California Stormwater Quality Association

Dedicated to the Advancement of Stormwater Quality Management, Science and Regulation

Removing Barriers to Low Impact Development (LID)

Proposition 84 Grant 12-421-550

LID Technical Standards Review

Technical Memorandum #2
Permeable Pavement Details and Standards Review

May 2017

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Permeable Pavement Details and Standards Review

Prepared for

California Stormwater Quality Association

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May 2017

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Preface

The California Stormwater Quality Association (CASQA) is a professional member association dedicated to the advancement of stormwater quality management through collaboration, education, implementation guidance, regulatory review, and scientific assessment. CASQA has been a leader since 1989 when the field of stormwater management was in its infancy. CASQA's membership is comprised of a diverse range of stormwater quality management organizations and individuals, including cities, counties, special districts, industries, and consulting firms throughout the state. A large part of CASQA's mission is to assist California stormwater permittees in developing, implementing, and maintaining effective stormwater quality management programs by drawing upon the collective experiences of its individual members, to share successes and avoid the pitfalls.[5]

CASQA was awarded a Proposition 84 Stormwater Grant (Grant) to provide Low Impact Development (LID) implementation support to municipalities throughout California. As part of the Grant, CASQA provided technical support to municipalities including developing LID technical resources and using existing LID details and standards, developed by others, including details and standards for bioretention and permeable paving. Subsequently, CASQA entered an agreement with a team of specialists to provide review of the LID details and standards to verify that the materials being used are comprehensive, technically accurate, and identify areas of technical uncertainty or where differences in technical opinion exist.

The team of specialists include CASC Engineering and Consulting, Inc. as the project manager and technical specialist, EOA, Inc. as a technical specialist, and the Interlocking Concrete Pavement Institute as a technical specialist. The team brings together Jeff Endicott, PE, BCEE, Jill Bicknell, PE, and David Smith from these respective organizations.

This Technical Memorandum #2 provides review and commentary on Permeable Paving details and standards, including a general review and reviews focused on the paving system surface layer and storage layer. David Smith is the primary author of Technical Memorandum #2, with technical and editorial review provided by Jill Bicknell and Jeff Endicott.

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[5] https://www.casqa.org/about

Introduction

CASQA was awarded a Proposition 84 Stormwater Grant (Grant) to provide Low Impact Development (LID) implementation support to municipalities throughout California. As part of the Grant, CASQA provided support to municipalities including developing LID technical resources and using existing LID details and standards, developed by others, including details and standards for bioretention and permeable paving. Subsequently, CASQA entered an agreement with a team of specialists to provide review of the LID details and standards to verify that the materials being used are comprehensive, technically accurate, and identify areas of technical uncertainty or where differences in technical opinion exist.

The team of specialists have been assigned three major tasks, including:

- Task 1 – Bioretention Details and Standards Review;
- Task 2 – Permeable Pavement Details and Standards Review; and
- Task 3 – Future Efforts Related to LID.

Task 1 and Task 2 each include several defining subtasks.

This Technical Memorandum #2 provides the specialist team's comments and recommendations relative to the modification of permeable pavement standards and details currently in use as part of the Grant, which consists of the details and standards adopted by the City of Salinas, California in 2008. Prior to the current review, these standard and details have not been peer reviewed to the same degree as the bioretention standards and details that are the subject of Task 1 and Technical Memorandum #1.

This memo provides the following deliverables:

- Deliverable 2A - A general review of pervious pavement standards and detail drawings issued by the City of Salinas. Some of each are revised, others deleted or replaced. Recommended drawings are provided in draft form. Areas are identified that, if developed, can increase technical credibility and soundness of permeable pavement design to meet desired performance.
- Deliverable 2B - Reviews the surface layer element in these standards to determine if sufficient guidance and specifications can be provided without resorting to brand/product specific details and standards. This involved a *replacement* of standards provided by the City of Salinas.
- Deliverable 2C - Reviews the pervious pavement storage layer and provide flexible details and standards that address soils with good, moderate and poor/no infiltration. Guidance is provided on use and placement of underdrains for each condition, and these are incorporated into the drawings. *Underdrain placement* is mostly covered in 2A for good, moderate and poor infiltration soils.

These deliverables are informed by several key recent references:

1. Caltrans Pervious Pavements Design Guidelines on http://www.dot.ca.gov/hq/oppd/stormwtr/guidance/DG-Pervious-Pvm_052716.pdf.
2. *Permeable Pavements*, a 240-page book issued by ASCE in 2015 available for purchase on http://www.asce.org/templates/publications-book-detail.aspx?id=15418.

3. A near final draft of an ASCE/ANSI standard on design, construction and maintenance of permeable interlocking concrete pavements (100+ pages). Expected publication is later in 2017. Much of the content of this standard applies to all permeable pavements.
4. Porous asphalt, pervious concrete, permeable interlocking concrete, and grid pavement industry references, i.e. the National/California Asphalt Pavement Association (NAPA/CalAPA), National Ready Mix Concrete Association (NRMCA), American Concrete Institute (ACI), and the Interlocking Concrete Pavement Institute (ICPI)
5. 'Tech Briefs' on porous asphalt, pervious concrete and permeable interlocking concrete pavement available from the U.S. Federal Highway Administration (FHWA).
6. Caltrans, Greenbook, AASHTO, ACI and ASTM test methods and material standards

Deliverable 2A - General Review of Pervious Pavement Details and Standards

These include the subparts:

2A-1: Providing general potential recommended modifications of the pervious pavement standard currently used (i.e., from the City of Salinas).

2A-2: Including suggested annotation of drawings and additional text to support the standards that clarify guidance. *Mostly new or replacement drawings are provided through the entire memo so they can be read in context with the narrative.*

2A-3: Identifying where future work is needed to increase technical credibility and soundness of pervious pavement design to meet desired performance.

2A-1: Recommended Modifications to the City of Salinas Template

An initial, critical change in terms is recommended. When referring generally to the field of pavement systems intentionally designed to pass water through them for runoff reduction, 'porous' or 'pervious' should be changed to 'permeable' throughout the entire document when collectively referring to all pavement systems. While synonyms, the terms porous, pervious, and permeable differentiate surfacing materials with underlying base configurations, i.e. porous asphalt, pervious concrete, and permeable interlocking concrete pavements. These terms have been designated by their respective industries. For permeable pavements supported by a rigid lattice structure, typically plastic or concrete, are called grid pavements.

The permeable surfaces/systems conform to those in the 2015 book, *Permeable Pavements*, and are used throughout this document for consistency with ASCE-established terms. This is first comprehensive book published by the engineering profession that establishes and standardizes nomenclature for permeable pavements. Terms of the 2008 City of Salinas guidelines are updated to terms in this recent reference.

Etymology is instructive. The Latin root for permeable (*permeare*) means capable of *passing* something such as air or water. The Latin root for pervious (*pervius*) means capable of *accepting* something such as air, water, or even ideas. The Latin root for porous (*porus*) means full of holes. When referring to permeable pavements collectively, all *pass water* through them making them *permeable.* Hence the name change of this section to **Permeable Pavements**.

The following provides edits to the existing overall permeable pavement guidelines published by the City of Salinas.

Permeable Pavement Systems

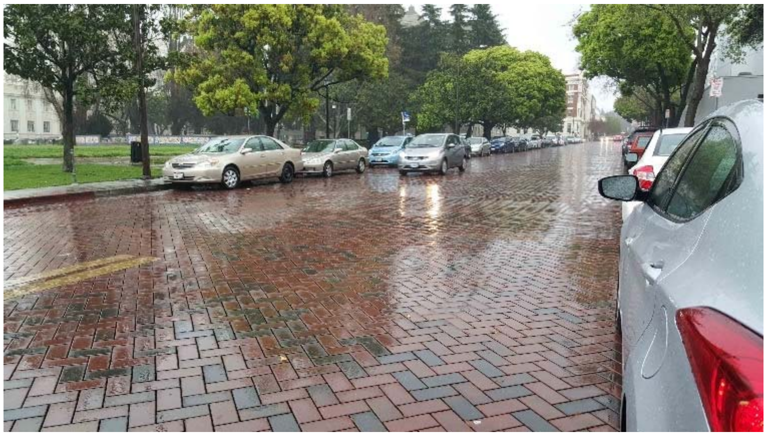

Figure 1. Permeable pavement in Berkeley, CA

Permeable pavement systems allow infiltration of stormwater while providing a stable load-bearing surface for pedestrians and vehicles. These systems contain openings in their surfaces that allow infiltration of runoff into their underlying, engineered permeable base/subbase materials and then into existing site soils. Generally, underlying engineered base/subbase materials consist of crushed, washed, open-graded aggregate (hereinafter, open-graded aggregate) separated from underlying site soils by a geotextile or a geomembrane. Engineered, open-graded aggregate base/subbase materials store and treat pollutants prior to infiltrating into underlying soils or discharging into a conventional storm drain system through underdrains. Permeable pavement systems can preserve natural drainage patterns, enhance groundwater recharge and soil moisture, deter salt water incursion, reduce the need for detention ponds (plus related liability and mosquitoes), and provide resilient infrastructure by managing local flooding. Although a good replacement for <u>some</u> conventional impervious concrete and asphalt <u>streets</u>, permeable paving systems may not yet be suitable for heavily trafficked applications.

There are several different types of permeable pavement systems are listed below. The applications and limitations for each are provided in the text. The first three pavements are most common and generic cross sections are illustrated within the text.

- Porous Asphalt Pavement
- Pervious Concrete Pavement
- Permeable Interlocking Concrete Pavement
- Grid Pavements
- Permeable Aggregate Pavement

Justification: The order is changed to reflect the order in the ASCE book, *Permeable Pavements* and other state guidelines (e.g., North Carolina and Minnesota). **Porous turf** is deleted because it is not considered in the aforementioned ASCE book. It cannot be designed for water quality volume (WQv) management. To a modest extent, it is covered under grid pavements, as turf is one option to place within their surfaces. Turf can be reinforced with plastic or concrete grids when subject to pedestrian and especially vehicular traffic. Such grids can help prevent turf and soil compaction. Introducing fibers or netting to create porous turf likely does not reduce the risk of turf/soil compaction which results in a reduction of its already initially low infiltration rate.

Porous gravel is renamed **Permeable Aggregate Pavement** because the term 'gravel' can be misleading. Within the aggregate and pavement industries, gravel is defined as rounded or semi-rounded rock that passes a 3 in. sieve and is retained on an ASTM No. 4 sieve. Gravel naturally occurs in streambeds or riverbanks smoothed by the action of water. This rock is not crushed. This material is acceptable as decorative permeable landscaping material but is *unacceptable* for base and subbases for permeable pavements subject to pedestrian and vehicular use. Gravel has low aggregate interlock (low shear strength) that results in a higher risk of excess shifting, rutting and overall inferior structural support for pedestrians and vehicles.

