Permeable Interlocking Concrete Pavement
Design & Construction

Intermediate
LID Design
Module 3.3
Seattle, WA
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Pendleton Blvd, JBLM
courtesy Mutual Materials Co.
Design Information
  • Sources

System Components
  • Pavers
  • Aggregates
  • Edge Restraints

Construction

PICP Sections

Structural considerations

Percival Landing Park, Olympia
courtesy Mutual Materials Co.
Carving a new path in town?

Pavement systems that offer durability, life-cycle and aesthetics.

- Sustainability
- Pavement Systems
- Design
- Installation
- Maintenance

www.icpi.org
PICP ‘Design Manual’
- Fourth edition

- Design
- Specifications
- Construction
- Maintenance
Design software:

“PICP Permeable Design Pro”

Balances system performance
  • Structural support
  • Hydraulic capacity
  • Uses single event model
System Components

Concrete Pavers  the “wearing course”

Permeable Joint Material

Open-graded Bedding Course

Open-graded Base Reservoir

Open-graded Subbase Reservoir

Underdrain  (as required)

Geotextile–Design Option per Design Engineer

Uncompacted Subgrade Soil

courtesy of ICPI
“Permeable” Interlocking Concrete Pavers

Paver units themselves are **not** permeable.

Permeability comes from wide joint spacing and/or openings in the pavers.

*Figure 1-3. Various types of paving units used in PICP*

courtesy of ICPI
Typical Paver Shapes for PICP

Drainage joints
courtesy of Mutual Materials

courtesy of Uni-Group USA

Drainage ‘features’ or shape
“Permeable” Interlocking Pavers

ASTM C936: 
Standard Specification for Solid Concrete Interlocking Paving Units

Note... the physical property requirements for permeable paving units are the same as impermeable paving units:

- Maximum face area = 101 sq. in.
- Minimum thickness = 2.36 in. (60 mm)
- Minimum Compressive Strength = 8,000 psi
- Maximum 24 hr. cold water absorption = 5%
- Freeze-thaw durability per ASTM C 1645
- Abrasion resistance
- Dimensional tolerance
Additional paver considerations:

Aspect ratio \((L:T)\) guidelines apply -

- 4:1 pedestrian only (ASTM reqm’t)
- 3:1 to 4:1 for residential driveways
- 3:1 or less for all vehicular areas

FIG. 1 Length, Width, and Thickness of Concrete Paving Units

courtesy of ASTM
“ADA” Requirements

302 Floor or Ground Surfaces

302.1 General. Floor and ground surfaces shall be stable, firm, and slip resistant and shall comply with 302.

Advisory 302.1 General. A stable surface is one that remains unchanged by contaminants or applied force, so that when the contaminant or force is removed, the surface returns to its original condition. A firm surface resists deformation by either indentations or particles moving on its surface. A slip-resistant surface provides sufficient frictional counter-force to the forces exerted in walking to permit safe ambulation.
“ADA” Requirements

302.3 Openings. Openings in floor or ground surfaces shall not allow passage of a sphere more than \( \frac{1}{2} \) inch (13mm) diameter except as allowed in 407.4.3, 409.4.3, 410.4, 810.5.3 and 810.10. Elongated openings shall be placed so that the long dimension is perpendicular to the dominant direction of travel.
“ADA” Requirements

303 Changes in Level

303.1 General. Where changes in level are permitted in floor or ground surfaces, they shall comply with 303.

303.2 Vertical. Changes in level of 1⁄4 inch (6.4 mm) high maximum shall be permitted to be vertical.
303.3 Beveled. Changes in level between ¼ inch (6.4 mm) high minimum and ½ inch (13 mm) high maximum shall be beveled with a slope not steeper than 1:2.
System Components

Concrete Pavers

Permeable Joint Material

Open-graded Bedding Course

Open-graded Base Reservoir

Open-graded Subbase Reservoir

Underdrain (as required)

Geotextile—Design Option per Design Engineer

Uncompacted Subgrade Soil

courtesy of ICPI
Paver Joint fill Aggregate

Free-draining ("open-graded") aggregate that complies with the gradation requirements of ASTM D 448, No. 8:

