A.3 PERMEABLE PAVEMENT

Location: Kellogg Park, San Diego, California.

Figure A.3-1. Permeable interlocking concrete pavement.

A.3.1 DESIGN

The design of a permeable pavement system follows a nine-step process, as Table A.3-1 describes.

Table A.3-1. Permeable pavement iterative design step process

Design step		Design component/ consideration	General specification
1	**Determine Integrated Management Practice (IMP) Treatment Volume**	Runoff calculations	Per chapter 2 of the County SUSMP, the volume of the 24-hour 85th percentile storm is required for the water quality treatment method.
2	**IMP Siting (A-35)**	Layout and site incorporation	Based on available space, incorporate into parking lots, parking lanes along roadways, pedestrian sidewalks and plazas, and fire access roads.

Design step		Design component/ consideration	General specification
3	**Select Permeable Pavement Surface Course (A-35)**	Surface course type	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. Concrete grid pavers and plastic grid systems are also available.
4	**Determine IMP Function and Configuration (A-41)**	Impermeable liner	If noninfiltrating, use an impermeable clay layer, geomembrane liner, and concrete (as described in Common Design Elements).
		Underdrain (required if subsoil infiltration rate is less than 0.5 inches per hour [in/hr], as in hydrologic soil groups C and D [HSG C & D])	Schedule 40 PVC pipe with perforations (slots or holes) every 6 inches. The 4-inch diameter lateral pipes should join a 6-inch collector pipe, which conveys drainage to the downstream storm network. Provide cleanout ports/observation wells for each underdrain pipe (see Common Design Elements).
		Internal water storage (IWS)	If using underdrain and infiltration, elevate the outlet to create a sump to enhance infiltration and treatment.
		No underdrain	If design is fully infiltrating, ensure that subgrade compaction is minimized.
		Lateral hydraulic restriction barriers	Use a geomembrane, concrete, or bentonite clay to restrict lateral flows to adjacent subgrades, foundations, or utilities.
		Subgrade slope and geotextile	Subgrade slope should be 0.5 percent or flatter. Baffles should be used to ensure retention of water quality volume. Geotextile should be used along perimeter of cut to prevent soil from entering the aggregate voids.
5	**Design the Profile (A-43)**	Surface area and reservoir depth	Water quality volume should be fully stored within the aggregate base layers below the surface course. Base layer should be washed ASTM No. 57 stone. (Washed ASTM No. 2 may be used as a sub-base layer for additional storage.)
		Structural Design	A qualified and licensed professional should complete a pavement structural analysis.
6	**Design for Overlow/Bypass (A-44)**	Large-storm routing	Poured-in-place systems: System can overflow internally or on the surface. Modular/Paver-type systems (PICP): Internal overflow is required to prevent upflow and transport of bedding course.
7	**Edge Restraints and Transitions (A-45)**	Transition strip	Provide a concrete transition strip between any permeable and impermeable surface and around the perimeter of PICP installations.
8	**Design Signage (A-46)**	Signage regulations	Signage should indicate prohibited activities that cause premature clogging and alert pedestrians and maintenance staff that the surface is intended to be permeable.
9	**Design for Multi-Use Benefits (A-46)**	Additional benefits	Provide educational signage, enhanced pavement colors, or stormwater reuse systems.

A.3.1.1 Step 1. Determine Required Storage Volume

Permeable pavement must be sized to fully capture the desired or required design storm volume. Chapter 2 of the County SUSMP presents relevant sizing regulatory requirements.

A.3.1.2 Step 2. IMP Siting

Permeable pavement is typically designed as a self-treating area intended to treat stormwater that falls on the pavement surface area in spaces that are traditionally impervious. Permeable pavement may be designed as self-retaining areas where run-on will be allowed from a drainage area equal to no more than twice the area of the permeable pavement. Permeable pavement can be incorporated in many ways to achieve more than one project-level or watershed-scale objective. Examples include the following:

- Parking lots
- Parking lanes in rights-of-way along roads
- Sidewalks and pedestrian plazas
- Access roads and shoulders
- Alleys

Failure of permeable pavement typically occurs because the pore space becomes clogged. The following are situations where permeable pavement may require additional maintenance if implemented:

- Runoff from pervious surfaces or high-sediment areas
- Sites with a likelihood of high oil and grease concentrations
- Overhanging trees with excessive defoliation

Permeable pavement can be combined with other integrated management practices (IMPs) to form a treatment train that can enhance water quality treatment and reduce runoff volume and rate.

