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Lori Schaus, MASc., P.Eng
Senior Pavement Engineer
Background

• While permeable pavements have been around for a long time...1800s in Europe
• North American versions began in the 1960s
• Primary goals:
  • Reduce stormwater runoff
  • Improve water quality
  • Reduce flooding
  • Groundwater recharge
Goal of ASCE Standard

- Maximize value of permeable pavements
- Assess suitability for a particular site
- Structural design
- Hydrologic design
- Subgrade evaluation
- Pavement materials selection
- Design details and construction specifications
- Construction quality control/assurance
- Pavement maintenance
Site Design

Permeable Pavements

Permeable Pavements Task Committee

Edited by
Bethany Eisenberg, LEED AP
Kelly Collins Lindow, PE
David R. Smith

Chapter 1: Introduction and Design Considerations Common To All Permeable Pavements

CHECKLIST 1

Design Considerations Common To All Permeable Pavements

1. REGULATION (Check Requirements and Guidelines)
   a. Determine if the local regulatory agency allow permeable pavements. If not, determine who can authorize approval.
   b. Determine if these pavements are prohibited in certain areas, such as groundwater recharge zones, land use
      and environmental situations.
   c. Determine if there are credits afforded to reduce stormwater utility fees, permitting fees, or reduced site
      development costs for using permeable pavements.
   d. Determine if there are regulatory hydrologic control or water quality requirements associated with the use of
      permeable pavements.
   e. Determine if there are water quality control requirements specific to permeable pavement use.
   f. Determine if there are specific design guidelines or specifications mandated under applicable federal, state, or
      local regulations.

2. SITE Identification Site Conditions
   a. Groundwater elevation—The bottom of the permeable pavement base/subbase should be at least 0.5 m (2 ft) above
      the seasonal high groundwater level within the soil subgrade.
   b. Groundwater supply—Identify nearby groundwater supply wells or recharge zones and requirements.
   c. Flood plains—The use of permeable pavement in floodplain areas is generally not recommended due to an
      increased risk of flooding during flood events.
   d. Bedrock—Identify bedrock elevations and/or karst geology. Bedrock directly under the permeable pavement
      base/subbase typically requires the use of an impermeable liner.
   e. Soil properties—Determine soil type and physical properties.
      * Soil Classification—Determine classification of soil bearings or test sites on the site.
      * Soil Profiles—Identify soil types and estimate elevation of regulated or low permeability soils if present.
      * Drainage Capacity—Estimate the drainage capacity of the underlying soils (CRB, RPE, or resilient modulus) and
        determine the soil support value. Determine requirements for extended vehicular traffic.
      * Soil Compaction—Specify soil compaction requirements. If the underlying soils have a low
        California Bearing Ratio (CBR), compact the soils to 95% of the standard Proctor density which reduces their
        infiltration rate.
      * Soil Permeability—Determine soil permeability (hydraulic conductivity, k) and rate to be used for
        design, and check with local requirements/regulations on methodologies and guidelines. For
        larger projects with adequate budgets, it may be advantageous to compact the soil subgrade in a
        test pit or pits and then measure permeability. Identify low permeability soils and constraints.
      * Soil/Groundwater Contamination—Research identify the presence of any soil or groundwater
        contamination and how it may affect design. Permeable pavements should not be used in areas
        of groundwater/salt contamination without underdrain above the liner.
   f. Rainfall—Evaluate regional rainfall and estimate how frequently the pavement will be inundated and
      how quickly the pavement will drain based on the ability of the underlying soils to infiltrate water.
Scores are entered based on project information; weighting of factors can be adjusted

Decision range and scoring guidelines should be “calibrated” to local experience
Project Suitability

Waterline:
- Warring has two waterlines in the site area:
  1. 6" cast iron pipe installed in 1922
  2. 8" cast iron pipe installed in 1910

Gas:
- Three gas lines are in the site area:
  1. 3" semi-high pressure installed in 1970
  2. 8" unknown pressure installed in 1939
  3. 8" unknown pressure installed in 1937

Cost:
- Assuming the pavers will be installed at a rate of $36/ft and the area of the alternative is 53,000 ft², an estimated cost for Site 6 is $1,325,000.