Pollutant Removal Performance Data

The pollutant removal performance of permeable pavements is summarized in the International Stormwater BMP Database available at www.bmpdatabase.org (ISBD, December 2014). Caution must be exercised when using summary performance data, especially when trying to predict event-based BMP performance from data summaries that may be based on long-term, multi-event data sets representing varying levels of percent capture. By way of explanation, full infiltration permeable pavement installations may effectively infiltrate the entire WQv for small storms, thereby preventing 100% of the entrained pollutant load from flowing downstream: that same pavement section will infiltrate only a portion of the total inflow for large storm events, thus providing 100% pollutant removal for the WQv and likely less pollutant removal for inflows in excess of the WQv.

Permeable Pavement Infiltration Types

Full Infiltration
Where the soil subgrade infiltration is sufficiently high to infiltrate the WQv, then that condition typically uses a full infiltration design. While this design approach does not require perforated underdrains, there should be a means to handle overflows, typically through a pipe or pipes at the pavement perimeter that leads to a storm drain or water course. Another design approach is placing a concrete outlet structure with a screened opening next to the open-graded base. The opening is set at a level to handle excess water in the base. All permeable pavements can be designed for full infiltration. Figure 2 schematically illustrates these two approaches to a full infiltration design.

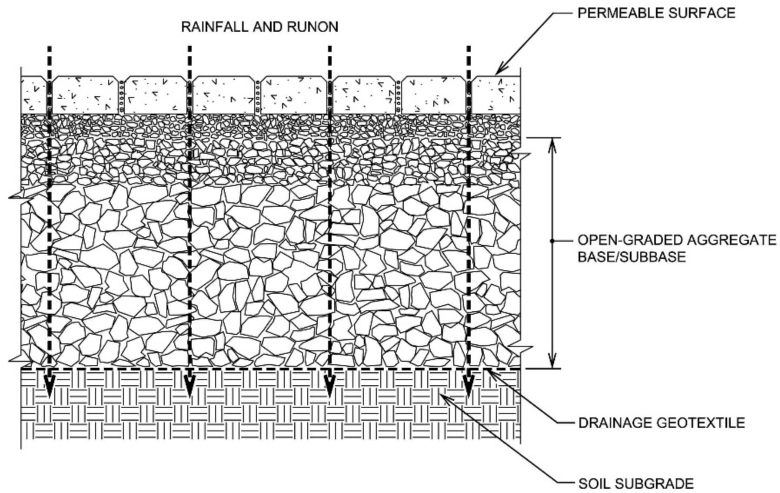

Figure 2. Full infiltration schematic design

Partial Infiltration

Partial infiltration storage creates a zone to temporarily store and infiltrate the WQv. The depth of the storage zone is a function of the infiltration capabilities of the underlying soils and the design WQv. This approach to detention and infiltration is typically accomplished using porous asphalt, pervious concrete, or permeable interlocking concrete pavement systems. These systems provide high surface infiltration and can receive and store runoff volumes from adjacent impervious surfaces. Permeable base materials such as washed, open-graded aggregates placed below the permeable pavement surface detain and treat pollutants prior to infiltration into underlying soils and/or discharge to drainage to a conventional storm drain system.

Figure 3 schematically illustrates a partial infiltration design. Such designs use a perforated underdrain or underdrains. These are typically set into the soil subgrade and be surrounded by at least 3 in. of open-graded aggregate (typically ASTM No. 57 stone). Placing underdrains into the soil subgrade surface helps protect them during compaction of the overlying aggregate. Underdrain outlets are raised to enable WQv capture and/or additional volume capture if desired, and then outflow to storm drain or receiving water.

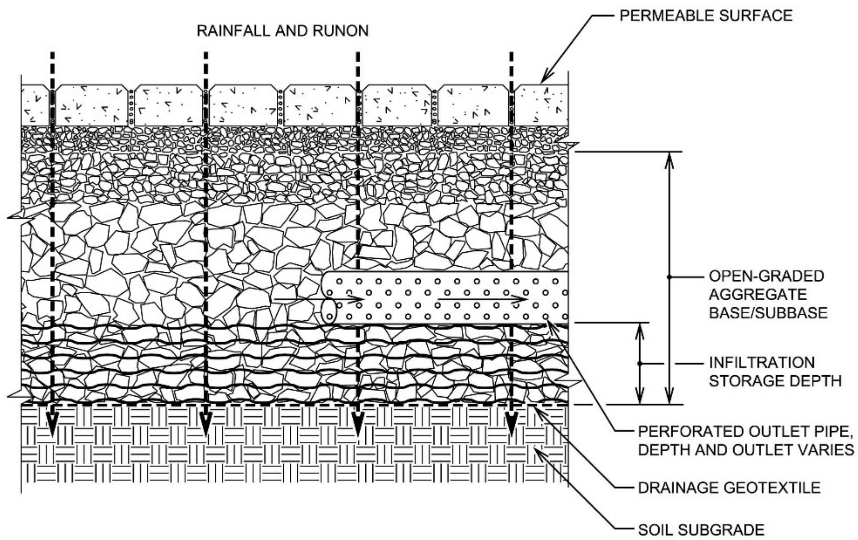

Figure 3. Partial infiltration schematic design with outlet pipe/underdrain

No-infiltration

No-infiltration designs create detention but with no water infiltrating into the soil subgrade. These provide a minimum 2 in. deep storage zone to temporarily store the WQv. Deeper retention may be required depending on the extent of run-on contributed from adjacent impervious surfaces. Permeable base materials such as washed, open-graded aggregates placed below the permeable pavement surface detain and treat pollutants prior to infiltration into underlying soils or discharge to a conventional storm drain system. The pollutant removal capabilities of no-infiltration permeable pavement designs are not well documented, and more research is needed. Pending the availability of this research, no-infiltration systems should not be relied upon for pollutant removal. In the meantime, No-infiltration systems are suitable for flow control and runoff collection.

Figure 4 schematically illustrates a no-infiltration design. Such designs use a catch basin and weir, or an outlet drain at a specified height to detain and release excess captured water. Underdrains are not typically used. Instead there is a small diameter bleed pipe (or pipes) to empty the storage reservoir of water over a specified number of hours.

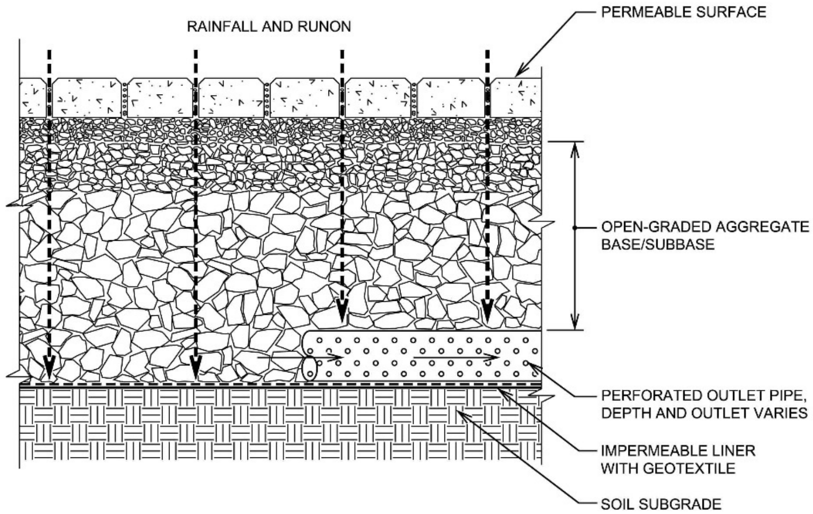

Figure 4. No-infiltration schematic design

Full, partial, and no-infiltration designs creating a 2 in. deep storage zone to store the WQv requires a minimum thickness of 6 in. of open-graded aggregate with a minimum of 30% porosity. Greater thicknesses may be required for additional water storage and/or structural capacity to support vehicular traffic. Specification resources for open-graded aggregate are provided for each pavement system.

Overflow designs shall not rely on water escaping upwards through the pavement surfaces. This defeats a primary benefit of permeable pavements, i.e., trapping sediment in the surface so it can be removed via vacuuming. Water flowing upward through the surface will mobilize unwanted sediments into the runoff. Similarly, designs that create a detention pond (typically with curbs) on the surface are not recommended. These structures can mobilize sediments as well as creating nuisance flooding from a permeable pavement surface clogged with sediment.

Applications and Advantages

Porous asphalt, pervious concrete and permeable interlocking concrete pavements can replace conventional pavement, but are limited to parking areas and low traffic volume roadways where the Caltrans Traffic Index generally does not exceed 9. Applications include patios, residential driveways, on-street parking lanes, local residential and collector streets, parking stalls in commercial or retail parking lots, overflow parking areas, alleys, maintenance walkways/trails, emergency vehicle and fire access lanes, median crossovers, roadway shoulders, and equipment storage areas.

Justification: *Caltrans Pervious Pavement Design Guidance* allows for a lifetime Traffic Index or TI = 9. This is equivalent to 1 million, 18,000 lb equivalent single axle loads or ESALs. Full-scale load testing in 2014 by the UC Pavement Research Center validated the structural capacity of open-graded aggregates in a weak, saturated clay soil subgrade. The following helps characterize the meaning of a TI = 9 traffic over 20 years:

- An average annual daily traffic (AADT) of 750 vehicles traveling in one direction
- 10% commercial vehicles (~75 each day)
- Average ESAL per commercial vehicle (trucks) = 2
- 0% annual growth in traffic
- 360 traffic days per year

Potential Limitations

- Not applied in heavily trafficked areas or where speeds exceed 30 miles per hour for porous asphalt, pervious concrete and permeable interlocking concrete pavements. Grid and permeable aggregate pavements should be applied in areas where speeds do not exceed 15 mph.

Justification: Speed limits on porous asphalt, pervious concrete, and permeable interlocking concrete pavements are per Caltrans, see Table 1-1 in *Pervious Pavement Design Guidance* (May 2016). Grid and permeable aggregate pavements are at significantly higher risk for instability if subject to 30 mph vehicles. Vehicle speeds should be restricted to maximum of 15 mph due to higher surface instability under accelerating, turning and braking tires.

- Care must be taken when applying in commercial or industrial areas to avoid placement in areas where a risk of chemical spills exists.
- The surface may become clogged with sediment if not properly installed and maintained, thereby increasing maintenance costs. Adjacent impervious pavements are the major source of sediment deposition onto permeable pavements. Therefore, the ratio of impervious pavement to permeable at-grade surfaces contributing sediment should not exceed 2:1 from the permeable pavement area receiving runoff.

Justification: All permeable pavements are subject to a higher risk of surface clogging if there are offsite sediment sources, not just paving blocks. There are several research papers demonstrating this, as well as papers demonstrating the impact of sediment contribution from impervious surfaces (see References).

