements must include: type of use, ownership, level of traffic, the local environment and any contributing catchments.

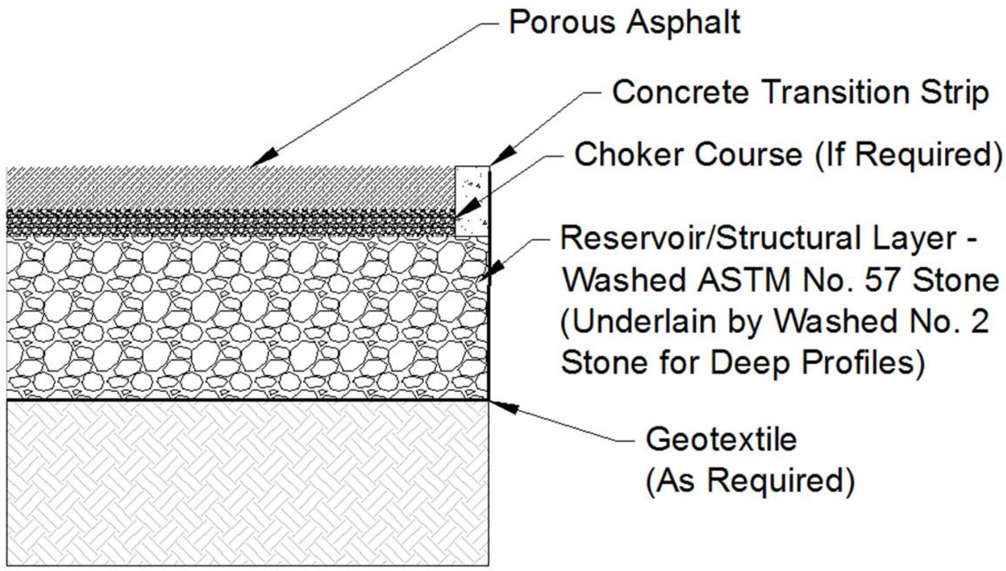
Table 3. Typical maintenance activities and associated costs and frequency

Frequency	Cost	Activity
Routine Maintenance (required monthly to every 2 years)		Remove excess sediment and debris adjacent impervious surfaces and in voids/joints of permeable pavement. Check for and stabilize erosion. Pavement should be swept with a vacuum power or regenerative air
Routine (small)	\$5.32/ft^2	
Routine (medium)	\$1.33/ft^2	
Routine (large)	\$0.67/ft^2	
Intermediate Maintenance (required every 6 to 10 years)		For paver systems, whenever void space between joints becomes apparent or after vacuum sweeping replace bedding fill material to keep fill level with the paver surface.
Intermediate (small)	\$3.71/ft^2	
Intermediate (medium)	\$1.85ft^2	
Intermediate (large)	\$1.85/ft^2	
End of Life Replacement (service life of 20 years)		Excavate to the depth of soil media. Test soil for excessive soil contamination of common stormwater pollutants (e.g. metals, nutrients). Continue to remove underlying soil if pollutants exceed standard for contaminated soil. Replace with clean soil.
Replacement (small)	\$6.50–\$9.50/ft^2	
Replacement (medium)	\$6.50–\$9.50/ft^2	
Replacement (large)	\$6.50–\$9.50/ft^2	
Note: Small System = 500 ft^2; Medium System = 2000 ft^2; Large System = 4000 ft^2		

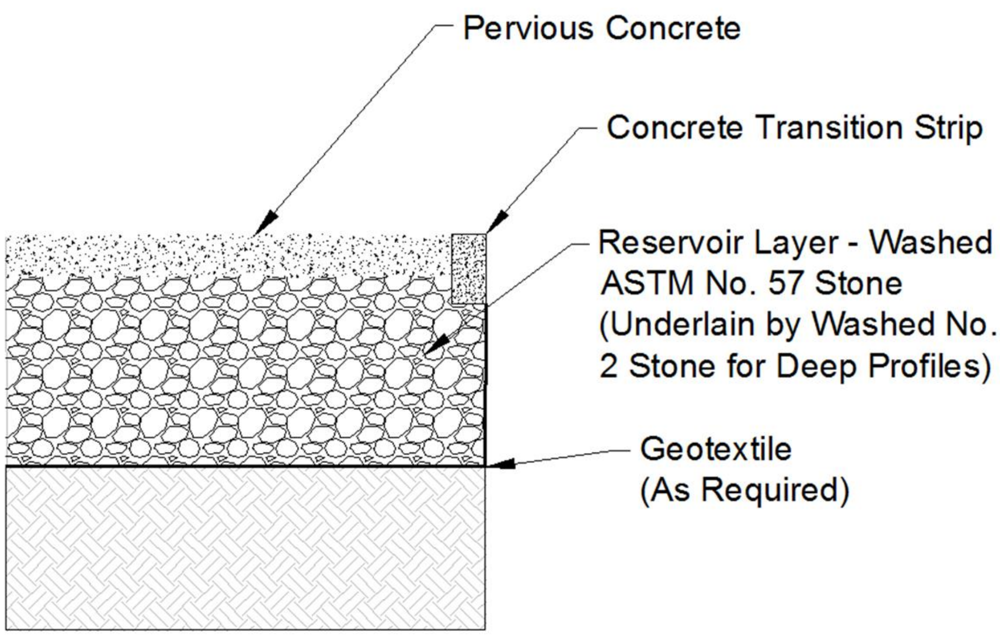
Redeveloping Existing Installations

Various jurisdictional stormwater management and mitigation plans (SUSMP, WQMP, etc.) define "redevelopment" in terms of amounts of additional impervious area, increases in gross floor area and/or exterior construction, and land disturbing activities with structural or impervious surfaces. The definition of "redevelopment" must be consulted to determine whether or not the requirements for new development apply to areas intended for redevelopment. If the definition applies, the steps outlined under "designing new installations" above should be followed. Permeable pavement can be implemented to reduce the overall imperious area of a newly developed or redevelopment site. Many jurisdictions consider permeable pavement areas to be self-treating areas with some allowing some amount of run-on for treatment.