A.3.1.3 Step 3. Select Permeable Pavement Surface Course

Multiple types of permeable pavement are currently available: pervious concrete, porous asphalt, permeable interlocking concrete pavers (PICP), concrete grid pavers, and plastic grid systems, among others. Pervious concrete and porous asphalt are considered pour-in-place solutions while PICP, concrete grid pavers, and plastic grid systems are considered modular.

In general, pour-in-place solutions are best suited for large-scale application while modular systems are better suited for smaller areas because of the labor intensity required for installation.

More detailed information for the various types of permeable pavement follows.

A.3.1.3.1 Pervious Concrete

Table A.3-2 specifies the properties of pervious concrete. Design mix should conform to the latest version of the American Concrete Institute's (ACI) 522.1-13 *Specification for Pervious Concrete Pavements* (ACI 2013). Figure A.3-2 shows a typical pervious concrete profile.

Table A.3-2. Pervious concrete properties

Property	Description	Source
Materials	Portland cement, fly ash, gravel, water	NRMCA 2004
Composition	Water-to-cementitious ratio: 0.30–0.38 to 1 Void content: 15 to 25 percent Gravel size: 13 millimeters or less (No. 8 or 89 stone) Unit weight: 105 to 140 pounds per cubic foot.	NRMCA 2004 GCPA 2006
Thickness	4 to 8 inches over a gravel No.57 stone reservoir	
Placement method	Pour-in-place	
Permeability	1,500 inches per hour. Subgrade is the limiting factor.	Bean et al. 2007
Compressive strength	Ranges from 500 to 4,000 pounds per square inch	
Flexural strength	Ranges from 150 to 550 pounds per square inch	
Shrinkage	Control joints: one-quarter of pavement thickness, maximum of 20 feet on centers (15 feet recommended) perpendicular to the curb	

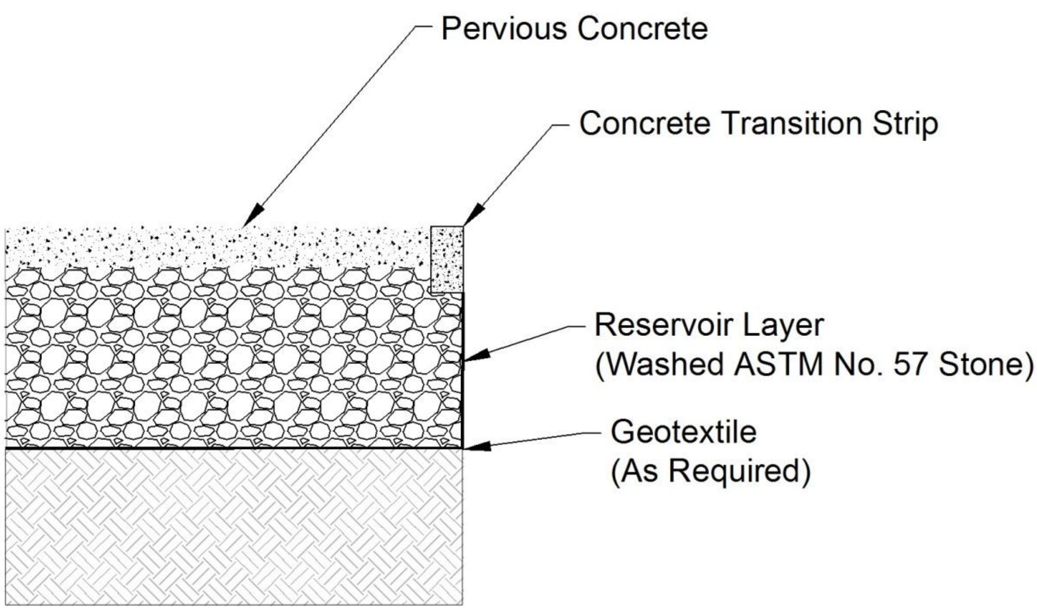

Figure A.3-2. Typical pervious concrete cross section.

A.3.1.3.2 Porous Asphalt

Table A.3-3 describes the properties of porous asphalt. Design mix should conform to the latest version of the National Asphalt Pavement Association (NAPA) *Porous Asphalt Pavements for Stormwater Management* (NAPA 2008). Figure A.3-3 shows a typical porous asphalt profile.

Porous asphalt can be installed directly over existing concrete to form a permeable friction course (PFC) overlay. PFCs do not provide the same volume storage capacity as a porous asphalt system, but they can provide water quality improvements in addition to enhanced driver safety, noise reduction, and improved ride quality (Eck et al. 2012; NCHRP 2009; Rand 2006).