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.5 mm (1/2 in.)</td>
<td>100</td>
</tr>
<tr>
<td>9.5 mm (3/8 in.)</td>
<td>85 to 100</td>
</tr>
<tr>
<td>4.75 mm (No. 4)</td>
<td>10 to 30</td>
</tr>
<tr>
<td>2.36 mm (No. 8)</td>
<td>0 to 10</td>
</tr>
<tr>
<td>1.16 mm (No. 16)</td>
<td>0 to 5</td>
</tr>
</tbody>
</table>

Table 1. ASTM No. 8 Grading Requirements

courtesy of ICPI

Note… if No. 8 aggregate is not available, industry recommendations are to use No. 89 or No. 9 stone.
Aggregates for use with PICP

In addition to the gradation requirements for joint filler, bedding layer, base and subbase, all aggregates should be:

- **Crushed stone**
  - 90% fractured faces
  - *Do not use rounded river rock!*

- **Hard, durable material**
  - LA Abrasion < 40 per ASTM C131
  - *min. CBR of 80% per ASTM D1883*

- **No fines**
  - Less than 2% passing the #200 sieve
System Components

- Concrete Pavers
- Permeable Joint Material
- Open-graded Bedding Course
- Open-graded Base Reservoir
- Open-graded Subbase Reservoir
- Underdrain (as required)
- Geotextile—Design Option per Design Engineer
- Uncompacted Subgrade Soil

courtesy of ICPI
Bedding Course Aggregate

Free-draining ("open-graded") aggregate that complies with the gradation requirements of ASTM D 448, No. 8:

![Table 1. ASTM No. 8 Grading Requirements](chart.png)

Other names for ASTM No. 8: ¼” clear crushed; 3/8” clear crushed; ¼ - 10 clear crushed
<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Bedding &amp; Jointing</th>
<th>Jointing only</th>
<th>Jointing only</th>
</tr>
</thead>
<tbody>
<tr>
<td>½ in. (12.5 mm)</td>
<td>100</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>3/8 in. (9.5 mm)</td>
<td>85 to 100</td>
<td>90 to 100</td>
<td>100</td>
</tr>
<tr>
<td>No. 4 (4.75 mm)</td>
<td>10 to 30</td>
<td>20 to 55</td>
<td>85 to 100</td>
</tr>
<tr>
<td>No. 8 (2.36 mm)</td>
<td>0 to 10</td>
<td>5 to 30</td>
<td>10 to 40</td>
</tr>
<tr>
<td>No. 16 (1.16 mm)</td>
<td>0 to 5</td>
<td>0 to 10</td>
<td>0 to 10</td>
</tr>
<tr>
<td>No. 50 (0.30 mm)</td>
<td></td>
<td>0 to 5</td>
<td>0 to 5</td>
</tr>
</tbody>
</table>

Washed material: percent passing No. 200 (0.075 mm) sieve < 2%
System Components

- Concrete Pavers
- Permeable Joint Material
- Open-graded Bedding Course
- Open-graded Base Reservoir
- Open-graded Subbase Reservoir
- Underdrain (as required)
- Geotextile—Design Option per Design Engineer
- Uncompacted Subgrade Soil

courtesy of ICPI
Base Course Aggregate

Free-draining ("open-graded") aggregate that complies with the gradation requirements of ASTM D 448, No. 57:

Table 2. ASTM No. 57 Base Grading Requirements

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>37.5 mm (1 1/2 in.)</td>
<td>100</td>
</tr>
<tr>
<td>25 mm (1 in.)</td>
<td>95 to 100</td>
</tr>
<tr>
<td>12.5 mm (1/2 in.)</td>
<td>25 to 60</td>
</tr>
<tr>
<td>4.75 mm (No. 4)</td>
<td>0 to 10</td>
</tr>
<tr>
<td>2.36 mm (No. 8)</td>
<td>0 to 5</td>
</tr>
</tbody>
</table>

Other names for ASTM No. 57: 1-1/2” clear crushed drain rock; 1-1/4” clear crushed drain rock.
System Components

