Permeable Pavements in Cold Climates

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Outline

• Introduction and background
• Design methods
• Summary of performance & maintenance
• Case Studies
  – Paired Intersection Study (Minnesota)
  – Porous Asphalt Study (New Hampshire)
  – Woodbridge Neighborhood (Minnesota)
  – Experiences in Colorado
• Summary and Conclusions
Porous pavements developed as early as the 1930s.
Full Depth Permeable Pavement

- Water infiltrates through permeable pavement surface and other layers
- Stored in gravel layer (~40% voids)
- Water infiltrates into soil or is collected by drain tile
Benefits Permeable Pavement

- Volume reduction
- Improved water quality
- Hydroplaning resistance
- Spray reduction
  - Increased visibility
- Smoother ride
- Noise reduction
- Less salt required

Images source: Barrett 2008
Types of Permeable Pavement

- Porous Asphalt
- Pervious Concrete
- Permeable Pavers
- Permeable Articulated Concrete Blocks
Permeable Pavement Design

• No uniform or standard design across industries
• See Weiss et al. (2015) for design recommendations
• Examples of design variations:
  – NAPA: AASHTO design w/ SN. Use non-woven geotextile.
  – ACPA: PerviousPave, uses model developed for StreetPave. Use geotextile liner.
  – ICPI: AASHTO w/ SN. Geotextile fabric is optional
Keys for Success

• Proper Construction
  – Mix design
  – Compaction
  – Void ratio
  – Curing
• Proper and regular maintenance

Photo courtesy of M. Maloney, Shoreview, MN
Summary of Hydraulic Performance

- Surface infiltration rates decrease but are not rate limiting.
- Method needed to determine permeability of sub-base before design.
- Geotextile fabrics can reduce/eliminate infiltration.
- Infiltration rates are maintained through winter.

Photo: http://ih.constantcontact.com/
Summary of Water Quality Impact

• Removes solids & solid-bound contaminants
• Mass load reduction often through infiltration
• Nitrification may occur (ammonium to nitrate), but total N removal is low
• Dissolved phosphorus removal is minimal
Summary of Maintenance

- Surface cleaning is effective but variable
- Particle removal (top ¼ inch) is major issue
- Pressure washing (45°) and/or vacuuming with regenerative air sweepers is most effective
- Brushes can push material farther into voids
- Clean multiple times per year

Images: Elginsweeper.com
Impact of Vacuuming

Permeable articulated concrete blocks/mats before (A) and after (B) cleaning with a Vac Head.

(Photo courtesy of University of Louisville and D. Buch, PaveDrain, LLC).
Summary of Maintenance

• Major cause of clogging is reduction of surface pavement void space:
  – Heavy loads
  – Particles
  – Lack of maintenance

• No standard to measure or evaluate clogging

Open voids

Partially clogged voids
Porous Asphalt Paired Intersections – Robbinsdale, MN

Constructed 2009-2010

- Objective was to evaluate potential salt load reduction on porous asphalt pavements
- Also durability, maintenance, and water quality

Construction in September 2010 (Wenck 2014)
Paired Intersection Study

- TMDL study for Shingle Creek, MN: Reduce Cl by 81%
- Two porous asphalt pavement intersection constructed: 1) Sand sub-base, 2) Clay sub-base
- Designed for 2-yr storm
- The porous asphalt sections were not salted during the winter
- Conventional asphalt sections were salted
Paired Intersection Study

4” Asphalt

Max 2” choker course (0.5” crushed stone)

12” Reservoir Layer (1.5”-2.5” stone)

6” drain tile

Geotextile

Porous Asphalt Cross-Section (Wenck 2014)
Paired Intersection Study

- Porous asphalt sections: ~150 feet long by ~28 feet wide (4200 square feet)
- Cost: Site 1 was $42,670
  Site 2 it was $32,200.
- Site 1 construction was negotiated as part of a change order. Site 2 the contract was awarded to the low bidder.
Paired Intersection Study

Results

• Winter reservoir temperatures warmer than the pavement temperature

• Reservoir air voids provided insulation

• Insulation minimizes winter freezing and keeps reservoir temperatures cooler in spring
Paired Intersection Study