Warning Street scored well due to:
- Medium longitudinal grade
- Potential Warring Street issues and concerns:
  - High traffic volume with delivery trucks to service school
  - Heavily used bus routes in both directions
  - High bike presence
  - Old waterline
  - High risk of sediment/biomass loading due to many street trees
  - Trees causing roadway upheaval

Source: Google Earth Pro, 2013

City of Berkeley Permeable Paver Pilot Project
Berkeley, California

URS
April 2013
Project Suitability

Potential Extents of Permeable Paver

Site Details:
- **Waterline**: 12" asbestos cement pipe installed in 1959.
- **Gas**: 10" transmission gas line installed in 1983.

Cost:
- Assuming the paving will be installed at $25/sf and the area of the alternative is 24,000 sf, an estimated cost for Site 1A is $600,000.

Potential Allston Way Issues and Concerns:
- Low longitudinal grade
- Medium traffic volume
- Minimal street trees and potential biomass issues
- Bus routes in both directions
- Medium presence of bikers
- Many utilities throughout (water, gas, electrical, storm drainage, sanitary sewer, communications)
- Runoff from Civic Center Park
- Old waterline

Measurements:
- 600' x 40' = 24K SF

Source: Google Earth Pro, 2013

May 2013
City of Berkeley Permeable Paver Pilot Project
Berkeley, California

URS
## Decision Support Tools

### A. Primary Evaluation Criteria

<table>
<thead>
<tr>
<th>Consideration</th>
<th>Performance Score</th>
<th>Weighting</th>
<th>Weighted Value</th>
<th>Low = 0.2</th>
<th>Medium = 0.6</th>
<th>High = 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Significant Longitudinal Grades</td>
<td>High</td>
<td>20.0</td>
<td>20.0</td>
<td>Grades &gt; 5 percent</td>
<td>Grades of 3 to 4 percent</td>
<td>Grades &lt; 3 percent</td>
</tr>
<tr>
<td>2 Geotechnical Risks</td>
<td>High</td>
<td>15.0</td>
<td>15.0</td>
<td>High complexity</td>
<td>Medium complexity</td>
<td>Low complexity</td>
</tr>
<tr>
<td>3 Presence of Utilities</td>
<td>Medium</td>
<td>25.0</td>
<td>15.0</td>
<td>Waterline &gt; 50 years old</td>
<td>Waterline between 30 and 50 years old</td>
<td>Waterline &lt; 30 years old</td>
</tr>
<tr>
<td>4 Traffic Volume (ADT)</td>
<td>High</td>
<td>20.0</td>
<td>20.0</td>
<td>High Traffic Volume</td>
<td>Medium Traffic Volume</td>
<td>Low Traffic Volume</td>
</tr>
<tr>
<td>5 Presence of Bike Paths</td>
<td>High</td>
<td>20.0</td>
<td>20.0</td>
<td>Regular/designated use</td>
<td>Occasional use</td>
<td>No use</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.0</strong></td>
<td></td>
<td><strong>90.0</strong></td>
<td><strong>Weighted Total:</strong></td>
<td><strong>54.0</strong></td>
<td></td>
</tr>
</tbody>
</table>