- Concrete Pavers
- Permeable Joint Material
- Open-graded Bedding Course
- Open-graded Base Reservoir
- Open-graded Subbase Reservoir
- Underdrain (as required)
- Geotextile—Design Option per Design Engineer
- Uncompacted Subgrade Soil

courtesy of ICPI
Subbase Course Aggregate

Free-draining ("open-graded") aggregate that complies with the gradation requirements of ASTM D 448, No. 2:

![Table 3. ASTM No. 2 Subbase Grading Requirements](chart)

**Other names for ASTM No. 2:** Permeable ballast or railroad ballast
Again….aggregates for use with PICP

In addition to the gradation requirements for joint filler, bedding layer, base and subbase, all aggregates should be:

- **Crushed stone**
  - 90% fractured faces
  - *Do not use rounded river rock!*

- **Hard, durable material**
  - LA Abrasion < 40 per ASTM C131
  - min. CBR of 80% per ASTM D1883

- **No fines**
  - Less than 2% passing the #200 sieve
Edge Restraints
Edge Restraints Application Guide

Commercial Vehicular
  Cast-in-place concrete
  Precast concrete
  Cut Stone

Pedestrian & Residential Driveways
  All of the above
  Compacted base at perimeter with spiked edging

Pedestrian Only
  All of the above
  Geogrid & edging
Edge Restraint Guidelines

Commercial Vehicular
Cast-in-place concrete – straight curb or curb & gutter, precast concrete, cut stone

Drain to bioswale

Curb depth to bottom of asphalt dense-graded base
Edge Restraint Guidelines

*Pedestrian & Residential*

All of the above

Compacted dense-graded base at perimeter with spiked edging
Residential driveway with compacted base sides

- TOP OF PVC LEVEL WITH TOP OF ASTM NO. 57 STONE
- 4 IN. PVC PIPE MIN. 2% SLOPE
- POP-UP DRAIN RECESS TOP 1/4 IN. INTO GRADE PLACE ELBOW ON MIN 3 IN. THICK COMPACTED ASTM NO. 8 STONE

- ASTM NO. 8, 9, OR 89 JOINT FILL
- ASTM NO. 8 BEDDING 2–3 IN. THICK
- CONCRETE PAVERS 3 1/8 IN. THICK
- ASTM NO. 57 BASE 2–3 IN. THICK
- ASTM NO. 4 SUBBASE 8–10 IN. THICK

- COVER PIPE OPENING AND FASTEN 16 MESH FIBERGLASS SCREEN

- 18 IN. MIN.

- EDGE RESTRAINT WITH SPIKES MIN. 1 FT. O.C.
- SOIL WITH VEGETATIVE COVER
- COMPACTED CLASS 2 BASE-WRAP IN GEOTEXTILE
- SOIL SUBGRADE
- GEOTEXTILE
Setting/checking grades
Edge base contains bedding
Screeded bedding & layout

Dense-graded base along edges

No. 8 stone
Alignment
Compaction
Plastic edge restraint examples
Final sweeping
Joints filled
Edge Restraint Guidelines

Pedestrian Only
All of the above
Geogrid & edging....
Troweled Concrete Edge Restraint
Geotextiles

- Option of the design engineer
- Non-woven recommended (high water flow)
- AASHTO M-288 provides minimum requirements
- AOS selection criteria in PICP manual
- Or use manufacturer’s recommendations
- Place on sides & bottom
- Minimum overlap 12 in. (0.3 m)
- Poor soils overlap 24 in. (0.6 m)
- AASHTO M-288
  - Tables 1 & 2: Strength & Subsurface Drainage Geotextile Requirements
Geotextile (optional)
Pre-Installation
Material Access & Flow
Contamination of permeable surface and aggregates

Good practice: Keeping dirty tires off of PICP surface!

Other material placement and movement options?
Dumping the near end first: avoid truck tires compacting the soil subgrade

Construction Sequence
Construction practices....

Open-graded base storage

Contaminated base or bedding must be replaced!

Geotextile under pile
Or place on impervious surface
Open-graded base storage

Don’t store on soil

Good housekeeping
Mechanical or Manual Installation?

- Most important: available paver pattern
- Cost & time savings
- Site access
- Area
Stitching required in herringbone patterns.

Pattern requires full pavers only.