Table A.3-3. Porous asphalt properties

<table>
<tr><th>Property</th><th>Description</th><th>Source</th></tr>
<tr><td>Materials</td><td>Fine and course aggregate, bituminous binder</td><td></td></tr>
<tr><td>Composition</td><td>Void content: 15 to 20 percent
Aggregate Gradation:
<table><tr><th>Aggregate size</th><th>Percent passing</th></tr><tr><td>0.75 inches</td><td>100%</td></tr><tr><td>0.50 inches</td><td>85% – 100%</td></tr><tr><td>0.375 inches</td><td>55% – 75%</td></tr><tr><td>No. 4</td><td>10% – 25%</td></tr><tr><td>No. 8</td><td>5% – 10%</td></tr><tr><td>No. 200</td><td>2% – 4%</td></tr></table></td><td></td></tr>
<tr><td>Thickness</td><td>3 to 7 inches over a gravel No.57 stone reservoir
1 to 2 inch choker course to stabilize the surface</td><td>Ferguson 2005</td></tr>
<tr><td>Placement method</td><td>Pour-in-place</td><td></td></tr>
<tr><td>Permeability</td><td>150 to 300 inches per hour. Subgrade is the limiting factor.</td><td>Roseen and Ballestero 2008</td></tr>
</table>

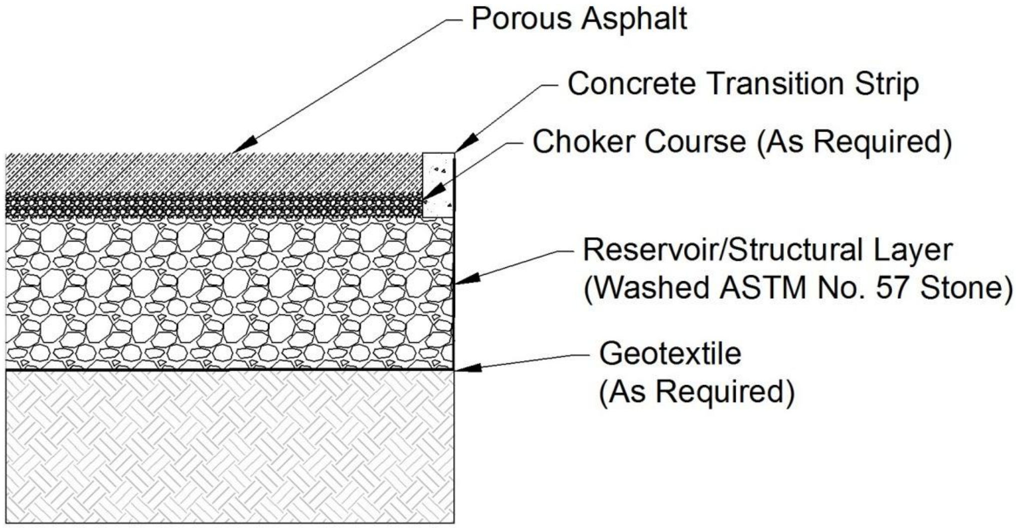

Figure A.3-3. Typical porous asphalt cross section.

A.3.1.3.3 Permeable Interlocking Concrete Pavement (PICP)

Table A.3-4 describes the properties of PICP. Figure A.3-4 depicts a typical PICP profile.

Table A.3-4. PICP properties

Property	Description	Source
Materials	Concrete interlocking paver, pea gravel	
Composition	Pervious openings: 8 to 20 percent of surface area Bedding layer: washed No. 8 stone Reservoir/Structural layer: washed No. 57 stone	
Thickness	Minimum of 2.36 inches per ASTM C936 Bedding of 1.5 to 3 inches fine-gravel	ICPI 2004
Placement method	Modular installation. Orientation is critical to structural purposes; herringbone pattern provides the most efficient structural design.	
Permeability	14 to 4,000 inches per hour. Subgrade is the limiting factor.	Bean et al. 2007; Borgwardt 2006
Compressive strength	Minimum of 8,000 pounds per square inch per ASTM C936	