Results

• Suggests winter infiltration into subgrade is possible

• Conventional pavement sites were slushier than the porous asphalt sites due to infiltration into PP

• Bare pavement on the porous test sections comparable to conventional sections but had a lag
Paired Intersection Study

Slush gathering and refreezing on the traditional asphalt at Site 1 on January 17, 2010

Slush free porous asphalt on January 17, 2010
Paired Intersection Study

Site 1 Test Section looking south
Paired Intersection Study

Lessons Learned

- The unsalted, porous asphalt sections had a similar amount of bare pavement compared to salted, conventional asphalt sections.

- The porous pavement over sand subgrade was more effective for ice control compared to the porous pavement on clay subgrade,
  - porous asphalt on sand can infiltrate all or most of the runoff
  - On clay, frequent overflows were observed

- Porous asphalt sections have been durable without any special snow plow equipment or adjustments.
Paired Intersection Study
Lessons Learned

- Effective maintenance on the porous asphalt sections appears to be vacuuming twice per year and patching with traditional asphalt, as necessary.

- Porous asphalt intersections have potential as an ice-control management practice in certain situations.
UNH Porous Asphalt Parking Lot


Photo from Roseen et al. 2014
UNH Porous Asphalt Study

- Each lot = 5000 ft²
- 4” of porous asphalt
- 18% voids, 5.8% asph.
- Filter Course: K=10-60 ft/day at 95% comp.
- Filter blanket prevents migration of fines
- 21 inch stone reservoir
- Underdrain 12 inches above bottom

Image from Roseen et al. 2014
UNH Porous Asphalt Study

- PA lot received 25% of typical salt load of 3 lb/1000 sf
- DMA received 100% of typical salt load
- Frost penetration deeper on PA (27” vs. 18”)
- PA lot thawed ~30 days before DMA
- 25% of runoff infiltrated in PA (Type C soils)

a) PA at 11:20 AM; b) PA at 1 PM; c) DMA at 11:20 AM; d) DMA at 1 Pm

(Roseen et al. 2014)
UNH Porous Asphalt Study

Lots one hour after plowing (-4° C)
(Photo: UNHSC)
UNH Porous Asphalt Study

- PA exported nitrate;
- PA: no impact on TP;
- PA reduced TPH (1970 µg/L to 166 µg/L)

- PA reduced TSS (54 mg/L to 6 mg/L)
- PA mean infiltration rate = 1700 in/hr after 3 yrs & no maintenance

Pavement after freezing rain: a) PA, b) DMA (Roseen et al. 2014)
UNH PA Parking Lot Study-Conclusions

- PA with 25% of salt load had same snow/ice cover as DMA lot
- Salt loads could be reduced by 64% with no compromise in safety
- PA froze but maintained high infiltration capacity
- PA had higher skid resistance (for wet, snow, & compacted snow)
- More salt applications may be necessary
- PA particles were found in voids after winter

Roseen et al. 2014. Photo: Heather Lynn Peters
Woodbridge Neighborhood-Shoreview, MN

Pervious Concrete, constructed in 2009.

Photo courtesy of M. Maloney
Woodbridge Neighborhood

Initially:
• 38 ac, fully developed
• 9000 yd² of asphalt
• Storm drainage concerns

Needed to:
• Replace road, upgrade utility, improve stormwater management
• Total cost = $15M

Photo courtesy of M. Maloney
Woodbridge Neighborhood

Why PC?
• Free draining soils
• Advances in mix designs and placement techniques
• Same cost as conventional asphalt with storm drains
Woodbridge Neighborhood - Construction

- 18” crushed rock reservoir
- Tri-roller screed for consolidation
- Curing fabric used instead of poly sheeting placed within 1 minute (7 day duration)
- Mix Design: 125 PCF, 21% air voids (+/- 3%)
- 7” of pervious concrete
- 1.5” Railroad ballast, 18-30” thick
- $86.30 per SY
- Saw cut joints 24-48 hours after pour