Pattern requires moving half stones.
Mechanical Installation

Mechanical installation of PICP can decrease construction time 20-80% over manual installation

*Manual paver installation:*
- approx 1,000 sq. ft. per man per day

*Mechanical paver installation:*
- 3,000 – 10,000 sq. ft. per machine per day
Weather...
Install Subbase & Base Materials
Gradation Comparison

Open-Graded Aggregate Gradation

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>% Passing</th>
<th>No. 2</th>
<th>No. 57</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 in. (75 mm)</td>
<td></td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>2.5 in. (63 mm)</td>
<td></td>
<td>90 to 100</td>
<td></td>
</tr>
<tr>
<td>2 in. (50 mm)</td>
<td></td>
<td>35 to 70</td>
<td></td>
</tr>
<tr>
<td>1.5 in. (37 mm)</td>
<td></td>
<td>0 to 15</td>
<td>100</td>
</tr>
<tr>
<td>1 in. (25 mm)</td>
<td></td>
<td>95 to 100</td>
<td></td>
</tr>
<tr>
<td>3/4 in. (19 mm)</td>
<td></td>
<td>0 to 5</td>
<td></td>
</tr>
<tr>
<td>1/2 in. (12.5 mm)</td>
<td></td>
<td></td>
<td>25 to 60</td>
</tr>
<tr>
<td>No. 4 (4.75 mm)</td>
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</table>
Subbase:
ASTM No. 2 Crushed Stone

Base:
ASTM No. 57 Stone
No. 2 & 57 Stone Not Available?

Other stone sizes okay – selection criteria:
   Min. void ratio = 32%, min. 90% fractured faces, LA Abrasion Loss < 40

*Layer choke criteria:*
   \( D_{15} \) base stone / \( D_{15} \) bedding stone < 5
   \( D_{50} \) base stone / \( D_{50} \) bedding stone > 2

\( D_x \) = particle size at which \( x \) percent of particles are finer

*Example:* \( D_{15} \) = aggregate particle size which 15% are smaller and 85% are larger (by weight)

*Note…read \( D_{15} \) and \( D_{50} \) on sieve analysis report*
Subbase and Base: Delivery, Installation & Compaction

- Moisten stones
- Lift thicknesses
  - Subbase (No. 2 stone or similar): Max. 6 in. lifts
  - Base (No. 57 stone or similar): One 4 in. lift
Compaction

Roller compactor – 10 T steel vibratory
  First two passes in vibratory mode
  Last two in static mode until no visible stone movement
Plate compactor – 13,500 lbf (60 kN) min. 2 passes
Density verification methods
Installing Bedding & Jointing Materials
Gradation & Base Capability

- **Bedding:** ASTM No. 8 stone – chokes into No. 57
- **Joints:** ASTM No. 8, 89 or 9 stone
- Similar gradations acceptable
- **Maximum joint width drives jointing material selection**
<table>
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<td>3/8 in. (9.5 mm)</td>
<td>85 to 100</td>
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<td>100</td>
</tr>
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Washed material: percent passing No. 200 (0.075 mm) sieve < 2%
Placing Bedding Material

Must be clean!
Place 2 in. (50 mm) thick rails on compacted No. 57
Adjust elevations as needed
Set & adjust screed bucket
  Laser guided screed – no rails used
Dump & spread bedding material
Distribute stone & screed
Manual/mechanical installation differences
Hand screed for residential & small commercial projects
Bedding layer touch-up
Removing screed rails as paving progresses

Fill rail imprint with stone
Powered screeding with asphalt spreader
Edge pavers cut and placed, then compacted.
Compact before sweeping in aggregate
Filling the openings with No. 8 stone, final compaction
Excess stones removed, then final compaction
Keeping sediment away from the pavers
PICP Design Basics: Exfiltration Options

- Full Exfiltration
- Partial Exfiltration
- No Exfiltration
Full Exfiltration

Sandy soils (> 0.5 in/hr)
No perforated drain pipes

Typ. No. 8 aggregate in openings
Curb/edge restraint with cut-outs for overflow drainage
Concrete pavers min. 3 1/8 in. (80 mm) thick
Bedding course 1 1/2 to 2 in. (40 to 50 mm) thick (typ. No. 8 aggregate)