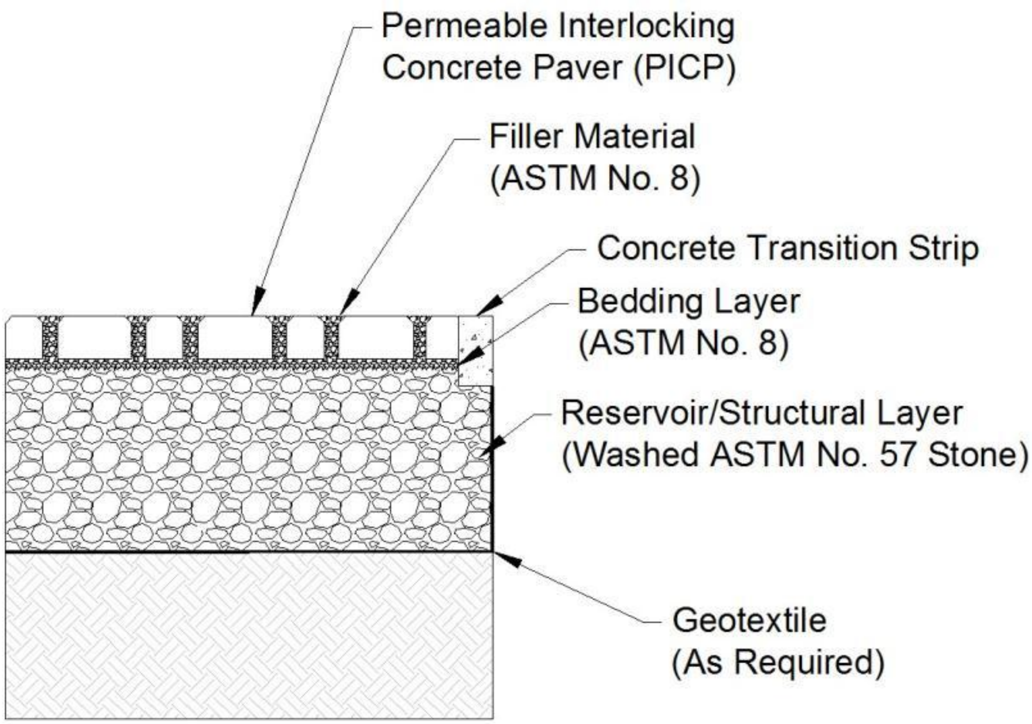

Figure A.3-4. Typical PICP cross section.

A.3.1.3.4 CONCRETE GRID PAVERS

Table A.3-5 describes the properties of concrete grid pavers. Concrete grid pavers should conform to ASTM C1319, *Standard Specification for Concrete Grid Paving Units*. The typical profile is similar to the PICP profile (Figure A.3-4).

Table A.3-5. Concrete grid pavers properties

Property	Description	Source
Materials	Concrete paver (max size 24 by 24 inches), fill material (topsoil and grass, sand, or aggregate)	
Composition	Pervious openings: 20 to 50 percent of surface area Bedding layer: sand or washed No. 8 stone Reservoir/Structural layer: washed No. 57 stone	ICPI 2004
Thickness	Minimum of 3.5 inches Bedding of 1 to 1.5 inches	ICPI 2004
Placement method	Modular installation	
Compressive strength	Minimum of 5,000 pounds per square inch	

A.3.1.3.5 Plastic Grid Systems

Table A.3-6 describes the properties of plastic grid systems. Plastic grid systems are also known as *geocells*, *turf pavers*, or *turf reinforcing grids*. Figure A.3-5 depicts a typical plastic grid system profile.

Table A.3-6. Plastic grid system properties

Property	Description	Source
Materials	Flexible-plastic interlocking unit, fill material (gravel or topsoil with grass)	
Composition	Pervious openings: 90 to 98 percent of surface area Bedding layer: sand or washed No. 8 stone Reservoir/Structural layer: washed No. 57 stone	Ferguson 2005
Thickness	Varies by manufacturer. No standard exists. Bedding of 1 to 2 inches	
Placement method	Modular installation.	
Compressive strength	Minimum of 2,000 to 6,700 pounds per square inch	Invisible Structures 2001