- Improperly designed, constructed or maintained permeable pavements may cause uneven driving and walking surfaces. These conditions may be problematic for traversing with high heel shoes and complying with ADA design guidelines.
- Where ADA access is required, use paving products designed for ADA compliance such as porous asphalt or pervious concrete with 100% of the aggregate passing the 3/8 in. sieve, or pavers with integrated spacers that maintain paver-to-paver spacing to provide an ADA compliant surface.

Siting Criteria

- Permeable pavement is typically installed in areas with a maximum slope of 5%. Generally, slopes over 2% will require check dams to slow the flow of water through the base reservoir and encourage infiltration. The section on **Permeable Pavement Storage Layers** includes a check dam detail.

Justification: While not common, permeable pavements can be installed on subgrades with as high as 15% slope with the application of check dams or terraced subgrades in the base reservoir. This practice is described in the book, *Permeable Pavements* and has been successfully accomplished for porous asphalt and permeable interlocking concrete pavement projects.

- If designed to infiltrate stormwater into underlying soils, permeable pavements are considered indirect infiltration systems. Therefore, apply site screening and infiltration testing on soil subgrades. Apply separation and setback standards for indirect infiltration systems presented in Section 4.3.3.

Justification: The infiltration rate of soil subgrades of all permeable pavements must be established in-situ for hydrologic and hydraulic design.

- Unless otherwise determined by a geotechnical engineer and/or municipal regulations, the bottom of the pavement structures using full and partial infiltration designs should be no closer than 3 ft from the seasonal high ground water table. The bottom of the pavement structures using a no-infiltration design should be no closer than 2 ft from the seasonal high ground water table.

Justification: The City of Salinas requires 5 feet clearance between the bottom of the structure and the seasonal high groundwater table for non-liner designs. Other state permeable pavement guidelines allow 2 to 3 ft clearance. An important design question is will the extra water from some permeable pavement applications cause groundwater mounding, unstable soils, and flooded basements? Water tends to move through soils more easily in a lateral direction rather than vertically. Designs should consider lateral movement of water in subgrades into adjacent areas and the risk of damage.

- Permeable pavements are not recommended on fill soils if slope stability is at risk, or compacted soils render an unacceptably low infiltration rate for full and partial infiltration designs.
- Permeable pavements within 10 ft of a building foundation (where foundation waterproofing and drainage pipes cannot be confirmed) should apply impermeable membrane vertically on or near the foundation to keep water away from it.

Design and Construction Criteria Applicable to Permeable Pavements

The following are applicable to all permeable pavement types.

- Licensed professional civil engineers shall design permeable pavements.
- Calculate the Water Quality Volume (WQv) per the methods presented in Section 4.4.2 to determine the minimum required surface area for the permeable pavement detention:

  Minimum surface area = WQv/0.17 ft

  Or calculate the appropriate depth for the given surface area.
- Base and subbase layers shall be capable of bearing design loads without prematurely deforming. See structural design considerations for each pavement type.
- Permeable pavements should be the last to install during construction or redevelopment. If not installed as a final item, provisions for cleaning and testing the surface infiltration rate at the conclusion of the project shall be provided.

Justification: Covered in detail later in the text.

- Use a washed, open-graded aggregate base course to provide a permeable reservoir. Additional details are provided under the **Materials Specifications** section for each pavement type.
- When designing the base course, or base (or subbase) reservoir, to detain the water quality volume, select the appropriate porosity value for the material used. Porosity is the ratio of void space volume to the total volume of soil or rocks. Generally, the higher the soil porosity, the greater the ability to hold, transmit and infiltrate water. Porosity can be determined using ASTM C29 *Standard Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate*. The quarry supplier may provide porosity test data results for open-graded aggregates.
- Strength and durability of materials under saturated soil subgrade conditions must be considered.
- When installing the open-graded aggregate base/subbase course, it must be compacted as it is placed in lifts.

- Appropriate gradations of aggregate material must be used to minimize the migration of particles from one layer to the next. This aggregate layer is sometimes called a choke course. For permeable interlocking concrete pavements, the choke (base) course prevents the bedding course under the pavers from entering the larger aggregate subbase. For porous asphalt, the purpose of the choke layer of open-graded aggregate is to lock it into the larger aggregate beneath to create a stable platform for construction equipment
- For porous asphalt, a choke course of ASTM No. 57 stone (or similar sized open-graded aggregate) is required over the larger aggregate (typically ASTM No. 2 stone) used for the reservoir. This choke layer is generally 1 to 2 in. thick. When compacted into the larger stone size layer beneath, the choke layer facilitates movement of the asphalt paving machine across the aggregate.
- For permeable interlocking concrete pavements, a 4 in. thick base or choke course of ASTM No. 57 stone (or similar sized open-graded aggregate) over an ASTM No. 2, 3, or 4 stone subbase layer is required for vehicular applications. Pedestrian and residential driveway applications may use a base consisting of solely ASTM No. 57 stone.
- Permeable interlocking concrete pavements use a 1½ to 2 in. thick bedding layer of ASTM No. 8 or similar size stone under the paving units. Joint filling material may be ASTM No. 8, 89 or 9 stone, or similar gradations. Sand is not used in the joints or bedding.

Justification: Delete: Geotextile should not be used between aggregate layers as it presents a risk of filling with sediment and clogging. There is no research data demonstrating the efficacy of geotextiles in improving structural capacity of open-graded aggregate bases or subbases.

Justification: Delete as it is not always a true statement. Fill materials for grid cells and bedding materials are covered in the grid pavements section.

- For permeable pavements in privately owned parking lots, alleys, and streets designers should consider confining at perimeters with a concrete curb a minimum of 6 in. thick extending a minimum of 4 in. into the top of the aggregate base course. Besides providing a means to confine pavement surfaces during construction, curbs against adjacent vegetated areas can help prevent sediment entering onto the pavement. Curbs also can help prevent structural damage at the pavement edges. Alternatively, for porous asphalt and pervious concrete, the pavement edges can be thickened for additional structural support. For publicly-owned parking lots and streets, curbs thicknesses shall conform to local municipal or Caltrans standards. Residential applications do not require concrete curbs.

Justification: Minimum dimensions are provided for width and depth. Designers may wish to use thicker dimensions at their discretion. A curb penetrating 4 in. into the base is sufficient to contain the permeable pavement surface while providing some confinement of the base layer to help avoid rutting or damage at the perimeter.

- Direct sediment-laden runoff away from the permeable pavements.
- Do not install porous asphalt, pervious concrete, or grid pavement systems during rain events. Open-graded aggregates used in all systems can be installed during rain events as long as the soil subgrade is not saturated and the aggregate is kept free of sediment.

Justification: Permeable interlocking concrete pavements do not use sand in their assemblies per Interlocking Concrete Pavement Institute (ICPI) recommendations. See the 2011 ICPI publication, *Permeable Interlocking Concrete Pavements*. This system can be constructed during rain events as they consist of manufactured, ready-to-install products. Porous asphalt and pervious concrete cannot be constructed during rain events as they are plastic materials formed on the job site. Grids generally cannot be constructed during rain because when they include installation of sand, topsoil and grass.

- Drainage geotextiles shall be placed on the bottom and sides of the subbase layer.
- An impermeable liner (no-infiltration design) and an underdrain system shall be included in the design of the BMP in areas where there is outdoor storage or use of chemicals or materials within the drainage area that could threaten groundwater quality if a spill were to occur, or where in the opinion of a professional registered geotechnical engineer, infiltration of stormwater may result in slope failure, foundation settlement, pavement failure or a negative impact to existing underground infrastructure. The pollutant removal capabilities of no-infiltration permeable pavement designs are not well documented, and more research is needed: pending the availability of this research, No-infiltration systems should not be relied upon for pollutant removal. In the meantime, No-infiltration systems are suitable for flow control and runoff collection.
- During construction, do not allow heavy vehicles with tires to traverse the subgrade soil or aggregate within excavated recharge beds or areas of completed ~~porous~~ permeable pavement.
- Upon completion of installation and as a basis for acceptance by the project owner, the surface infiltration rate of porous asphalt and pervious concrete should be tested using ASTM C1701 *Standard Test Method for Infiltration Rate of in Place Pervious Concrete*. The permeable interlocking concrete pavement surface infiltration rate and that of grid pavements designed for WQv storage should be tested using ASTM C1781 *Standard Test Method for Surface Infiltration Rate of Permeable Unit Pavement Systems.* Test results from these two methods are comparable. The minimum acceptable infiltration rate shall be 100 in./hr. Permeable Aggregate Pavement does not require surface infiltration testing due to its high surface infiltration rate.

Justification: These test methods were developed by ASTM for construction acceptance testing are referenced in the Caltrans Pervious Pavements Design Guide. The test methods are also referenced for evaluating surfaces for vacuum maintenance (see Inspection and Maintenance Requirements section).

- Once permeable pavement is in place, ensure contributing drainage areas of the construction site have erosion and sediment control measures in place and are maintained until the site is stabilized.
- The storage capacity of the stone reservoir beneath permeable pavements depends upon local detention requirements and can be sized to capture, detain and filter the Water Quality Volume (WQV) as discussed in Section 4.4.2.
- A pre-construction (pre-paving) meeting for all permeable pavements is recommended. Schedule a pre-paving conference at a mutually agreed upon time and place to meet with the Engineer (i.e., owner's representative). Make the arrangements for the meeting facility at the job site or close to it as possible so it can be visited. Review the project plans and specifications. Discuss methods and timing of performing each item of the work.

  Pre-paving conference attendees should sign an attendance sheet provided by the Engineer. The pre-paving conference must be attended by the following representatives:

  1. Project superintendent
  2. Industry-certified construction foreman or crew leader for the permeable pavement construction. For pervious concrete, the required designation is a certified pervious concrete craftsman or installer by the National Ready Mix Concrete Association (NRMCA).

For PICP, the required designation is ICPI PICP Specialist from the Interlocking Concrete Pavement Institute (ICPI). Concrete grid pavements require a Commercial Installer Certification from ICPI. Plastic grids and the porous asphalt industries do not offer certification of construction personnel. In all cases, experience requirements should be specified and verified.

3. Earthwork construction foreman
4. Utility company representative(s)
5. Base/subbase construction foreman
5. Concrete/asphalt quality control or technical services manager

Do not start paving work until the listed personnel have attended the pre-paving conference.