### B. Secondary Considerations

<table>
<thead>
<tr>
<th>Consideration</th>
<th>Rating</th>
<th>Weighting</th>
<th>Weighted Value</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 Groundwater Contamination Risk</td>
<td>High</td>
<td>20.0</td>
<td>20.0</td>
<td>Existing contaminants present</td>
<td>Potential for contaminants</td>
<td>No contaminants present</td>
</tr>
<tr>
<td>7 Soil Infiltration Rates</td>
<td>Low</td>
<td>20.0</td>
<td>4.0</td>
<td>Infiltration &lt; 0.5 in/hr</td>
<td>Infiltration &gt;0.5 in/hr &lt; 1.5 in/hr</td>
<td>Infiltration &gt; 1.5 in/hr</td>
</tr>
<tr>
<td>8 Potential for Sediment/Biomass Loading</td>
<td>High</td>
<td>20.0</td>
<td>20.0</td>
<td>Significant risk of sediment loading</td>
<td>Potential risk of sediment loading</td>
<td>No risk</td>
</tr>
<tr>
<td>9 Target Design Volumes and Runoff</td>
<td>Medium</td>
<td>20.0</td>
<td>12.0</td>
<td>Intense storms</td>
<td>Moderate frequency/intensity</td>
<td>Frequent/non-intense storm</td>
</tr>
<tr>
<td>10 Risk of Flooding</td>
<td>High</td>
<td>20.0</td>
<td>20.0</td>
<td>Frequent</td>
<td>Occasional</td>
<td>None</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.0</strong></td>
<td></td>
<td><strong>56.0</strong></td>
<td><strong>Weighted Total:</strong></td>
<td><strong>22.4</strong></td>
<td></td>
</tr>
</tbody>
</table>

### Sub Totals

- A. Primary Considerations: 60 54.0
- B. Secondary Considerations: 40 22.4

**Grand Total:** 100 76.4

### Decision

- **Yes**
## Project Suitability

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Location</th>
<th>Positive</th>
<th>Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Center Street</td>
<td>No trees, low traffic</td>
<td>Bike lanes, bus traffic, slope,</td>
</tr>
<tr>
<td>2A</td>
<td>Addison West</td>
<td>No trees, little slope</td>
<td>Buses, utilities, contributing area (park)</td>
</tr>
<tr>
<td>2B</td>
<td>Addison East</td>
<td>No bikes, no trees, no buses</td>
<td>Heavy trucks, steep, possible soft soil?</td>
</tr>
<tr>
<td>3</td>
<td>Hopkins Triangle</td>
<td>Low slope, low traffic</td>
<td>Buses</td>
</tr>
<tr>
<td>4A</td>
<td>Cedar West</td>
<td></td>
<td>High speed, buses, steep, many trees, BART, many utilities</td>
</tr>
<tr>
<td>4B</td>
<td>Cedar East</td>
<td>Minimal trees, no bikes</td>
<td>Buses, residential area</td>
</tr>
<tr>
<td>5</td>
<td>Hopkins Street</td>
<td>No bikes, good pavement</td>
<td>Many trees, buses, downspouts in curbs, high traffic, narrow road</td>
</tr>
<tr>
<td>6</td>
<td>Warring Street</td>
<td>Many trees, flat slope</td>
<td>Very high traffic, buses, utilities</td>
</tr>
<tr>
<td>7</td>
<td>Allston Way</td>
<td>Some contributing area</td>
<td>Occasional buses</td>
</tr>
</tbody>
</table>
## Project Suitability

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Location</th>
<th>Primary</th>
<th>Secondary</th>
<th>Total</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Center Street</td>
<td>43.2</td>
<td>28.8</td>
<td>72.0</td>
<td>Can Consider</td>
</tr>
<tr>
<td>2A</td>
<td>Addison Street West</td>
<td>44.4</td>
<td>28.8</td>
<td>73.2</td>
<td>Can Consider</td>
</tr>
<tr>
<td>2B</td>
<td>Addison Street East</td>
<td>26.4</td>
<td>25.6</td>
<td>52.0</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>Hopkins Triangle</td>
<td>44.4</td>
<td>25.6</td>
<td>70.0</td>
<td>Can Consider</td>
</tr>
<tr>
<td>4A</td>
<td>Cedar Street West</td>
<td>21.6</td>
<td>25.6</td>
<td>47.2</td>
<td>No</td>
</tr>
<tr>
<td>4B</td>
<td>Cedar Street East</td>
<td>40.8</td>
<td>25.6</td>
<td>66.4</td>
<td>Can Consider</td>
</tr>
<tr>
<td>5</td>
<td>Hopkins Street</td>
<td>40.8</td>
<td>25.6</td>
<td>66.4</td>
<td>Can Consider</td>
</tr>
<tr>
<td>6</td>
<td>Warring Street</td>
<td>26.4</td>
<td>25.6</td>
<td>52.0</td>
<td>No</td>
</tr>
<tr>
<td>7</td>
<td>Allston Way</td>
<td>54.0</td>
<td>25.6</td>
<td>79.6</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Need: Validated Base Thickness Charts