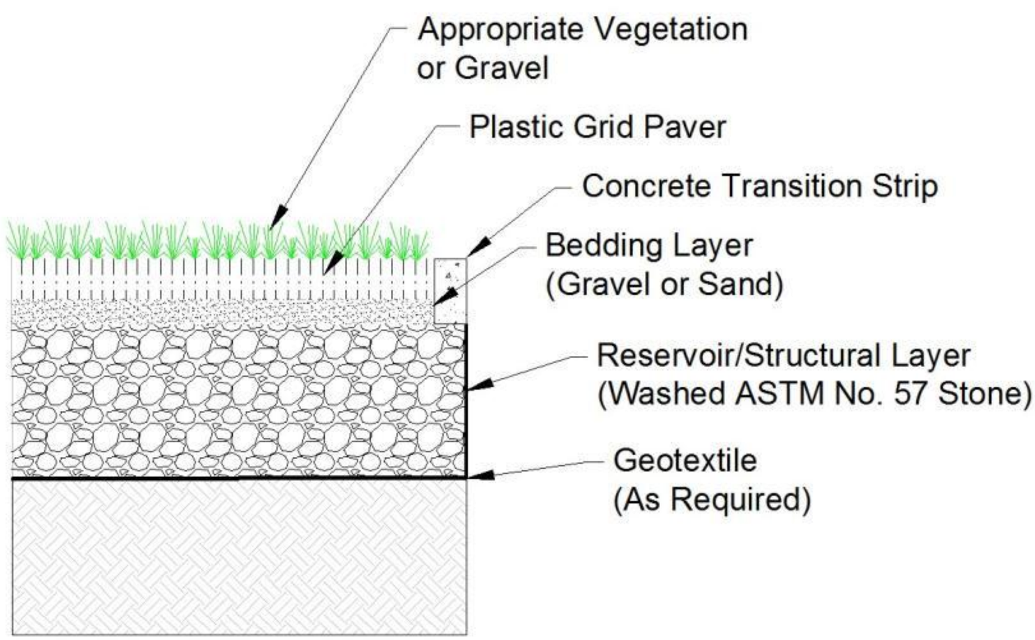

Figure A.3-5. Typical plastic grid system cross section.

A.3.1.4 Step 4. Determine IMP Function and Configuration

Permeable pavement configuration selection should follow the selection matrix outlined in the Bioretention section (A.1.1.2). Figure A.3-6 through Figure A.3-9 illustrate the recommended configurations.

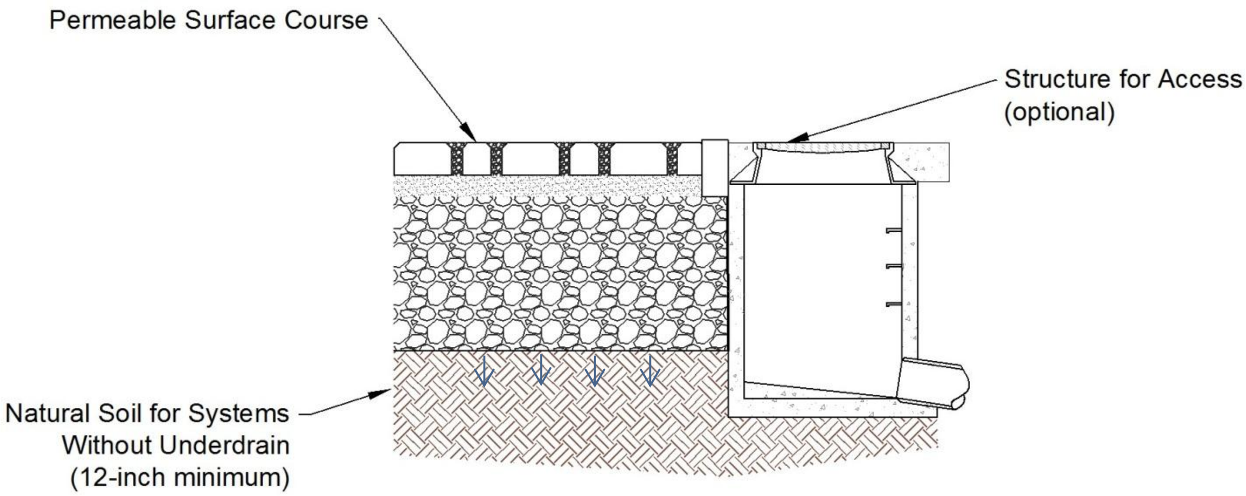

Figure A.3-6. Configuration 1 – Infiltration permeable pavement with no underdrain.