Operation Inspection and Maintenance Requirements

- For porous asphalt, pervious concrete, and permeable interlocking concrete pavements, inspect and remove accumulated loose sediment, debris and litter using regenerative vacuum equipment at least twice per year. Monitor the rate of buildup of leaves, pine needles, and sediment in the surface and adjust this cleaning period as needed.
- If aggregates in grid openings in grids (designed for WQv capture) become sediment-filled, it will require replacement with clean aggregate. Removal can be done by vacuuming. Sand and grass used in grids that accumulate sediment for non-WQv capture applications is difficult to clean and will likely still infiltrate water, albeit more slowly.
- If ponds remain on the surface more than 30 minutes after a rainstorm cover greater than 10% of the total permeable area, conduct surface infiltration testing to determine if vacuum cleaning is needed. For surface infiltration testing, use ASTM C1701 for pervious concrete and porous asphalt, use C1781 for permeable interlocking concrete pavements and grid pavements designed for WQv capture. Areas typically first to accumulate sediment are those next to impervious pavements and in low elevation areas. Conduct the appropriate ASTM test method in these areas. Conduct vacuum cleaning if the measured surface infiltration rate is below 20 in./hr. Heavily clogged surfaces or pavements with neglected vacuuming may require the use of a true vacuum machine with water to withdraw sediment compacted into the surface. These machines exert greater vacuum force than regenerative air equipment.

Justification: Permeable pavements generally do not use sand filters in their assembly unless there is a pressing need to reduce phosphorus. In such cases, sand filters typically contain iron filings or proprietary coatings on the aggregates (e.g., aluminum oxide). Sand filters or other bio-retention designs may be used upslope or downslope receiving outflow from a permeable pavement. Such devices capture and reduce target pollutants draining into them, especially nutrients.

- Inspect the structural integrity of the pavement surface, looking for signs of surface deterioration, such as settlement, rutting, cracking, or spalling. Replace or repair affected areas. Refer to ASTM D6433 *Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys* for procedures on conducting a structural condition survey for porous asphalt and pervious concrete. Refer to ASTM E2840 *Standard Practice for Pavement Condition Index Surveys for Interlocking Concrete Roads and Parking Lots* for procedures on conducting a structural condition survey for permeable interlocking concrete pavement. These ASTM methods provide a means to calculate a condition index which can be used to determine when maintenance or replacement is required.

- Besides the permeable pavement surface, inspect inlets, pretreatment BMPs and any flow diversion structures for sediment buildup and structural damage. Perform standard maintenance procedures. Maintain a database of visual condition surveys and remedies to comply with NPDES permit requirements.

Winter maintenance - An advantage of permeable pavements is they provide downward egress for melting ice and snow, thereby reducing ice formation and the potential for pedestrian slips and falls, as well as deicer use. Permeable pavements do not heave in the winter due to drainage of saturated soils and aggregate bases/subbases well before the entire pavement structure freezes. This aspect extends the pollutant reduction performance into the freezing temperature season. Similarly, permeable pavements experience thaw earlier compared to conventional pavements, i.e., pollutant reduction resumes in the late winter/early spring.

Permeable pavements can be snow plowed. A rubber plow edge is recommended to minimize scarring of the pavement surface. Applying sand or ash for tire traction is not recommended. If inadvertently used, it must be removed by vacuuming in the spring. If left on the pavement, it will clog the surface and reduce infiltration.

Anti-icers and deicers can be used on porous asphalt and permeable interlocking concrete pavement. Pervious concrete should cure a year prior to the application of anti-icers and deicers. Use of fibers and air-entrained concrete can provide additional winter durability. Deicers containing magnesium chloride should not be used on any concrete surfaces. Deicers should not be used on grid pavements with grass as they will kill it. Grids with grass should not be snow plowed unless the plow operator is directed to raise the plow slightly to prevent grass tearing and removal.

2A-3: Identifying future work to increase technical credibility and soundness of pervious pavement design to meet desired performance

The following are research and practice needs that need development for permeable pavements.

1. Use of lightweight deflectometers (LWDs) to assess deflection of soil subgrades and compacted, open-graded bases. Such devices have two ASTM standards for their use. AASHTO is expected to release provisional standards on their use in the field. These will not include measurement protocols for open-graded aggregate bases/subbases and such protocols need to be developed. Since density of compacted open-graded aggregates cannot be consistently measured with nuclear density gauge, LWDs offer an alternative, cost-effective approach for contractor quality control/quality assurance for installation of these materials. They help indicate when compaction is adequate. Unlike nuclear density gauges, no certification of these devices or operators is needed to use LWDs. Several state DOTs have adopted their use for assessing the deflection of compacted soil subgrades, dense-graded and stabilized road bases.
2. The ASCE Transportation and Development Institute is completing a national standard for design, construction and maintenance of permeable interlocking concrete pavements. Much of this content is applicable to other permeable pavements. With publication expected in 2017, this standard should be referenced in future CASQA documents.
3. Full-scale load testing of porous asphalt and pervious concrete, as well as hybrid permeable interlocking concrete pavements with pervious concrete on the soil subgrade or directly under

the concrete pavers. UC Pavement Research Center has developed mechanistic models for Caltrans and industry. These require validation and development of base/subbase thickness design tables for traffic. Such research should explore ways to increase structural capacity beyond a Caltrans Traffic Index of 9. This will likely be accomplished with hybrid systems. CASQA should request funding for such research from the Caltrans Department of Environmental Assessment. The research should be conducted at UC Pavement Research Center in Davis (the research arm of Caltrans) and the primary deliverable needed for use by consultants and agencies is a validated set of thickness design tables for porous asphalt, pervious concrete and hybrid systems using permeable interlocking concrete pavement that increase applications into more streets, and institutionalize their use among road agencies as well as by stormwater agencies.

4. Pervious concrete research at the University of Missouri is demonstrating significant pollutant reductions with fly ash mixes. This information, performance criteria and costs should be incorporated into use of pervious concrete when applied to the soil subgrade in hybrid designs.
5. The National Asphalt Pavement Association is developing Structural Design Guidelines for Porous Asphalt Pavements which will be available in the summer of 2017. This guide uses the AASHTO empirical design method.

Deliverable 2B – Recommendations for Surface Layer Element

This section reviews the surface layer elements in the City of Salinas standard and provides additional guidance and specifications that can be provided without resorting to brand/product specific details and standards.

Background: As an initial, significant "global" edit, the text under each pavement type found in the City of Salinas guideline is *deleted*. Siting criteria for each pavement was found to be repetitive and that subject is covered in the initial section above. Instead, a description of each pavement type is provided as new text, essential material specifications for referral, structural design guidelines, and salient characterizations of the construction process.

Porous Asphalt

Porous asphalt typically consists of two surface layers: asphalt treated permeable base (ATPB) supporting an open-graded friction course (OGFC). As the surface, OGFC consists of a finer (smaller size) aggregate gradation than the ATPB. This OGFC layer can be used alone in sufficient thickness to support traffic. If rutted or heavily clogged, the OGFC can be milled, the remaining surface vacuumed, and then replaced with same. Another, less expensive option is using only ATPB with consideration given to limiting aggregate sizes. Tack coats or prime coats using emulsified or cutback asphalts typical to conventional asphalt construction are not used with porous asphalt materials. Surface seal coats for maintenance are not used as well.

Figure 5: Porous asphalt

Figure 6: Porous asphalt parking lot in Fremont, CA

Material Specifications - OGFC: Refer to Caltrans Specification 39-2.04 or the Greenbook Specifications for Open Graded Friction Course material requirements. ATPB (if using): Refer to Caltrans Specification 29-2 Asphalt Treated Permeable Pavement Bases. AGFC and ATPB use stiffer PG (performance grade) asphalt binders than those used to bind conventional asphalt pavements. Binders used in porous asphalt are typically PG 70-10, PG 70-22M, PG 64-28M, MAC-15TR or PG 76-22M. (PG refers to the performance graded asphalt binder testing protocol. The binder grade identifies various binder characteristics correlated to pavement performance. The letters after the grade refer to the types of binder modifications required required). The use of liquid antistrip is recommended.

The recommended porosity is 16% to 22% per ASTM D6752 *Standard Test Method for Bulk Specific Gravity and Density of Compacted Bituminous Mixtures Using Automatic Vacuum Sealing Method.* Other applicable material standards are draindown of the binder which should be no greater than 0.3% per ASTM D6390 *Standard Test Method for Determination of Draindown Characteristics in Uncompacted Asphalt Mixtures*. The durability of the asphalt mixes can be characterized using ASTM D7064 *Standard Practice for Open-Graded Friction Course (OGFC) Mix Design*. This reference includes the Cantabro abrasion test to assess abrasion durability. Recommended abrasion loss for unaged samples is ≤ 20 and ≤ 30 for seven day aged samples.

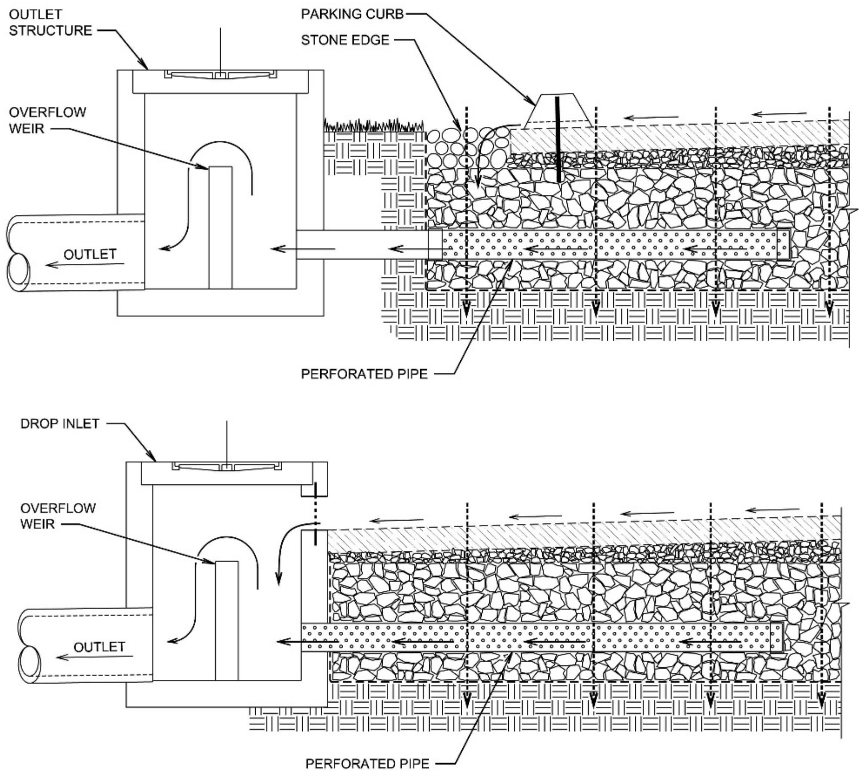

Figure 7: Porous asphalt partial exfiltration design with outlet options (FHWA)

Structural Design - Recommended minimum thicknesses from the National Asphalt Pavement Association may be adjusted by a qualified civil engineer familiar with porous asphalt mix and pavement design. Do not use the OGFC or ATPB layers for water storage.