Design Tables for PICP
Accelerated Pavement Testing
UC Pavement Research Center
Section 1

Section 2

Section 3

Curb 150 x 225 MM

80 MM Thick Concrete Pavers w/ Jointing Stone

50 MM Bedding No. 8 Stone

100 MM Base No. 57 Stone

No. 2 Stone Subbase

Geotextile on all sides and bottom

450 MM

200 MM

300 MM
Summary of Rutting Models

<table>
<thead>
<tr>
<th>Layer</th>
<th>Rut Model¹</th>
<th>Moisture Condition</th>
<th>Model Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>a</td>
</tr>
<tr>
<td>Combined bedding &amp; base</td>
<td>(RD_{BB} = a \times h_{SB} + b)</td>
<td>Dry</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wet</td>
<td>-0.012</td>
</tr>
<tr>
<td>Subbase</td>
<td>(RD_{SB} = (a \times SSR^b) \times N^c)</td>
<td>Dry</td>
<td>3.10E-06</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wet</td>
<td>3.10E-06</td>
</tr>
<tr>
<td>Subgrade (Silty clay)</td>
<td>(RD_{SG} = (a \times SSR + b) \times N^c)</td>
<td>Dry</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wet</td>
<td>0.03</td>
</tr>
</tbody>
</table>

¹ \(RD_{xx}\), rut depth of xx layer (BB=surface (paver, bedding and base); SB=subbase; SG=subgrade), mm;  
\(h_{SB}\), thickness of subbase, mm;  
SSR, shear stress/strength ratio at the top of the layer;  
\(N\), load repetition;  
a, b, c, model constants.
### Summary of Rutting Models

#### PICP Design Tool

<table>
<thead>
<tr>
<th>Layer</th>
<th>Moisture Condition</th>
<th>Thickness (mm)</th>
<th>Stiffness (MPa)</th>
<th>Poisson’s Ratio</th>
<th>ε (kPa)</th>
<th>φ (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface (60 mm concrete over plus 60 mm #8 bedding and 100 mm #87 base)</td>
<td>Wet</td>
<td>230</td>
<td>8</td>
<td>0.35</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dry</td>
<td>110</td>
<td>0.35</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subbase (ASTM #2)</td>
<td>Wet</td>
<td>450</td>
<td>75</td>
<td>0.35</td>
<td>6</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Dry</td>
<td>122</td>
<td>0.35</td>
<td>6</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Subgrade (Clay)</td>
<td>Wet</td>
<td>45</td>
<td>17</td>
<td>0.35</td>
<td>15</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Dry</td>
<td>60</td>
<td>0.35</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Climate

- **50** Number of Days in a Year When the Subbase has Standing Water (Wet Days)²

#### Traffic Volume Calculation

<table>
<thead>
<tr>
<th>Traffic Volume Calculation</th>
<th>Axle Type</th>
<th>Axle Load (kN)</th>
<th>Axle-Load Distribution (%)</th>
<th>Lifetime Repetition</th>
<th>Lifetime E-SALs (Millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Wet Season</td>
<td>Dry Season</td>
</tr>
</tbody>
</table>

