Permeable Pavement Overview

Meeting of CCPIC
City of Berkeley
City of Davis
City of Martinez

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Permeable Pavement Team and Sponsors

• Contributors to published work presented:
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• Work sponsored by:
  – Concrete Masonry Association of California and Nevada
  – Interlocking Concrete Pavement Institute
  – California Department of Transportation
Permeable Pavement for Stormwater Management

• Impervious pavement in urban areas contributes to
  – Water pollution (*oil, metal, etc.*)
  – Reduced groundwater recharge
  – Increased risk of flooding
  – Local heat island effect
    (*less evaporation*)

• Gaps to be filled
  – Designs for heavy vehicles
  – Cost and environmental impact comparisons
  – Other obstacles to successful use and implementation
Permeable Pavement Studies by UCPRC

- Goal: Mechanistic based design methods for heavy vehicle applications, fill other gaps
- Studies by UCPRC
  - Caltrans Study (2008-2010)
    - Hydraulic and structural design method and tables for permeable concrete and asphalt pavements
    - Not yet validated with traffic
  - CMACN / ICPI Study (2013-2014)
    - Design method and tables for PICP
    - Validated with Heavy Vehicle Simulator
  - Caltrans Study (underway)
    - Survey of experience and knowledge regarding permeable pavements
General Concept
Shoulder or Traveled Way

Permeable surface
(Interlocking Conc Pavers, HMA-O or PCC-O or PCC with holes)
*Fatigue (except for pavers)*

Granular reservoir layer
*Rutting (Shear Stress/Strength Ratio)*

Optional permeable 15 cm PCC-O subbase

Lightly compacted subgrade
*Rutting (Shear Stress/Strength Ratio)*
Caltrans Study: Hydraulic profile of water content for LA area: permeable shoulder

Los Angeles 1998
Permeable Shoulder only

Permeable Base (40 cm)
Modeled subgrade (145 cm)
Permeable surface layer (15 cm)

Water Content
- 0.10
- 0.15
- 0.20
- 0.25
- 0.30
- 0.35
- 0.40

Depth (m)
-2.0
-1.5
-1.0
-0.5
0.0
0.10
0.15
0.20
0.25
0.30
0.35
0.40

Date
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct

Rain intensity (m/day)
0.02
0.04
0.06
0.08
0.10

Rain Volume/Surface Area (mm)
0
10
20
30
40

0
20
40
Caltrans Studies: LCCA, LCA

- **LCCA**
  - *Realcost* for LCCA
  - BMP costs from Caltrans reports
  - Permeable pavement costs from Teichert
  - 40 year analysis, discount rates, agency costs

- **LCA**
  - Framework produced for future LCAs

- **Field measurements of clogging on older projects**
  - Concrete only
Caltrans Studies:
Key Findings: LCCA

• Shoulder Retrofit of Impermeable Road
  – Drains two lanes
    • 0.75 x cost of lowest cost BMP
  – Drains three or more lanes
    • 0.5 x cost of lowest cost BMP

• Maintenance yard/parking lot
  – Same cost as lowest cost BMP
  – 0.15 x cost of highest cost BMP
Caltrans Studies: Structural Design

• Scope
  – Base/reservoir/permeability design for three regions
  – HMA-O/PCC-O/Cast PCC slab for two regions
  – With and without PCC-O subbase below reservoir

• HMA-O
  – Three part process
    • Determine base/reservoir thickness based on subgrade permeability & rainfall
    • Determine HMA thickness
    • Check subgrade stress to subgrade strength ratio

• PCC-O and Concrete Slabs with Holes
  – Two part process
    • Determine base/reservoir thickness
    • Determine PCC-O thickness for given slab length
ICPI Study

- Study approach
  - Literature review
  - Field testing
  - Test track design
  - Test track construction
  - Accelerated load testing
  - Data Analysis
  - Design method & tool
  - Design tables
  - Final report
    • includes interim reports
ICPI Study: Mechanistic approach

• Distress
  – Unbound layer rutting

• Approach
  – Shear stress to shear strength ratio (SSR) at top of layer
    – $0.3 \leq \text{SSR} \leq 0.7$