- Pedestrian areas (sidewalks, plazas, courtyards, etc.): Minimum 3.0 in.
- Vehicular traffic: Minimum 4 in. section of asphalt mix (OGFC or combination of OGFC and ATPB). OGFC must be placed in minimum 1 in. lifts and ATPB must be placed in minimum 3 in. lifts. Use Caltrans Highway Design Manual Topic 633 to determine the OGFC thickness for Traffic Indices up to 9. Use the measured R-value of the soil subgrade and use a Gravel Factor of 1.4 for OGFC. Maximum recommended Caltrans Traffic Index = 9.

Construction Considerations - Refer to Section 39 of Caltrans Standard Specifications for guidance on construction. A tracked asphalt paver machine is recommended to place the hot ATPB on the compacted, open-graded aggregate base. This is typically a large aggregate-size for the reservoir layer choked with 1 to 2 in. of smaller open-graded aggregate compacted into the surface, typically ASTM No. 57 stone. Compact ATPB in one layer using a steel-wheel, 10-ton tandem roller in static mode. Compact when the ATPB mixture is from 200 to 250° F. Make 1 to 3 passes.

For OGFC, with not less than 6% asphalt cement content, if the ambient air temperature is below 70° F, cover loads in trucks with tarps to keep the mix hot (refer the Caltrans Standard Specifications or Greenbook Specifications for minimum temperature requirements). The tarps must completely cover the exposed load until the mixture is transferred into the paver's hopper or to the pavement surface. Tarps are not required if the time from discharge to truck until transfer to the paver's hopper or the pavement surface is less than 30 minutes.

Compact OGFC on the ATPB with steel-wheel, 10-ton tandem roller in static mode. Follow Caltrans guidance for OGFC compaction and temperatures for mixes with no modifiers, with modifiers, or with an asphalt rubber binder. Allow the pavement to cure for 24 hours prior to opening to vehicular traffic.

When sections of the porous asphalt require saw cutting, the cut material should be removed and dust on the remaining material removed with vacuuming. Do not use water as it can wash into the pavement and risk clogging.

Pervious Concrete

Pervious concrete consists of small-size, (typically 3/8 in.) open-graded aggregate bound with cement to produce a rigid pavement surface. Unlike conventional concrete, the amount of sand in a pervious concrete mix is greatly reduced or eliminated. This results in a concrete material with void content typically between 15% to 25% percent.

Figure 8: Pervious concrete

Figure 9: Pervious concrete street

Material Specifications - Use Caltrans Specifications 40-8 Pervious Concrete Pavement and 90-7 Pervious Concrete and also review ACI 522.1 *Specifications for Pervious Concrete*. The maximum size aggregate for pervious concrete surface layer shall not exceed ½ in. While not common, when the pavement is constructed in two or more layers, layers below the surface layer may have a larger maximum size aggregate. The cementitious material content should not exceed 590 lbs/cy. Joint filler inserted into isolation joints at other pavements or structures must comply with ASTM D994 *Standard Specification for Preformed Expansion Joint Filler for Concrete (Bituminous Type)*. Steel dowel bars and tie bars normally used in conventional concrete pavements are not used in pervious concrete.

Unit weight measured on the job site using ASTM C1688 *Standard Test Method for Density and Void Content of Freshly Mixed Pervious Concrete* is a means to compare the pervious concrete mix while in a plastic state to those in the project specifications. Unlike conventional concrete pavement, compressive strength or flexural strength is not used to assess the quality of hardened pervious concrete. This is due to differences in cores taken from the pavement and then tested in compression in the laboratory to the in-situ compressive strength of a monolithic surface. Test methods eventually may be developed.

As an alternative to measuring compressive strength, cylinders can be cored and removed from the hardened pavement, cured and tested for density in the laboratory using ASTM C1754 *Standard Test Method for Density and Void Content of Hardened Pervious Concrete*. The results are compared to those in the project specifications. Air entrainment of the cement paste is required in areas where the pavement may become susceptible to freeze thaw conditions.

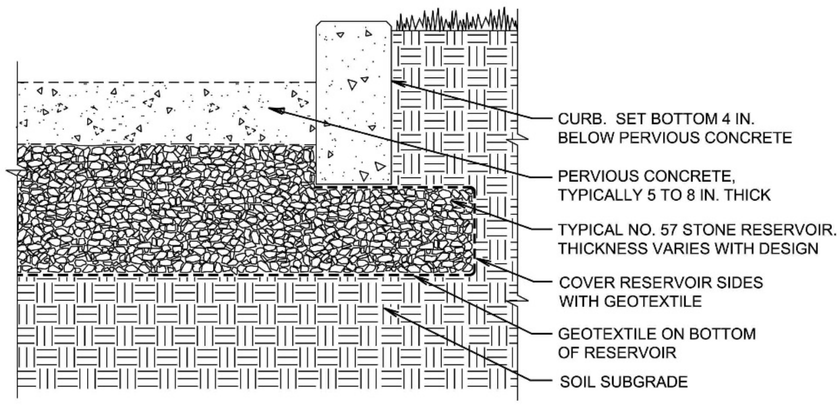

Figure 10. Typical pervious concrete cross section

Structural Design - Pedestrian: minimum 4 in. thick. Vehicular traffic: cars only: minimum 6 in. thick. Areas with truck traffic, Caltrans Traffic Index < 9; minimum 8.5 in. thick. Caltrans Traffic Indexes from 9 to 10: minimum 9.5 in. thick. Do not use the pervious concrete layer for water storage.

Construction Considerations - Refer to Caltrans Specifications 40-8 Pervious Concrete Pavement and 90-7 Pervious Concrete, and also review ACI 522.1 *Specifications for Pervious Concrete*. This guide specification covers materials, preparation, forming, placing, finishing, jointing, coring, and quality control as well as testing, evaluation and acceptance. Place pervious concrete when the air temperature is above 40° F. Pervious concrete should also not be placed during hot, dry, or windy conditions due to adverse loss of moisture. Pervious concrete cannot be pumped and must be delivered via a ready-mix concrete truck. While it cannot be pumped, it can be placed via conveyor belt to accomplish delivery. Pervious concrete must be discharged from the truck within 60 minutes of batching. Use of a hydration stabilizer can extend this time by an additional 60 minutes.

Unlike finishing conventional fresh concrete, finishing fresh pervious concrete does not use bull floats, darbies, or trowels except to form the edges or for minor touchup. With forms in place, pervious concrete is continuously poured into place, compacted, and joints formed. The fresh surface is covered with plastic sheets to help prevent evaporation and allow the water to cure or harden the concrete mix. Curing takes seven days (This may be shortened by proven proprietary admixtures to the concrete). If plastic sheets are not used, or are placed but do not form an impervious surface, moisture from the curing concrete will evaporate. This can reduce its structural capacity and early deterioration can be expected.

The plastic sheets should extend far enough beyond the edge of the paved area so that it can be secured firmly against the fresh concrete surface. The edges of the plastic must be fastened such that air does not circulate under it and remove moisture needed for curing. Weights used to hold down the edges can be boards under sand bags or sand bags alone. Placing unconfined soil on the plastic is not recommended because it can contaminate the pervious concrete and aggregate layers beneath if the plastic is inadvertently separated or torn from spreading or removing the soil. Stapling the plastic to wooden forms surrounding the pavement is recommended. Maintaining secured plastic during the curing time is essential. The contractor should visit the site daily including weekends and holidays to verify that the plastic remains secured.

When sections of the pervious concrete require saw cutting, the cut material should be removed and dust on the remaining material removed with vacuuming. Do not use water as it can wash into the pavement and risk clogging.

Experienced pervious concrete material suppliers and contractors are essential to a successful result. Use National Ready Mixed Concrete Association (NRMCA) certified personnel.

According to Caltrans specifications, the paving crew must meet one of the following criteria:

1. Employ one or more NRMCA certified pervious concrete craftsman who must be on site actively working with and guiding the placement crew during pervious concrete placement.
2. The crew must employ three or more NRMCA certified pervious concrete installers who must be onsite actively working with and guiding the placement crew during pervious concrete placement.
3. The crew must employ one or more NRMCA certified pervious concrete installer and three or more NRMCA certified pervious concrete technicians who must all be on site actively working with and guiding the placement crew during pervious concrete placement.

Permeable Interlocking Concrete Pavement

Permeable interlocking concrete pavement (PICP) consists of (impervious) manufactured concrete units that form permeable voids and joints when assembled into a laying pattern. The openings typically comprise 5% to 15% of the paver surface area filled with small-sized aggregates that allow water to pass rapidly. Paving units may be made of clay or stone as well.

Figure 11: Permeable interlocking concrete pavement

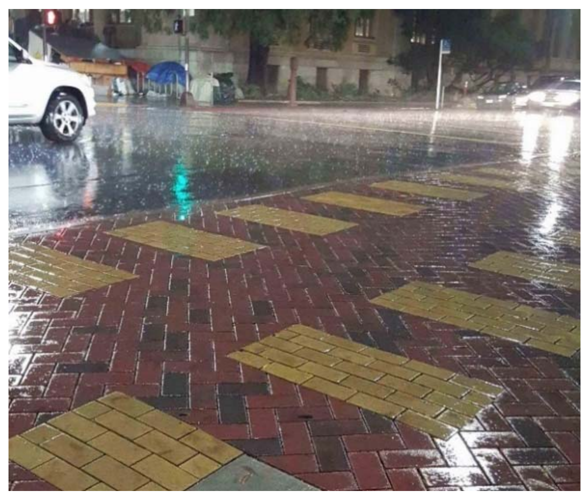

Figure 12: Permeable interlocking concrete pavement in Berkeley, CA

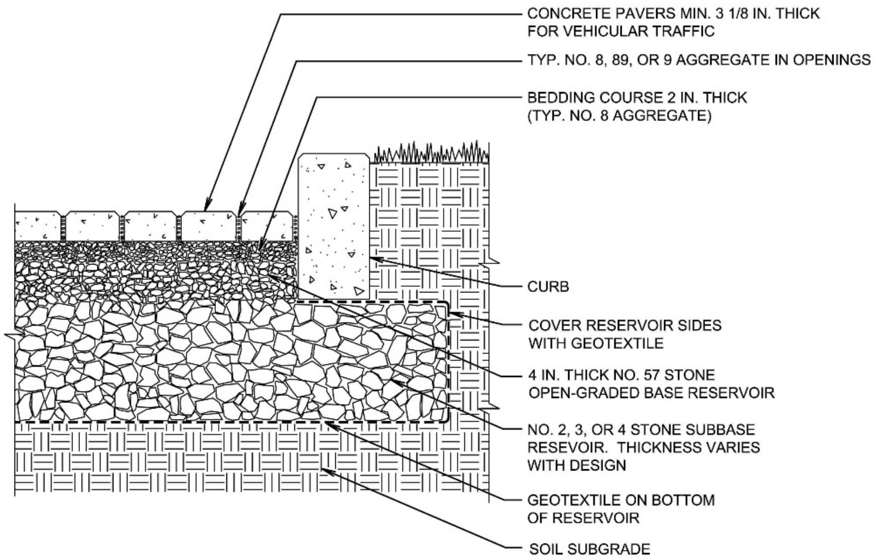

Figure 13: Typical permeable interlocking concrete pavement cross section

The aggregate-filled openings allow stormwater to enter an open-graded aggregate bedding layer and base/subbase that supports the pavers while providing water storage and runoff treatment. Do not use paving units that do not include aggregate in the joints. The aggregate-filled joints facilitate trapping sediment at the pavement surface. This location (rather than the bottom of joints) for sediment to collect facilitates its removal via vacuuming. Also, sediment on the surface of joints filled with aggregate facilitates inspection and the decision to vacuum them. Therefore, all projects require aggregate-filled joints.