#### Outcome

<table>
<thead>
<tr>
<th>Layer</th>
<th>Moisture Condition</th>
<th>Shift Factor</th>
<th>Rut Depth by Layer (mm)</th>
<th>Expected Total Rut Depth (mm)</th>
<th>Allowable Rut Depth (mm)</th>
<th>Satisfactory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface (60 mm concrete over plus 60 mm #8 bedding and 100 mm #87 base)</td>
<td>Wet</td>
<td>1.00</td>
<td>1.1</td>
<td>65.3</td>
<td>25.0</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>Dry</td>
<td>1.00</td>
<td>3.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subbase (ASTM #2)</td>
<td>Wet</td>
<td>1.00</td>
<td>15.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dry</td>
<td>1.30</td>
<td>2.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subgrade (Clay)</td>
<td>Wet</td>
<td>1.25</td>
<td>8.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dry</td>
<td>1.10</td>
<td>12.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

[Diagram showing Calculate Rut Depth and Design Subbase Thickness]

---

² The wet stiffness to dry stiffness ratio can be assumed as 0.8, 0.6 and 0.6 for surface, subbase and subgrade layers, respectively.

² Seasons when the subbase has standing water.
### Summary of Rutting Models

<table>
<thead>
<tr>
<th>Number of Days in a Year when the Subbase has Standing Water (Wet Days)</th>
<th>50 to 89</th>
<th>90 to 119</th>
<th>120 or more</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resilient Modulus of Subgrade, MPa (CBR)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry</td>
<td>40</td>
<td>60</td>
<td>100</td>
</tr>
<tr>
<td>Wet</td>
<td>24 (1.6)</td>
<td>36 (3)</td>
<td>60 (6.8)</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>60</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>24 (1.6)</td>
<td>36 (3)</td>
<td>60 (6.8)</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>36 (3)</td>
<td>48 (4.8)</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>36 (3)</td>
<td>60 (6.8)</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>36 (3)</td>
<td>48 (4.8)</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>36 (3)</td>
<td>48 (4.8)</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>36 (3)</td>
<td>60 (6.8)</td>
</tr>
<tr>
<td>Lifetime ESALs (Traffic Index)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum Subbase Thickness in mm for ASTM No. 2 Aggregate 25 mm Allowable Rut Depth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>50,000 (6.3)</td>
<td>175</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td>100,000 (6.8)</td>
<td>285</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td>200,000 (7.4)</td>
<td>395</td>
<td>285</td>
</tr>
<tr>
<td></td>
<td>300,000 (7.8)</td>
<td>455</td>
<td>340</td>
</tr>
<tr>
<td></td>
<td>400,000 (8.1)</td>
<td>500</td>
<td>380</td>
</tr>
<tr>
<td></td>
<td>500,000 (8.3)</td>
<td>530</td>
<td>410</td>
</tr>
<tr>
<td></td>
<td>600,000 (8.5)</td>
<td>555</td>
<td>435</td>
</tr>
<tr>
<td></td>
<td>700,000 (8.6)</td>
<td>580</td>
<td>455</td>
</tr>
<tr>
<td></td>
<td>800,000 (8.8)</td>
<td>600</td>
<td>470</td>
</tr>
<tr>
<td></td>
<td>900,000 (8.9)</td>
<td>615</td>
<td>485</td>
</tr>
<tr>
<td></td>
<td>1,000,000 (9.0)</td>
<td>630</td>
<td>500</td>
</tr>
</tbody>
</table>
Structural Design Example

- Traffic over design life = 196,550 ESALs (say 200,000)
- Subgrade modulus = 36 MPa (3,500 psi)
- For days where subbase has standing water:
  - Establish the design soil infiltration rate, e.g. 25 mm (1 in)/day
  - Correct the infiltration depth by dividing by the contributing drainage area (CDA) ratio (assume all CDA as 100% impervious for estimating purposes), e.g. for 2:1 CDA, corrected depth = 25/2 = 12.5 mm (0.5 in)
  - Count the days that exceed the adjusted daily infiltration depth and add any remaining depth from the previous day that has not drained within 48 hours (or other maximum drawdown time)
Structural Design Example