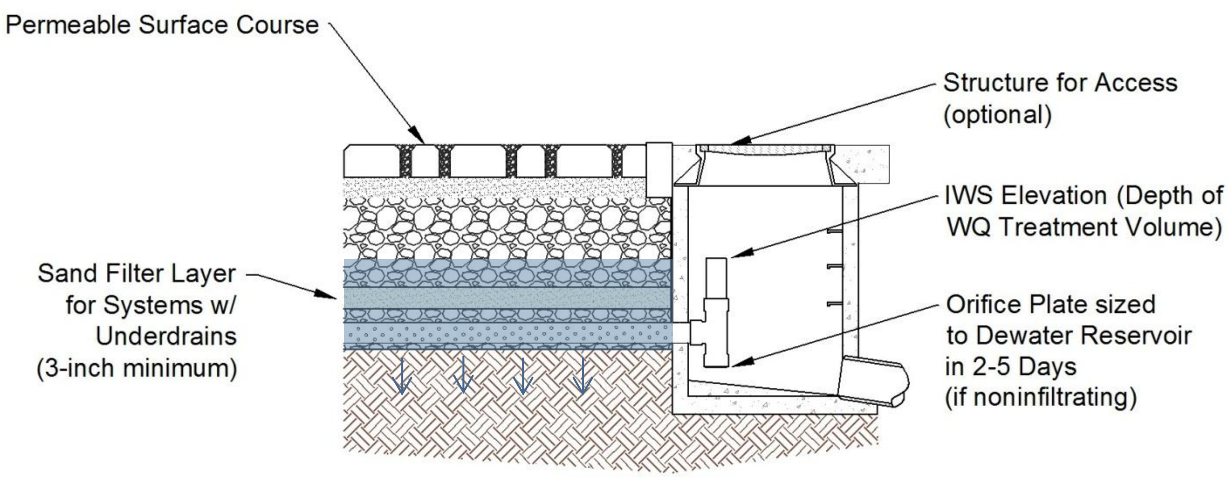

Figure A.3-7. Configuration 2 – Infiltration permeable pavement with upturned underdrain.

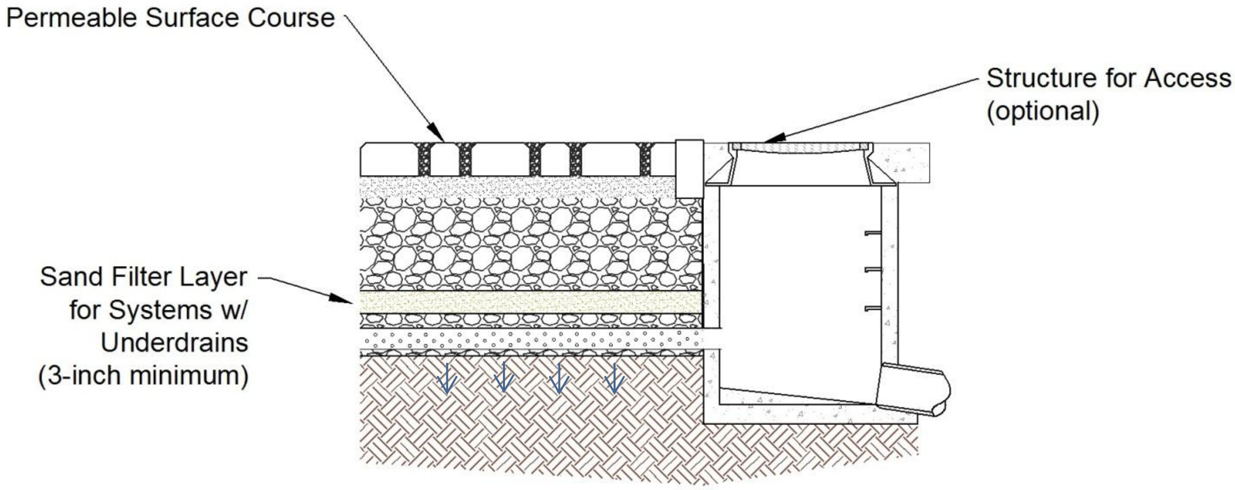

Figure A.3-8. Configuration 3 – Infiltration permeable pavement with underdrain on the subgrade.