Material Specifications - Refer to Caltrans Specification 40-9 Permeable Interlocking Concrete Pavement. This specification requires that concrete pavers conform to ASTM C936 *Standard Specification for Solid Concrete Interlocking Paving Units* and have a minimum thickness of 3.125 in. when subject to vehicular traffic. Herringbone or similar interlocking laying patterns are recommended in vehicular areas such as commercial drives, parking lots, alleys and streets. The joints between the concrete pavers are filled with permeable aggregate typically ASTM No. 8, 89, or 9 stone. Consult with the paver supplier to determine the appropriate ASTM stone size. The paving units are installed over 1½ to 2 in. thick bedding course consisting of ASTM No. 8 stone.

For pedestrian and residential driveway applications, the pavers and bedding layer are placed over a compacted base of washed ASTM No. 57 or washed Caltrans Class 3 Permeable Material. For all other vehicular applications, the base layer is reduced to 4 in. thick, and that is placed over a compacted subbase reservoir layer of washed ASTM No. 2, 3, or 4 stone or Caltrans Class 4 Aggregate Subbase.

If clay pavers are used for surfacing, they should conform to ASTM C1272 *Standard Specification for Heavy Vehicular Paving Brick*, have a nominal width and length of 4 x 8 in., and have a minimum thickness of 2.75 in. If cut stone pavers are used for surfacing, they should conform to ASTM C615 *Standard Specification for Granite Dimension Stone*, have a nominal width and length of 4 x 8 in., and be at least 3 in. thick.

Structural Design - Pedestrian: 6 in. minimum base thickness using washed No. 57 stone or Caltrans Class 3 Permeable Material. Vehicular: Use the design method and tables for up to a Caltrans Traffic Index(TI) = 9 found in Caltrans *Pervious Pavement Design Guide* available on http://www.dot.ca.gov/hq/oppd/stormwtr/pervious.htm. This design method for determining the subbase thickness is based on the number of days per year water is standing in the subbase (i.e., the soil subgrade is saturated). Do not use the paver joints and bedding materials for water storage.

Construction Considerations - The installation of permeable interlock interlocking pavement is different from regular interlocking concrete pavements which uses sand joints and a dense-graded base. A PICP Installer Technician Course certificate from the Interlocking Concrete Pavement Institute (ICPI) is required for the foreman or crew leader on the job site. Refer to guidelines in the Caltrans Pervious Pavement Design Guide and the permeable interlocking concrete pavement guide specification from www.icpi.org.

Pedestrian areas may use plastic or metal edging joined to geogrid to restrain the concrete pavers. Concrete curbs can be used in pedestrian or vehicular areas. Curbs are typically cast on the compacted reservoir layer. Geotextile should be placed vertically along the sides of the aggregate subbase. The compacted ASTM No. 57 base or Caltrans Class 3 permeable base material placed on the subbase contains or chokes the smaller size aggregates in the bedding layer placed above it. The bedding layer is screeded to 1½ to 2 in. thickness and is not compacted.

Concrete pavers are placed on the screeded bedding layer manually or with the assistance of machines to accelerate construction time. Cut pavers at edges should be no less than 1/3 of a whole paver if exposed to tires. If not exposed to tires, cut pavers at edges should be no less than ¾ in. wide. After the pavers are placed they are compacted with a minimum 5,000 lbf plate compactor. The paver joints are then filled with small, washed stones, i.e., ASTM No. 8, No. 89 or 9 aggregates. Once an area has the joints filled, the surface is swept clean and the pavers are compacted again with minimum 5,000 lbf plate compactor. All pavers within 6 feet of the laying face must have joints filled with aggregate at the completion of each day.

Follow ICPI guide specifications for tolerances on joint straightness and height above curbs after compaction. Once the pavers and jointing stone are compacted, the pavement surface is ready to accept traffic. The joints should be inspected 6 months after initial construction to ensure the joints are filled with aggregate.

Note: ASCE is expected to release a national standard on PICP design, construction and maintenance in 2017.

Grid Pavements

Grid pavements consist of concrete or plastic units with a minimum 20% open surface. The surface is filled with a permeable material, typically small sized, open-graded aggregate (e.g., ASTM No. 8 stone) for WQv capture, or sand, or topsoil and grass over a dense-graded base for non-WQv designs.


Figure 14: Grid pavements

Figure 15: Grid pavements in an emergency fire lane

When WQv management is required, grids should use small, open-graded aggregate (e.g., ASTM No. 8 stone) in their openings and bedding, as well as an open-graded base. For non-WQv applications, plastic and concrete grid units with grass or sand in their surfaces are often placed directly on a thin sand leveling course over a compacted, dense-graded base such as Caltrans Class 2 material. While capable of infiltrating direct (overhead) rainfall, this assembly does not have sufficient porosity in the surface or base to create storage capacity that manages WQv. Sand, topsoil and grass should not receive run-on from adjacent impervious pavement as this clogs them. Sand, topsoil and grass have very low initial infiltration rates (compared to open-graded aggregates) and incoming sediment risks clogging, which further slows infiltration.

Unless irrigated, grass surfaced grids are not recommended in parking lots that receive daily vehicular use as shade, engine heat, and drought periods risk killing the grass. Such applications should use sand or open-graded aggregate in their surfaces. Grass surfaces are reserved for automobile parking areas and stalls that receive intermittent use. Besides infiltration and runoff abatement, grids with grass provide a cooler surface than conventional pavements.

Material Specifications - Concrete grid units should meet the requirements in ASTM C1319 *Standard Specification for Concrete Grid Paving Units*. They should have a minimum thickness of 3 1/8 in. Plastic grids come in a range of thicknesses and consist of proprietary materials and configurations. Product specifications should be obtained from their manufacturers. If topsoil and grass are used, follow manufacturer's recommendations for each, or seek advice from a university extension agent specializing in turf grass. Sand should be washed and its gradation conform to ASTM C33 *Standard Specification for*

Concrete Aggregates. This type is often called 'concrete sand' because it is used in the manufacture of concrete.

When subject to vehicular traffic, all dense-graded aggregate bases should conform to Caltrans Class 2 or similar specifications as directed by the municipality. When WQv is desired, all open-graded aggregates should be crushed material such washed ASTM No. 57 stone or washed Caltrans Class 3 Permeable Material.

Structural Design - Pedestrian: minimum 6 in. thick Caltrans Class 2 or similar base. Vehicular: Minimum 8 in. thick base. For concrete grids, lifetime traffic should not exceed 7,500 18,000-lb equivalent single axle loads or a Caltrans Traffic Index ≤ 5. This suggests applications such as emergency fire access lanes and overflow parking for cars and very occasional use by trucks. Contact plastic grid manufacturers for recommendations on maximum equivalent single axle loads for specific applications. Do not use AASHTO H-20 loading as acceptance criteria because it does not assess the structural impacts of repetitive wheel loads.

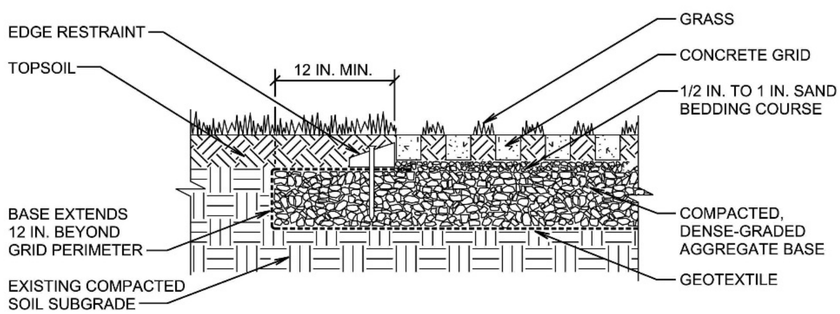

Figure 16: Typical grid pavement with concrete units over a compacted aggregate base

Construction Considerations - When grid pavements use compacted dense-graded aggregate bases, the soil subgrade also should be compacted for structural support and since infiltration into the soil is not an objective of this application. The soil subgrade and base should be compacted a minimum of 95% of maximum density per ASTM D698 *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3))*, Caltrans, or local municipal standards. Drainage geotextile should be placed on the bottom and sides of the compacted base.

Edge restraints are used to enclose concrete grid units. These are typically concrete curbs, or plastic or metal restraints staked into the compacted, dense-graded aggregate base. Edge restraints are typically not used to constrain plastic grids because they are delivered as a mat or fastened together on the job site. However, transitions to impervious pavements may require thickening them at their junction with plastic grids to prevent cracking and deterioration, and to restrain the bedding and grid surface materials.

When used for non-WQv capture designs, coarse, ASTM C33 washed sand is screeded to a consistent 1 in. thickness on the compacted base and the plastic or concrete grids placed on it. The units are cut to fit along the edges. Follow manufacturer's guidelines for cutting plastic grids.

When placed on open-graded aggregates, consider using small (or cut) concrete grids (i.e., 12 to 14 in. length) as they can reduce the risk of tipping under traffic. Concrete grids are typically cut with a powered masonry saw to fit them into the edges of an area. Once concrete grids are in place, they are compacted with a plate compactor to seat them into the bedding sand. The concrete and plastic grid openings are filled with topsoil and grass (or seed), sand, or ASTM No. 8 stone (or similar size) per the project specifications. The surface of concrete grids is swept clean and the units are compacted again with a plate compactor. Plastic grids are not compacted.

Permeable Aggregate Pavements

Permeable aggregate pavement simply consists of open-graded crushed stone, compacted with no surfacing applied. The advantage of this pavement is its low cost and rapid construction. The disadvantages are difficulty in traversing by foot or via mobility devices, lower structural capacity for supporting vehicles compared to applied permeable surfaces, and difficulty in removing trapped sediment without replacing some or all the aggregate. Another disadvantage can be dust emitted from the surface when vehicles pass. Given these constraints, aggregate pavements are intended for occasionally used parking lots and low-volume roads.

Material Specifications - The aggregate is typically washed ASTM No. 57 stone or washed Caltrans Class 3 Permeable Material. These materials can rut more readily under tires especially in thick depths (> 12 in.) especially without confinement from curbs. In such cases, consider using larger ASTM No. 2, 3 or 4 stone with a 1 to 2 in. thick choke course of No. 57 stone. These larger size aggregates tend to have higher shear capacity making them more stable under loads.