• For days where subbase has standing water:
  • Find historic rainfall for the year (e.g. statistics Canada)

![Statistics Canada](image-url)
Structural Design Example

• For days where subbase has standing water:
  • From rainfall intensity curve of total average annual occurrences versus daily precipitation
  • From curve only 20 percent of rain days exceed 12.5 mm (1 in) of rain
  • 139 days of rain x 0.20 = 27.8 days can cause standing water on the subgrade surface
### Structural Design Example

#### Number of Days in a Year when the Subbase has Standing Water (Wet Days)

<table>
<thead>
<tr>
<th></th>
<th>0 to 9</th>
<th>10 to 29</th>
<th>30 to 49</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Resilient Modulus of Subgrade, MPa (CBR)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry</td>
<td>40</td>
<td>60</td>
<td>80</td>
</tr>
<tr>
<td>Wet</td>
<td>24</td>
<td>36</td>
<td>48</td>
</tr>
</tbody>
</table>

#### Lifetime ESALs (Traffic Index)

<table>
<thead>
<tr>
<th></th>
<th>25 mm Allowable Rut Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Subbase Thickness in mm for ASTM No. 2 Aggregate</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lifetime ESALs (Traffic Index)</th>
<th>25 mm Allowable Rut Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>50,000 (6.3)</td>
<td>150 150 150 150 150 150 150</td>
</tr>
<tr>
<td>100,000 (6.8)</td>
<td>150 150 150 150 210 150 150 150 260 150 150 150</td>
</tr>
<tr>
<td>200,000 (7.4)</td>
<td>230 150 150 150 315 210 150 150 365 255 160 150</td>
</tr>
<tr>
<td>300,000 (7.8)</td>
<td>290 180 150 150 375 265 170 150 425 315 215 150</td>
</tr>
<tr>
<td>400,000 (8.1)</td>
<td>330 220 150 150 420 305 210 150 470 350 255 175</td>
</tr>
<tr>
<td>500,000 (8.3)</td>
<td>360 250 160 150 450 335 240 160 500 380 280 205</td>
</tr>
<tr>
<td>600,000 (8.5)</td>
<td>385 275 185 150 475 360 260 180 525 405 305 225</td>
</tr>
<tr>
<td>700,000 (8.6)</td>
<td>410 295 205 150 495 380 280 200 550 425 325 245</td>
</tr>
<tr>
<td>800,000 (8.8)</td>
<td>425 310 220 150 515 395 295 215 565 440 340 260</td>
</tr>
<tr>
<td>900,000 (8.9)</td>
<td>440 325 235 155 530 410 310 230 585 455 355 270</td>
</tr>
<tr>
<td>1,000,000 (9.0)</td>
<td>455 340 250 165 545 425 325 240 600 470 365 285</td>
</tr>
</tbody>
</table>
Hydrologic Design - General

- $dp =$ DEPTH OF OPEN GRADED BASE AND SUBBASE
- $P =$ DESIGN STORM RAINFALL CONTRIBUTING AREA, m (ft)
- $R =$ RUN-ON DEPTH FROM THE CONTRIBUTING AREA, m (ft)
- $Ac =$ Adjacent Contributing Area
- $Ap =$ Surface Area of Permeable Pavement
- $Curb$
- $V =$ VOLUME OF THE BASE AND SUBBASE
- $A_I =$ Subgrade Infiltration Area
- $I =$ Design Infiltration Rate of Subgrade
- $n =$ Porosity of Open Graded Base and Subbase
- $V_w =$ Volume of Water That Can Be Stored in the Base/Subbase
- $Q_u =$ Underdrain Discharge
SET BOTTOM OF V-NOTCH WEIR TO DESIRED STORAGE ELEVATION IN THE SUBBASE