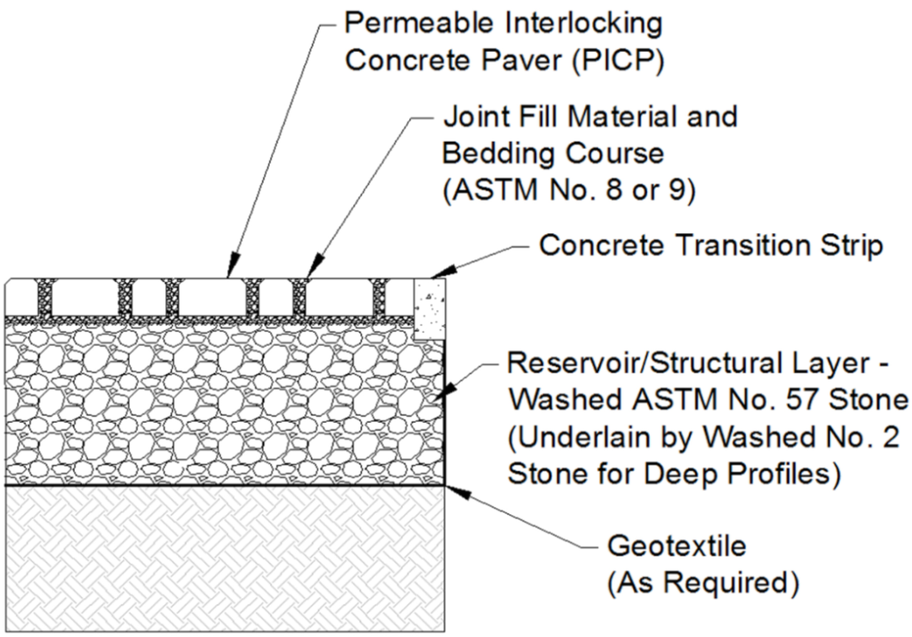
Schematic

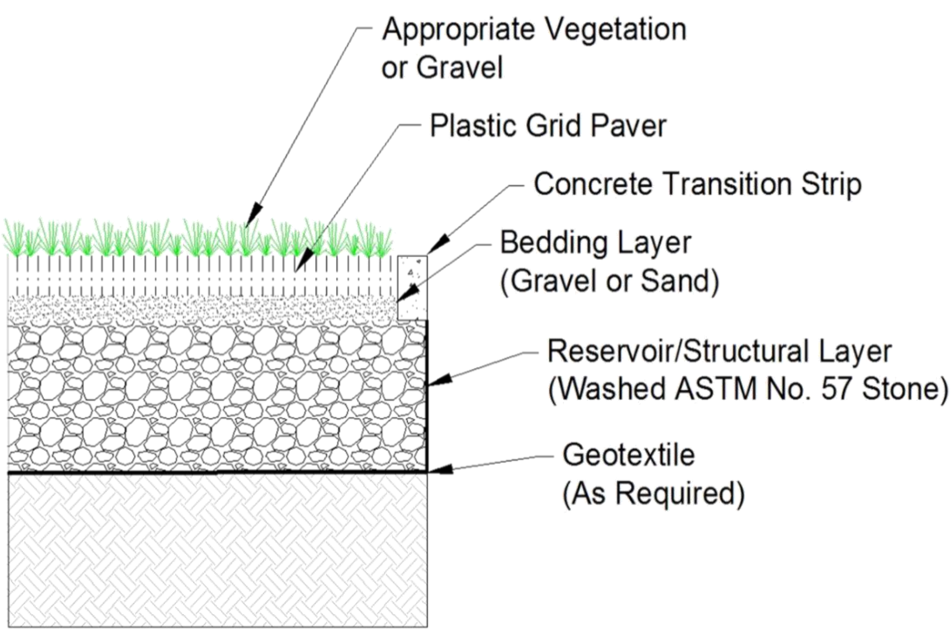


Porous Asphalt
Concrete Transition Strip
Choker Course (If Required)
Reservoir/Structural Layer - Washed ASTM No. 57 Stone (Underlain by Washed No. 2 Stone for Deep Profiles)
Geotextile (As Required)



Pervious Concrete
Concrete Transition Strip
Reservoir Layer - Washed ASTM No. 57 Stone (Underlain by Washed No. 2 Stone for Deep Profiles)
Geotextile (As Required)


Permeable Interlocking
Concrete Paver (PICP)
Joint Fill Material and
Bedding Course
(ASTM No. 8 or 9)
Concrete Transition Strip
Reservoir/Structural Layer -
Washed ASTM No. 57 Stone
(Underlain by Washed No. 2
Stone for Deep Profiles)
Geotextile
(As Required)


Appropriate Vegetation
or Gravel
Plastic Grid Paver
Concrete Transition Strip
Bedding Layer
(Gravel or Sand)
Reservoir/Structural Layer
(Washed ASTM No. 57 Stone)
Geotextile
(As Required)

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