Structural Design - Refer to the Federal Highway Administration *Appendix A: Gravel Road Thickness Design Method*. This reference allows a maximum of 400,000 lifetime ESALs or a Caltrans Traffic Index = 8. Consider the following input variables to this design procedure:

- High rutting which translates to a high difference in initial and final (almost unusable) serviceability.
- Expected number of lifetime ESALs.
- A low resilient modulus for the stiffness of the aggregate especially when saturated, typically well less than 20,000 psi.
- A low resilient modulus when the subgrade is saturated.
- Presence of freezing winter temperatures followed by a spring thaw.

Construction - As with other permeable pavements construction steps, a parking lot or road subgrade is excavated, drainage geotextile and underdrains applied as designed, and washed ASTM No. 57 or Caltrans Class 3 Permeable Material is applied and compacted. Additional guidance on aggregate base and subbase construction is provided in **Permeable Pavement Storage Layers**.

Maintenance - Open-graded aggregate is more susceptible to rutting then exposed, compacted dense-graded aggregate, especially when not confined with concrete curbs. Therefore, maintenance will consist of periodic regrading and re-compacting to remove ruts. The surface cannot be vacuumed and sediment will move to the subgrade quickly since there is no surfacing to trap it for later removal. This risks a reduction in the subgrade infiltration rate and possible overflow. Therefore, a means to handle overflow (typically outflow pipes or drainage swales at the perimeter) should be provided.

Pervious Pavement Storage Layer

Refer to **Permeable Pavement Infiltration Options** for a review of permeable pavement storage layer and details that address soils with, good, moderate and poor/no infiltration. Guidance is provided on use and placement of underdrains for each condition, and these are incorporated into the drawings in that section.

This section provides additional information critical to design, construction and monitoring of the water storage layer.

Permeable Pavement Storage Layers

Subgrade Infiltration Testing - The soil subgrade must be tested for infiltration using ASTM D3385 *Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer* or methods approved by the local municipality when the design is for full or partial infiltration. Infiltration testing is done prior to construction by digging test pits to a depth approximating the bottom of the pavement depth. Do not use percolation test methods for septic fields as they tend to overestimate infiltration rates. Use the average of infiltration values tested under saturated conditions for hydrologic design.

The number of infiltration tests depends on the permeable pavement area, soil type, current and past land use, and final subgrade elevation(s) from cuts. If there are no local requirements, the recommended number of tests is a minimum of two up to 7,000 sf and one additional for each additional 7,000 sf of permeable pavement. Measurements should be taken at the elevation of test pits approximate the interface of aggregate subbase and the native soil (i.e. the subbase bottom elevation(s). Linear road projects may require adjustment to the testing frequency.

Soil Compaction - While un-compacted soils are recommended under permeable pavements, some are built on compacted soil subgrades. This is due to some situations requiring subgrade compaction for additional structural support of traffic. If soil compaction is required by the engineer, then the compacted density of the soil subgrade should be determined from samples taken at the test pit (or from soil borings) using laboratory procedures per ASTM D698.

The soil is compacted within the test pits to a minimum of 95% of laboratory density. The density and moisture content measured with a nuclear density gauge per ASTM D6938 *Standard Test Method for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)*. When the established minimum density is achieved via compaction, conduct ASTM D3385 to determine the infiltration rate. Use the average of infiltration values tested under saturated conditions for hydrologic design.

R-value Tests - R-value laboratory tests will be required for structural design. These should be done according to California Test Method 301, ASTM D2844 *Standard Test Method for Resistance R-Value and Expansion Pressure of Compacted Soils*, or AASHTO T-190 of the same title. Soil samples can be taken from test pits dug for infiltration testing, or boring samples taken at the approximate bottom depth of the permeable pavement structure.

Excavation - If possible, subgrade soil excavation should be done by equipment positioned outside the area to be excavated. If not possible, then tracked excavation equipment should be used on the soil subgrade to help minimize compaction. If aggregate will not be immediately placed, or if the excavated area ~~can~~ will be used as a sediment basin (not recommended), then the excavation shall be left a minimum of 6 inches proud of final grades. When aggregate is ready to place, the sediment and soil are excavated to final design grades, graded and readied for geotextile, underdrain and aggregate placement.

Excavation may include sloped trenches for receiving aggregate and perforated underdrains. These trenches should be lined with drainage geotextile or an impermeable liner (for no-infiltration designs), and surrounded by at least 3 in. of ASTM No. 57 stone. Pipe perforations should face down while outlet pipes have no perforations. This underdrain position on the subgrade is generally faster and risks less damage to pipes from compaction compared to positioning the underdrains within the aggregate base or subbase.

For WQv management, provide underdrains with upturned outflow pipe(s) or direct pipe outlets positioned a minimum of 6 in. above the surface of the soil subgrade. This should capture at least a 2 in. water depth. Use non-perforated pipe for outflows. Outflow pipe heights may be higher to manage additional water depths per municipal requirements.

Geotextile – Drainage Geotextiles are recommended on the sides all excavations in the absence of a full-depth concrete curb to confine the base/subbase aggregates or an impermeable liner. Vertical placement of geotextiles helps prevent erosion of adjacent soil into the base/subbase layers. Geotextiles placed horizontally over the entire soil subgrade are recommended as well. Install with no wrinkles starting at the lowest subgrade elevation working upward to create a minimum downslope overlap of 12 in. on each geotextile section. Interstitially placed geotextile within aggregate layers is not recommended, as it may interfere with the structural capacity of the pavement, and may become clogged over time.

Geotextiles Selection – Drainage geotextile should be selected according to AASHTO M-288, *Geotextiles for Highway Applications*. The following should be used in this specification:

- Subsurface Drainage Geotextile Requirements based on the in-situ soil percent passing the No. 200 sieve. This can be determined via sieve analysis using ASTM C117 *Standard Test Method for Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing*.
- Estimate permeability (permittivity times geotextile thickness) so that it is a minimum of ten times of the permeability of the soil subgrade.
- Use Geotextile Class 2 strength property specifications. If there is a high risk of geotextile damage during construction, use Class 1.

Impermeable Liners - When specified, impermeable liners (also called geomembranes) can be polyvinyl chloride (PVC), high density polyethylene (HDPE), or ethylene propylene diene monomer (EPDM). Manufacturers of these materials should be consulted for appropriate applications, thicknesses, specifications and field construction guidance including seam welding or adhesives, and how to render a tight fit against penetrating drain pipes. Liners typically require thick (e.g., 10 oz./sy), non-woven geotextile over them for additional protection from tears or punctures during aggregate filling and compaction. Once assembled and installed, liners should be tested for leaks with special attention to seams and pipe penetrations for no-infiltration designs. Vertical impermeable liners may be used to help prevent water from entering foundations or other pavements.

Aggregate Materials - The storage layer (also called the reservoir layer) of open-graded aggregate base and subbase materials should have the following features:

- Minimum 30% porosity
- Crushed material with minimum 90% fractured faces
- Washed to minimize material passing the No. 200 sieve (i.e., < 2%)
- Meet ASTM gradations per C33 *Standard Specification for Concrete Aggregates* or D448 *Standard Classification for Sizes of Aggregate for Road and Bridge Construction* (ASTM C33 and D448 contain identical gradations) or AASHTO M-43 which has the same title as ASTM D448. ASTM and AASHTO publish identical gradation standards.
- Meet Caltrans gradations as noted herein when Caltrans specifications are used.
- Aggregates used in vehicular applications should have a Los Angeles Abrasion loss no greater than 40 per California Test Method 211 or ASTM C131 *Standard Test Method for Resistance to*

Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine. For larger aggregates, refer to C535 *Standard Test Method for Resistance to Degradation of Large-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine.*

- Do not use crushed, recycled concrete aggregates as their friable nature generates fines during compaction that risk clogging the subgrade.

Two-dimensional geogrids or three-dimensional geocells may be used to increase structural capacity of open-graded aggregates. In addition, pervious concrete can be placed directly on the soil subgrade to strengthen saturated subgrades, confine and stiffen open-graded aggregates, especially over weak, saturated clay and silt soils. Consult manufacturers and/or experienced pavement engineers on design and applications using these methods to increase structural performance.

Aggregate Storage Layer Installation - Aggregate storage and handling must be done to prevent contamination by sediment. If contaminated, the aggregate should not be used. Store aggregate piles on impervious pavement or on geotextile placed over grass or bare soil. When placing aggregate, equipment should ride on placed aggregate and not on the soil subgrade to prevent sediment contamination of the aggregate via the equipment.

Aggregate layers should be spread in maximum 8 in. thick lifts and compacted with a 10-ton roller, two passes in vibratory (low amplitude and high frequency) and two passes in static mode until there is no visible aggregate movement. Areas that cannot be reached or are too small to justify using a 10-ton roller should be compacted with a minimum 13,500 lbf vibratory plate compactor with a compaction indicator. The indicator signals the operator when compaction is completed under the compaction machine.

Underdrains – Underdrains are typically Schedule 40 HDPE or PVC perforated or non-perforated pipe. Underdrains require at least 8 in. of aggregate cover to protect them during compaction. Schedule 80 may be used to for additional protection during construction.

Underdrain use is determined by the soil infiltration rate and modeling its infiltration into the soil subgrade. Hence, the importance of characterizing subgrade infiltration with in situ testing while in a saturated condition. Infiltration rate data provides input into water balance models that determine if all of the water entering the pavement can be infiltrated in 72 hours including the rainstorm. When all of the WQv or design volume can be managed within 72 hours (or fewer as locally required), such projects do not require underdrains, but do need a means to handle excessive outflows. An approach to managing such overflows is illustrated in Figure 17.