100 MM (4 IN.) DIA. PERFORATED DISCHARGE PIPE (S) WITH MINIMUM 75 MM (3 IN.) NO. 57 AGGREGATE SURROUND

V-NOTCH WEIR

DISCHARGE PIPE TO STORM SEWER OR DAYLIGHT TO SURFACE FEATURE
Hydrologic Design - Infiltration

TYP. NO. 8, 89, OR 9 AGGREGATE IN OPENINGS

CONCRETE PAVERS MIN. 80 MM (3 1/8 IN.) THICK FOR VEHICULAR TRAFFIC (ASPECT RATIO ≤ 3)

CURB/EDGE RESTRAINT WITH CUT-OUTS FOR OVERFLOW DRAINAGE ( CURB SHOWN )

BEDDING COURSE 50 MM (2 IN.) THICK (TYP. NO. 8 AGGREGATE)

100 MM (4 IN.) THICK NO. 57 STONE OPEN-GRATED BASE

GEOTEXTILE ON SIDES OF SUBBASE AND UNDER CURB

MIN. 150 MM (6 IN.) THICK NO. 2 STONE SUBBASE

OPTIONAL GEOTEXTILE ON SUBGRADE PER DESIGN ENGINEER

SOIL SUBGRADE - ZERO SLOPE
Hydrologic Design - Partial

TYP. NO. 8, 89, OR 9 AGGREGATE IN OPENINGS

CONCRETE PAVERS MIN. 80 mm (3 1/8 IN.) THICK FOR VEHICULAR TRAFFIC (ASPECT RATIO < 3)

CURB/EDGE RESTRAINT WITH CUT-OUTS FOR OVERFLOW DRAINAGE (CURB SHOWN)

BEDDING COURSE 40 TO 50 MM (1 1/2 IN. TO 2 IN.) THICK (TYP. NO. 8 AGGREGATE)

100 MM (4 IN.) THICK NO. 57 STONE OPEN-GRADED BASE

MIN. 150 MM (6 IN.) THICK NO. 2 STONE SUBBASE

GEOTEXTILE ON TOP AND SIDES OF SUBBASE UNDER/BEYOND CURB

GEOTEXTILE ON SUBGRADE PER DESIGN ENGINEER

PERFORATED OUTFALL PIPE(S) SLOPED TO STORM SEWER OR STREAM

SOIL SUBGRADE SLOPED TO DRAIN
Hydrologic Design - Slopes

- 80 MM (3 1/8 IN.) THICK LOW PERMEABLE CONCRETE PAVERS WITH ASTM NO. 8, 89, OR 9 STONE IN THE JOINTS
- 50 MM (2 IN.) THICK NO. 8 STONE BEDDING
- 100 MM (4 IN.) THICK NO. 57 STONE BASE
- IMPERMEABLE MEMBRANE
- ORIFICE
- NO. 2 STONE SUBBASE MIN. 150 MM (6 IN.) THICK
- BLEED HOLE
- SOIL SUBGRADE
- OPTIONAL DRAINAGE GEOTEXTILE PER DESIGN ENGINEER
- 300 MM (1 FT.)
- Varies (Typical)
Hydrologic Design - Monitoring

100 TO 150 MM (4 TO 6 IN.) DIA. PERFORATED PVC PIPE AT TOP OF PAVERS

INSERT PIPE 100 TO 150 MM (4 TO 6 IN.) IN SOIL SUBGRADE

MINIMUM 1 M (3 FT.)

100 TO 150 MM (4 TO 6 IN.) DIA. PVC PIPE WITH COVER

100 TO 150 MM (4 TO 6 IN.) DIA. PERFORATED PVC PIPE EXTENDING 1.2 M (4 FT.) INTO BASE

SOIL SUBGRADE
Design Details

- Curb / Edge Restraint
- String Course
- 45 Degree Herringbone Pattern
- Saw Cut Paver - Not Less Than 1/3 Unit

- Curb / Edge Restraint
- String Course
- 90 Degree Herringbone Pattern
Design Details

True Herringbone Pattern
All half stones can be replaced by full stones, binding the layers together and creating a seamless stitch throughout.