4 in. (100 mm) thick No. 57 stone open-graded base
No. 2 stone subbase – thickness varies with design
Optional geotextile on bottom and sides of open-graded base
Soil subgrade–zero slope
Partial Exfiltration - detention & exfiltration

Silt/some clays
Perforated pipes at bottom of base

4 in. (100 mm) thick No. 57 stone open-graded base
No. 2 stone subbase – thickness varies with design
Optional geotextile on bottom and sides of open-graded base

Typ. No. 8 aggregate in openings
Curb/edge restraint with cut-outs for overflow drainage
Concrete pavers min. 3\(\frac{1}{8}\) in. (80 mm) thick
Bedding course 1\(\frac{1}{2}\) to 2 in. (40 to 75 mm) thick (typ. No. 8 aggregate)
Perforated pipes spaced and sloped to drain all stored water
Outfall pipe(s) sloped to storm sewer or stream

Soil subgrade sloped to drain
PICP Design Basics: Exfiltration Options

**No Exfiltration** - detention only

*High rock, High water table, poor soils*

- 4 in. (100 mm) thick No. 57 stone open-graded base
- No. 2 stone subbase – thickness varies with design
- Impermeable liner on bottom and sides of open-graded base
- Soil subgrade sloped to drain
- Outfall pipe(s) sloped to storm sewer or stream
- Curb/edge restraint with cut-outs for overflow drainage or optional overflow pipe
- Concrete pavers min. 3 1/8 in. (80 mm) thick, bedding course 1 1/2 to 2 in. (40 to 50 mm) thick (typ. No. 8 aggregate)
- Typ. No. 8 aggregate in openings
- Perforated pipes spaced and sloped to drain all stored water
Observation well:

- Install at lowest point of pavement
- Min. 6 in. dia. perf. pipe w/cap
- Monitor drainage rate, sediment, water quality, temperature

Figure 12. Observation well into PICP base and subbase with top accessible directly from the surface to observe drain down rate.
Maintenance

Annually: overall system performance inspection, check observation well, inspect after major storm, vacuum surface (once, twice, or more) to ensure optimum design life performance

Maintenance checklist (specific to each project)

Model maintenance agreement

Monitor adjacent uses
### Table 3-1: Minimum PICP subbase & base thicknesses

<table>
<thead>
<tr>
<th>PEDESTRIAN</th>
<th>Soaked CBR (R-value)</th>
<th>Resilient Modulus, psi (MPa)*</th>
<th>Base thickness, in. (mm) No. 57</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4 (9)</td>
<td>6,205 [43]</td>
<td>6 (150)</td>
</tr>
<tr>
<td></td>
<td>5 (11)</td>
<td>7,157 [49]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6 (12.5)</td>
<td>8,043 [55]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7 (14)</td>
<td>8,877 [61]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8 (15.5)</td>
<td>9,669 [67]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9 (17)</td>
<td>10,426 [72]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10 (18)</td>
<td>11,153 [77]</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>VEHICULAR</th>
<th>Soaked CBR (R-value)</th>
<th>Resilient Modulus, psi (MPa)*</th>
<th>Lifetime ESALs (Traffic Index)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4 (9)</td>
<td>6,205 [43]</td>
<td>Base thickness, in. (mm) No. 57</td>
</tr>
<tr>
<td></td>
<td>5 (11)</td>
<td>7,157 [49]</td>
<td>Subbase thickness in. (mm) No. 2</td>
</tr>
<tr>
<td></td>
<td>6 (12.5)</td>
<td>8,043 [55]</td>
<td></td>
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</tr>
</tbody>
</table>

**Assumptions:** 80% confidence level

Commercial vehicles = 10%; Average ESALs per commercial vehicle = 2
No. 57 stone layer coefficient = 0.09; No. 2 stone layer coefficient = 0.06
3 1/8 in. (80 mm) thick concrete pavers and 2 in. (50 mm) No. 8 bedding layer coefficient = 0.3
Total PICP cross section depth equals the sum of the subbase, base, 2 in. (50 mm) bedding and paver 3 1/8 in. (80 mm) thickness.
Thank you!

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