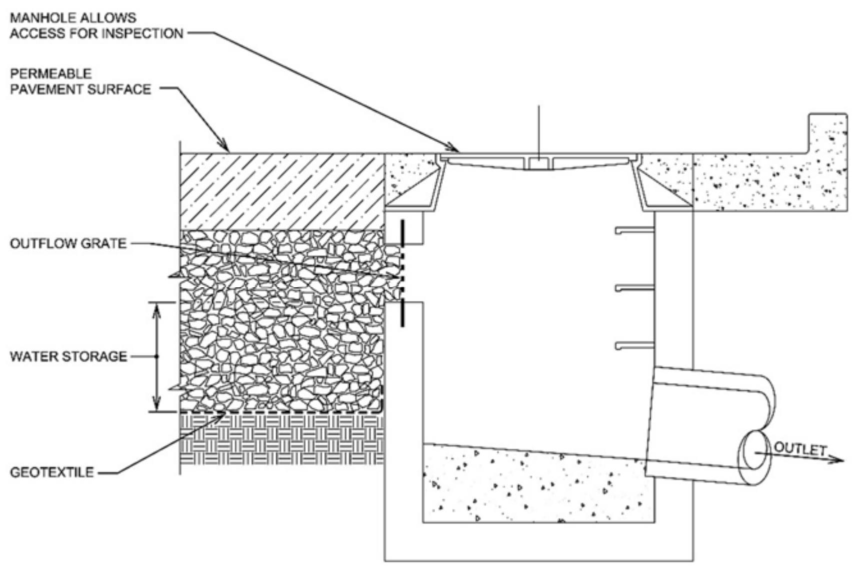

Figure 17. Full infiltration with overflow grate

Many permeable pavements have contributing run-on from impervious surfaces and many municipalities require management of that additional water depth beyond the WQv depth of 2 in. For most silt and clay soils, this typically means that all water entering the permeable pavement will not be infiltrated within 72 hours. Therefore, modeling is used to determine the portion of depth and volume of water that can be infiltrated within 72 hours with the remainder exiting via underdrains. Modeling the balance between water entering, infiltrating, and exiting via underdrains is an iterative process that establishes the depth and area of the aggregate storage reservoir. The result is a partial infiltration design with an underdrain(s) and outflow pipe(s) set to detain water for infiltrating and release the remainder. An example of this type of underdrain is illustrated in Figure 18.

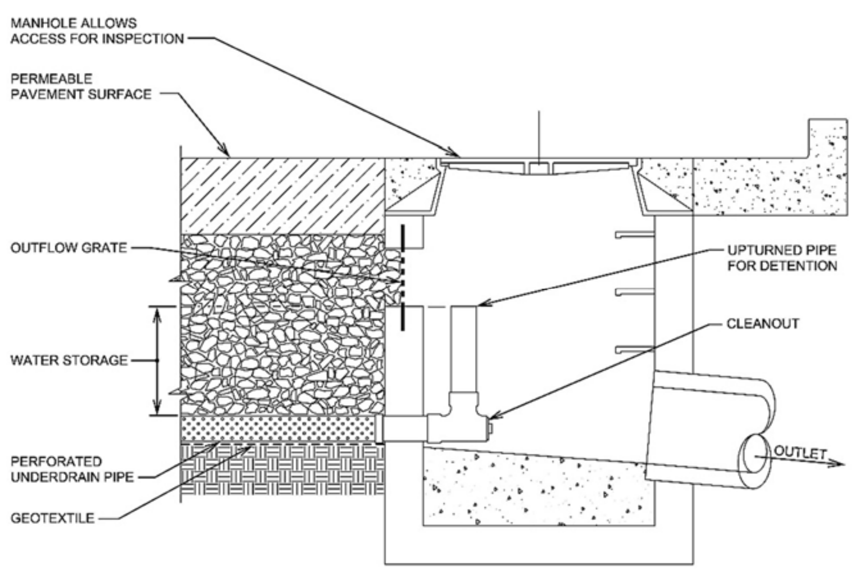

Figure 18: Partial infiltration design showing upturned elbow pipe for detention and outlet via a utility structure

No-infiltration designs are used when water needs to be collected due to site constraints such as adjacent foundations, high depth to bedrock/water table, or for water collection. These designs use a bleed pipe at the bottom of the aggregate enclosed by an impermeable liner to slowly empty the aggregate layer over 72 hours, while a larger pipe or pipes at a higher elevation handle overflows. Figure 19 illustrates an example of how these two drains are positioned.

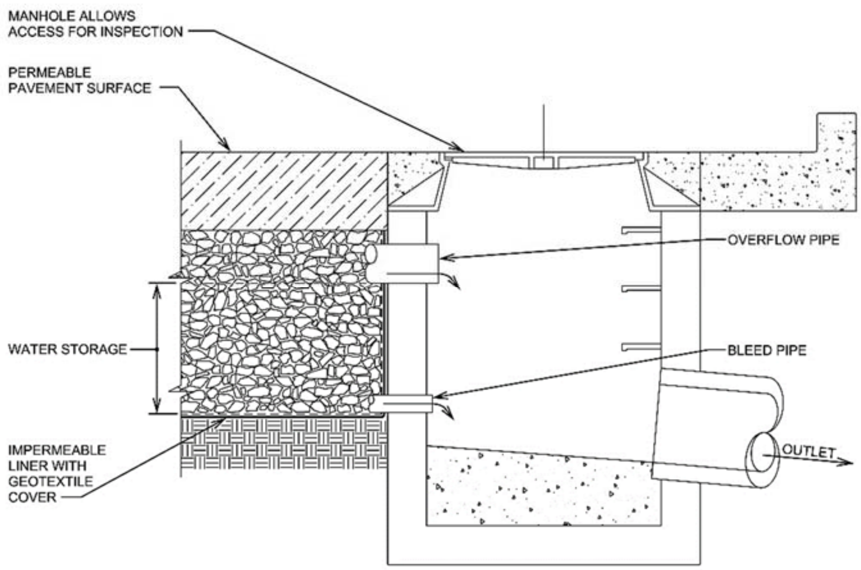

Figure 19. No-infiltration design showing with an impermeable liner penetrated by an overflow and bleed pipes

Once the storage layer thickness is established for each of these three approaches, that aggregate thickness should be compared that required for supporting anticipated traffic derived from structural design. Once these two design thicknesses are determined, the thicker of the two is used for the permeable pavement.

Check Dams – When slopes exceed 2%, consideration should be given to installing check dams to encourage infiltration rather than allowing water to run down the subgrade and collect at the lowest elevation. Figure 20 below illustrates an example of a check dam using impermeable membranes. This is more cost-effective than terracing the subgrade in a step-like fashion.

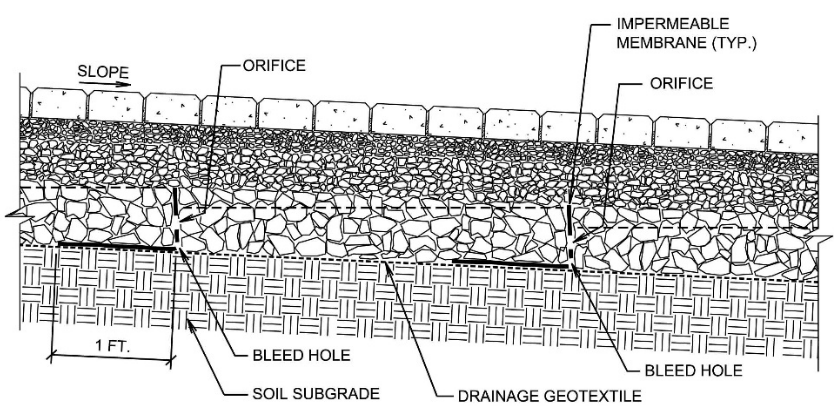

Figure 20. Check dams made with impermeable membrane with bleed and overflow holes

Aggregate Storage Layer Observation Well(s) - A 4 to 6 in. diameter vertical perforated pipe that serves as an observation well to monitor drawdown is recommended in permeable pavements subject to vehicular traffic. The pipe should be kept vertical during filling of the excavated area with open-graded aggregate and during compaction. The bottom of the pipe can be forced into the soil subgrade and held in place with aggregate during base/subbase filling and compaction. The pipe should be located at the lowest elevation and a minimum of 3 ft from the pavement perimeter. This well can be combined with underdrains and a cleanout to remove accumulated sediment from them. Figures 21 and 22 that illustrate wells accessible from the pavement surface and another located just outside the pavement.

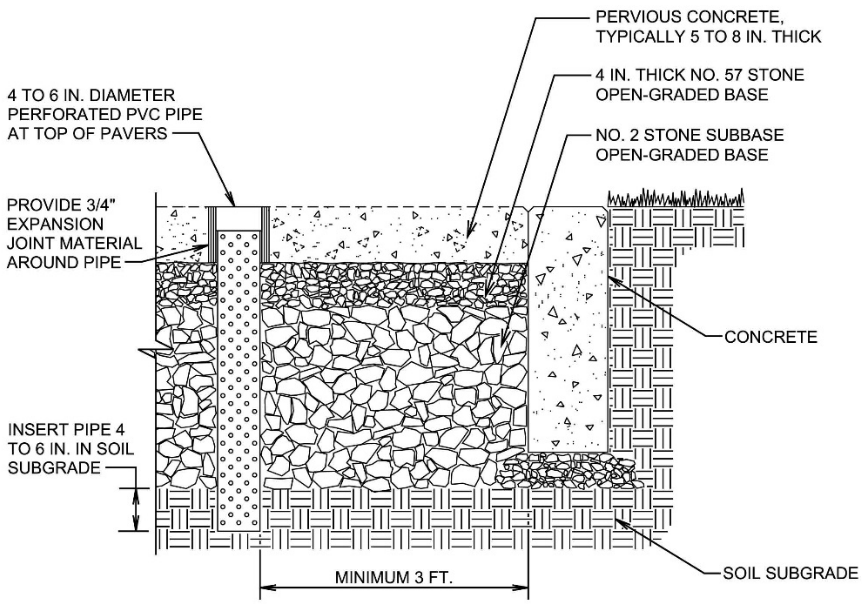

Figure 21: Observation well in permeable pavement

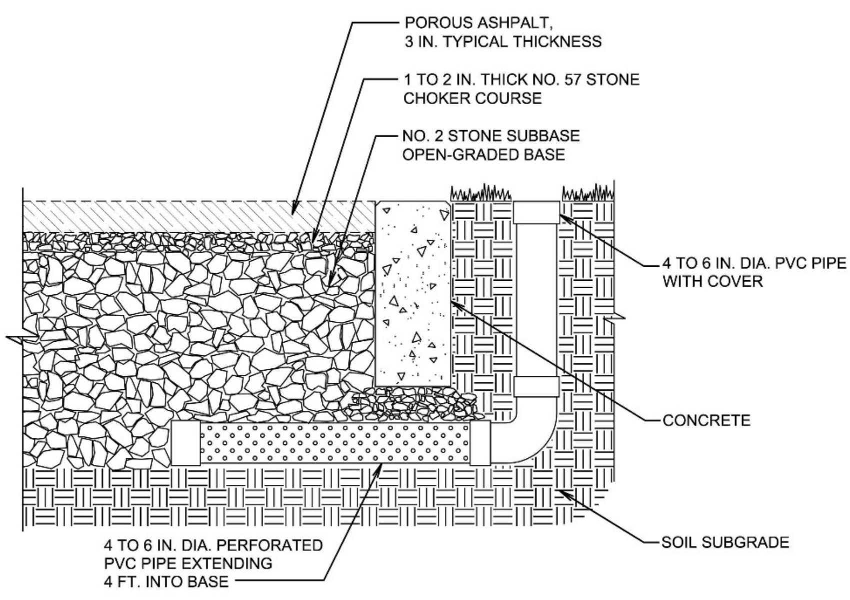

Figure 22: Observation well outside permeable pavement

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