Modified Herringbone Pattern
Make full use of the half stones. Once the layer is in place, rotate the full stone to interlock layers and fill the void with a half stone.
Line Marking
Key Construction Features

- A pre-construction site meeting is critical to the success of the permeable pavement installation
Pre-Construction Checklist

• Review erosion and sediment control plan/stormwater pollution prevention plan

• Determine when the pavement will be built in the construction sequence and measures for protection

• Identify aggregate material stockpile locations

• Review test (mock-up) location and criteria for acceptance

• Contractor’s methods for keeping all materials free from sediment during storage, placement, and on completed areas

• Contractor’s methods for checking slopes, surface tolerances, and elevations
Pre-Construction Checklist

- Diagrams of laying/layer pattern, stitching requirements (PICP) and joining layers
- Testing intervals for aggregates, edge restraints and for the surface materials
- Testing lab location, test methods, report delivery, contents and timing
- Contractor’s quality control and assurance methods and reporting
- Engineer inspection intervals and procedures for correcting work that does not conform to the project specifications
Light Weight Deflectometer (in-situ test)

- ASTM D2583 for surfaces or D2835 for soils and bases
- Weight dropped onto plate from standard height
- Sensor measures impact load
- Geophones measure pavement deflection
- Estimates resilient modulus or level of compaction via deflection
Underdrain Placement

- Installed in a trench the lowest point of the pavement subgrade
- Surrounded with open-graded aggregate offering protection during construction
- Pipes should be perforated, polyvinyl chloride (PVC), minimum 0.5 percent slope to an outlet
- Pipe spacing and size should be selected to ensure that the pavement does not flood and become completely saturated during storm events
Geosynthetics

- Generally placed vertically against the walls of excavated soil to separate the permeable pavement from adjacent soils
- Polyvinyl chloride or high density polyethylene
- Separates the base/subbase from adjacent pavements / buildings
- May enclose the sides and bottom to create a no infiltration design for water storage and flow control
Pavement Maintenance

- Inspection tasks may include the following:
  - Review maintenance and operations records and incidences to determine if there have been any issues
  - Document general site features, take photographs, etc.
  - Note any surface contamination or clogging
  - Note obvious sources of surface contaminants
  - Identify the extent and severity of any damage or deficiencies (e.g. settlement, ponding, cracked pavers, etc.)
  - Identify any changes in adjacent land use that may impact contributing area runoff
Pavement Maintenance

• Inspection tasks may include the following:
  • Inspect vegetation around PICP for cover and soil stability
  • Ensure edge restraints are performing
  • Check underdrains to ensure that they are still draining water from the pavement structure
  • Check observation wells for water storage
  • If a significant reduction in permeability from the last inspection, complete infiltration testing
Permeability Testing – ASTM C1781-13

ASTM WK40698

(What is a Work Item? / How to Input to a Work Item)

Work Item: ASTM WK40698 - New Test Method for Determining the Surface Infiltration Rate of Permeable Unit Pavement Systems

Developed by Subcommittee: C15.04 | Committee C15 Home | Contact Staff Manager

Work Item Status:
Date Initiated:01-29-2013
Technical Contact: Craig Walloch

Item: 019
Ballot: COS (13-07)

1. Scope

1.1 This test method covers the determination of the field
Permeability Improvements
Permeable Paver Joint Aggregate

• Top up of joint aggregate within 6 months of construction
Localized Settlement Repair

• Remove pavers from affected area
• Level bedding layer, add new material as necessary
• Replace pavers and jointing material
Underdrain Cleanout
ASCE Standard Schedule

• Standard is currently out for public comment
• Public comment period closes on April 1, 2018
• Committee will review and address all comments and make modifications if necessary
• ASCE editors will complete final review and then public the standard
• Several member of the ASCE PICP standards committee are here at the conference (many thanks for their hard work)
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