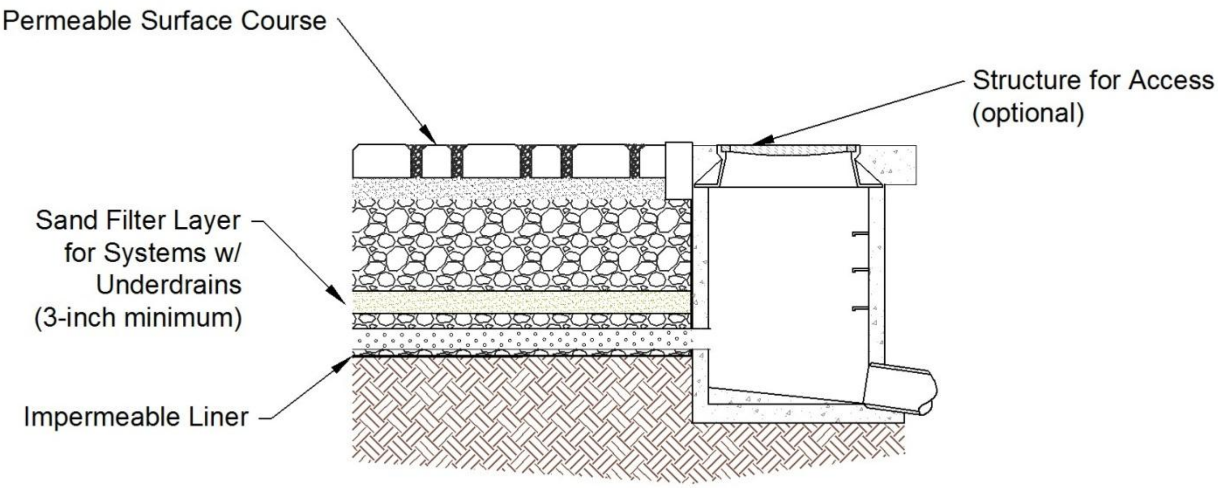

Figure A.3-9. Configuration 4 – Filtration permeable pavement with impermeable liner and underdrain on the subgrade.

A.3.1.4.1 Determine If Lateral Hydraulic Restriction Barriers Are Needed

Lateral restriction barrier guidance should follow the requirements outlined in the Bioretention section (A.1.1.2.4).

A.3.1.4.2 Design Subgrade Slope and Specify Geotextile

The subgrade slope should not exceed 0.5 percent. Baffles can be installed along the subgrade to provide grade control if necessary.

A geotextile should be placed beneath the reservoir media and along the perimeter of the cut in any infiltrating system. The geotextile should meet the specifications Table A.3-7 provides.

Table A.3-7. Geotextile layer specifications

Geotextile property	Value	Test method
Grab tensile strength (pounds)	≥ 120	ASTM D4632
Mullen burst strength (pounds per square inch)	≥ 225	ASTM D3786
Permeability (gpm/sq. ft.)	≥ 125	ASTM D4491
Apparent opening size (sieve size)	#70–#80 (min)	ASTM D4751

*The geotextile apparent opening size selection is based on the percent passing the No. 200 sieve in *A* Soil subgrade, using FHWA or AASHTO selection criteria.

A.3.1.5 Step 5. Design the Profile

Chapter 4 of the County SUSMP addresses methods for determining the size of the IMP area. The following sections present additional considerations when using this method, such as targeted pollutant removal.

Chapter 2 of the County SUSMP describes an alternative method to meet required water quality treatment volume. This method can be used to determine the volume of water that must be treated. Once the treatment volume is determined, vertical dimensions should be selected on the basis of pollutants of concern and site constraints before calculating the IMP footprint. The following subsections provide guidance on sizing the surface ponding depth, media depth, and surface area of the permeable pavement.

A.3.1.5.1 Surface Ponding Depth

Because permeable pavement supports transportation use, surface ponding should be kept to a minimum. If the permeable pavement becomes clogged, the surface ponding volume should be provided by the curb and gutter to retain the design storm volume.

A.3.1.5.2 Specify Sand/Soil Filter Layer

If no underdrain is required, a minimum of 12 inches of native soils should be provided at the subgrade of the permeable pavement.

If an underdrain is required, a minimum of 4 inches of ASTM C-33 washed sand should be included above the gravel of the underdrain drainage layer. A layer of choking stone might be required between the sand filter layer and the gravel drainage layer. Figure A.3-7 provides a profile illustration.

A.3.1.5.3 Calculate Surface Area and Reservoir Media Depth

The gravel base course is designed to store the water quality treatment volume determined in chapter 2 of the County SUSMP. The typical stone aggregate used is ASTM No. 57 stone (or equivalent) with an option to use ASTM No. 2 stone was a sub-base layer for additional storage.

The site layout typically constrains the area of installation; the following equation can be used to determine the depth of storage layer required to capture the water quality treatment volume.

$d = V / A \times n$

where

d = gravel layer depth (feet)
V = water quality volume
A = surface area (square feet)
n = porosity (use actual laboratory measured porosity of material)

A.3.1.5.4 Structural Design Requirements

Permeable pavement is used in settings where it is subject to vehicle loading; as a result, structural design elements should be carefully considered, including the following:

- Total traffic
- In situ soil strength
- Environmental elements
- Bedding and reservoir layer design

Consult the following transportation design guidance sources for additional structural design requirements:

- County of San Diego Parking Design Manual (2013)
- AASHTO Guide for Design of Pavement Structures (1993)
- AASHTO Supplement to the Guide for Design of Pavement Structures (1998)

A.3.1.6 Step 6. Select and Design Overflow/Bypass Method

High flows must safely overflow/bypass the permeable pavement without damaging the IMP. Table A.3-8 outlines recommended outlet configurations.