Curing of Pervious Concrete.
Photo courtesy of M. Maloney
Woodbridge Neighborhood - Maintenance

- Regenerative air sweeper (no brushes); ~ every 6 weeks
- No salt or sand application
- Plowed by one-ton pickup w/ regular plow
- Clogging occurs mostly in top ¼” of pavement
- Maintenance has maintained infiltration rates of 300-500 in/hr in most areas
Lessons Learned

• Construction & curing very important

• Saturated curing blankets have been successful

• Saw cut joints have been successful
Lessons Learned

• Reservoir aggregate should be large & angular
• Salt and turning traffic have caused isolated failure
• Organics are the main source of clogging
• Do not work PC by hand
• Do not “walk” screed around corners

1.5” Railroad ballast.
Photo: Florence Crushed Stone
The Denver (UDFCD) Experience
Aurora Wal-Mart Parking Lot

- Pervious Concrete
- Installed in 2004
- No info on mix design
- Raveling at joints (some saw cut)
Denver Safeway Parking Lot

- Pervious Concrete
- Installed in 2004
- No info on mix design
- Surface erosion

Photo courtesy of K. MacKenzie, UDFCD
University Plaza Parking Lot

- Pervious Concrete
- Installed in 2005
- No info on mix design
- Surface erosion

Photo courtesy of K. MacKenzie, UDFCD
Possible Causes of Failure

- Non-uniform void content
- Poor air entrainment in cement paste
- Chloride (applied/carried in)
- Cement paste consolidation
- Placement during adverse weather
- Loss of hydration water during curing
National Renewable Energy Lab
Parking Lot

- Pervious Concrete
- Installed in 2009
- Mix design followed new requirements
- PC use in Denver suspended

2011

Photo courtesy of K. MacKenzie, UDFCD
Denver Waste Management Building

- Porous Asphalt
- Installed in 2008
- Surface infiltration < 20 in/hr
- Intensive maintenance was ineffective

Parking lot after light rain.
Photo courtesy of K. MacKenzie, UDFCD
Denver Waste Management Building

• Cores revealed proper construction (17% voids, proper PSD, asphalt content, etc.)

• More than half of other PA sites have infiltration < 20 in/hr

• UDFCD does not recommend use of PA

Parking lot after snowfall. Photo courtesy of K. MacKenzie, UDFCD
Conclusions

• Permeable pavements can result in less winter salt application
• Permeable pavements can reduce runoff volume and improve water quality (with other benefits)
• Permeable pavements are more expensive to construct
• Construction & maintenance are critical to success
Conclusions (Cont’d)

• Maintenance: pressure washing and/or vacuuming
• Permeable pavements can withstand harsh winters
• Permeable pavements can maintain infiltration rates throughout the winter
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Questions?

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UNHSC (University of New Hampshire Stormwater Center). 2009. *UNHSC Design specifications for porous asphalt pavement and infiltration beds.* University of New Hampshire, Durham, NH, USA.


Porous Asphalt Design Recommendations

1. Particle size distribution & binder type are the 2 most important factors in mix selection *(Jones et al. 2010; Li et al. 2012)*

2. Void ratios of 25% & infiltration rates of > 7 cm/s possible by optimizing aggregate *(Partl 2003)*

3. Typical air voids are 16 – 20% *(NAPA 2008)*

4. Depth of aggregate bed to be 65% of frost depth *(UNHSC 2009)*

5. Typical aggregate gradations/specs given in reports *(NAPA 2008)*
Pervious Concrete Design Recommendations


2. Low water:cement ratios (i.e. 0.26-0.34)

3. Supplementary materials (e.g. fly ash)/admixtures may be used (must meet ASTM requirements)

4. Void content from 15-25%

5. Increase in sand content may increase freeze-thaw resistance (CRMCA 2009)
Permeable Paver Design Recommendations

1. Open-graded bases: <2% fines, density: 95-120 lb/ft³, porosities >30%

2. All stone & aggregate: >=90% fractured faces and a minimum Los Angeles abrasion value of less than 40

3. Base and sub-base: porosity >= 32%, CBR >= 80%