• Required inputs
  – Unbound layer stiffness, strength, and other mechanical properties
    – Obtained from lab and field testing

\[
\text{Shear Stress Ratio (SSR)} = \frac{\tau_f}{\tau_{\text{max}}}
\]

\[
\tau_f = \frac{\sigma_1 - \sigma_3}{2} \cos\phi = \frac{\sigma_d}{2} \cos\phi
\]

\[
\tau_{\text{max}} = c + \sigma_f \tan\phi
\]

\[
\sigma_f = \frac{\sigma_1 + \sigma_3}{2} - \frac{\sigma_1 - \sigma_3}{2} \sin\phi = \frac{\sigma_d + 2\sigma_3}{2} - \frac{\sigma_d}{2} \sin\phi
\]
ICPI Study: Test sections

Surface: 80 mm interlocking concrete paver
Bedding layer: 50 mm ASTM #8 aggregate
Base layer: 100 mm ASTM #57 aggregate
Subbase layer: Varying thickness ASTM #2 aggregate
Subgrade soil: Silty clay, compacted after excavation

<table>
<thead>
<tr>
<th>Subbase Thickness</th>
<th>Shear Stress Ratio (SSR)</th>
<th>Calculated (mm)</th>
<th>As-Built</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thin</td>
<td>0.8</td>
<td>Dry 450</td>
<td>650</td>
</tr>
<tr>
<td>Medium</td>
<td>0.5</td>
<td>800</td>
<td>950</td>
</tr>
<tr>
<td>Thick</td>
<td>0.2</td>
<td>1,350</td>
<td>1,450</td>
</tr>
</tbody>
</table>
ICPI Study: Cross sections
ICPI Study: Instrumentation

- Aggregate size limited options
- Stress (pressure cell)
  - Top of base
  - Top of subgrade
- Deformation (profiler + dipsticks)
  - Surface
  - Top of base
  - Top of subgrade
- Deflection (RSD)
- Water level
  - Manual and automated
ICPI Study: Testing conditions

- Extended HVS (13m) used to test all sub sections together
  - Bidirectional trafficking with wander
  - Wheel load range from 25kN to 80kN

- Three testing conditions
  - Dry
  - Wet: water table maintained at the top of the subbase
  - Drained: Wet subgrade, no water in the subbase
  - All testing at ambient temperature

- Failure criteria
  - >25 mm of surface rut
ICPI Study: HVS testing
ICPI Study: HVS testing
HVS Results: 450 mm

![Graph showing permanent deformation vs. load repetitions for different layers (Top of Subbase, Top of Subgrade, Total Deformation) in dry and wet conditions.](image)
HVS Results: 950 mm

Dry

Subbase

Subgrade

Wet

Subbase

Subgrade
ICPI Study: APT conclusions & use

• Conclusions:
  – Most rutting in top of subbase when wet at very high loads (close to 2x legal limit)
    • Adjust bedding layer design
  – Subgrade rutting diminished by increased subbase (reservoir) thickness

• Rutting models
  – Incremental-recursive models for each layer
  – Laboratory test data and layer elastic theory
  – Shear stress/strength ratio (SSR)
ICPI Study: Design tool

- Design tool developed (*Excel®* spreadsheet)
  - Number of days with water in the subbase
  - Material properties
  - Traffic and load spectra

- Tool used to validate ICPI design tables
  - Less conservative than current ICPI for dry conditions
  - Slightly more conservative for very wet conditions
Caltrans Survey of Local Agencies (underway)

Stakeholders' Thoughts On The Results of Projects
9 Answers

- Yes: 44.4%
- No: 22.2%
- Mostly: 22.2%
- Too soon to tell: 11.1%

# of answers
Speculated Obstacles in Implementation
73 Answers

- Maintenance: 22 (30.1%)
- May not work as a pavement: 21 (28.8%)
- Greater initial cost: 10 (13.7%)
- May not works as a catchment: 8 (11.0%)
- Lack of design guidelines: 4 (5.5%)
- Other: 3 (4.1%)
- Conflicts w/ utilities: 3 (4.1%)
- Industry resistance: 2 (2.7%)
Getting the Permeable Pavement Results

• Pervious Concrete and Porous Asphalt for Heavy Traffic
  – Preliminary permeable pavement designs that can be tested in pilot studies under typical California traffic and environmental conditions

• Permeable Interlocking Concrete Pavement for Heavy Traffic
  – Design method and validation results
  – Being incorporated into ICPI and ASCE designs
Questions?