Table A.3-8. Permeable pavement outlet/bypass recommendations

Permeable Pavement Type	Recommended Outlet Configuration
Pour-in-place (pervious concrete, porous asphalt)	Online: Volume in excess of storage capacity can be allowed to bubble up through the profile and run off the site as surface flow to a catch basin or slot drain.
Modular (block) systems (PICP, pavers, plastic grids)	Offline: Design system bypass for flows conveyed to IMP. Online: Store the 10-year storm volume in the aggregate reservoir or design underdrain system to safely convey larger storms. **Do not** allow bubbling up as this can dislodge and carry away the aggregate bedding.

A.3.1.7 STEP 7. EDGE RESTRAINTS AND TRANSITIONS

Edge restraints include standard concrete curbs (elevated or at grade) or specially designed monolithic concrete walls. They can be designed to perform the following functions:

- Identify the transition between permeable and impermeable for maintenance personnel.
- Restrain modular pavers and porous asphalt from lateral shifts or unraveling of edges.
- Create a hydraulic restriction layer to prevent lateral seepage.
- Delineate parking zones.

At intersections between permeable and impermeable surfaces, a hydraulic restriction layer is required and is installed along the entire length of the cut at least 2 feet laterally along the subgrade and under the impermeable surface. Figure A.3-10 shows a concrete transition strip.

Location: Los Angeles Zoo, Los Angeles, California.

Figure A.3-10. Concrete transition strip between PICP and standard asphalt.

A.3.1.8 Step 8. Design Signage

Signs should identify prohibited practices, such as stockpiling soils or mulch, and be clearly displayed to protect permeable pavements from premature clogging. Signage will also prevent poured-in-place permeable pavements from being mistaken as impermeable and accidentally being paved over during repair.

A.3.1.9 Step 9. Design for Multi-Use Benefits

Permeable pavements inherently provide multi-use benefits because the facilities double as parking lots and transportation corridors. In addition to these benefits, permeable pavement can be enhanced by incorporating the following design elements:

- Enhanced pavement textures, colors, and patterns can calm traffic, increase aesthetic appeal, enhance pedestrian safety, and draw attention to multi-use stormwater practices.
- Stormwater reuse systems can be installed to harvest and use captured runoff for nonpotable use (irrigation, ornamental water features, etc.).
- Permeable pavers can be used to maintain the character of historic districts while providing stormwater management solutions.
- Educational kiosks and signage raise public awareness of stormwater issues.

A.3.2 Critical Construction Considerations

Construction technique and sequencing are critical to permeable pavement performance. Failure of improperly constructed systems can be easily avoided by effectively communicating with the contractor and by inspecting the site during key steps. In addition to the general construction considerations chapter 4 provides, emphasizing the following points will help ensure successful installation of permeable pavement:

- Inspect aggregate upon delivery to ensure thorough washing was performed.
- Inspect elevations and grading.
- Test subgrade infiltration rate.
- Mitigate soil compaction to enhance infiltration.
- Inspect surface course placement and curing.

A.3.3 Operations and Maintenance

Maintenance of permeable pavement is critical to the success of the system. Table A.3-9 provides a detailed list of maintenance activities.

Table A.3-9. Operation and maintenance tasks for permeable pavement

Task	Frequency	Indicator maintenance is needed	Maintenance notes
Catchment inspection	Weekly or biweekly during routine property maintenance	Sediment accumulation on adjacent impervious surfaces or in voids/joints of permeable pavement	Stabilize any exposed soil and remove any accumulated sediment. Adjacent pervious areas might need to be graded to drain away from the pavement.
Miscellaneous upkeep	Weekly or biweekly during routine property maintenance	Trash, leaves, weeds, or other debris accumulated on permeable pavement surface	Immediately remove debris to prevent migration into permeable pavement voids. Identify source of debris and remedy problem to avoid future deposition.
Preventative vacuum/regenerative air street sweeping	Twice a year in higher sediment areas	N/A	Pavement should be swept with a vacuum power or regenerative air street sweeper at least twice per year to maintain infiltration rates.
Replace fill materials	As needed	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.
Restorative vacuum/regenerative air street sweeping	As needed	Surface infiltration test indicates poor performance or water is ponding on pavement surface during rainfall	Pavement should be swept with a vacuum power or regenerative air street sweeper to restore infiltration rates.

A.3.4 References

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