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Civil Engineering
Landscape Architecture
Environmental Restoration
Planning

Stormwater Seminar – October 17, 2007

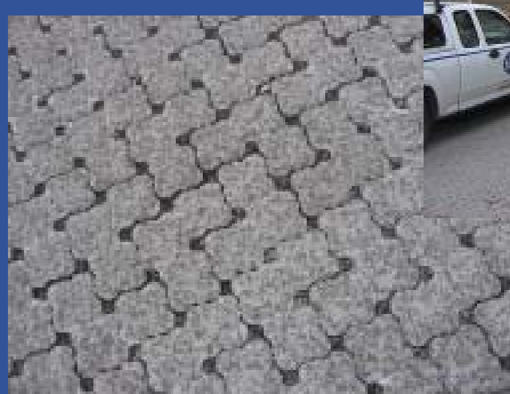
Permeable Paving: Examples and Lessons Learned

Kathryn Gwilym, PE, LEED® AP

Permeable Pavements

- Overview
- Design Considerations
- Pervious Material Types
  - Porous Portland Cement Concrete
  - Porous Asphalt Concrete
  - Pavers
  - GrassPave^2
  - Open-Celled Paving Grids
- Construction
  - Pre-planning & Preconstruction
  - Construction Issues
  - Post Construction
- Maintenance
- Lessons Learned




Benefits of Porous Pavements & Pavers

- Water Quality Treatment
- Flow Control
- Eliminates or minimizes the treatment facilities
- Optimizes Space within ROW utilities
- Reduces Temperature of Runoff to Streams
- Reduces Heat Island Affect
- Benefits Trees and Landscaping
- Paved Surface

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Design Considerations for Porous Pavements

- Determine your Design Goals
  - Reduce runoff flow rates? What storm event?
  - Water quality treatment?
  - Reduce impervious area?
  - Aesthetics?
  - Traffic loading?
- Design Conservatively (e.g. when determining depths for porous cement concrete and asphalt pavement sections)
- Location within project and for future
- Stabilization of adjacent areas
- Infiltration Rate through Porous Cement Concrete & Asphalt Pavement Section not limiting factor.
  - Seattle's porous cement concrete pavement street at High Point: 200 in/hr and greater.
  - Intensity of 100 year 24 hour storm event in Seattle: 2.3 in/hr (over 10 min interval)

Design Considerations for Porous Pavements Continued

- Subgrade Soil Characteristics Control Infiltration Rate
  - Existing subgrade soils testing
  - Infiltration rate after construction
  - 0.5in/hr minimum percolation rate of subgrade (NRMCA)

- Subgrade Slope and Storage
  - Ideal 0% to maximize storage but can increase excavation
  - Sloped conditions (1% to 5%) reduces the amount of useable storage space but decreases amount of excavation.   Use periodic impermeable check dams, or gravel trenches or other measures to allow water to backup & infiltrate/direct away.

- Overflow/Back-up System (various opinions yea or nay)

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Porous Portland Cement Concrete Pavement

- Mix with no fine aggregates
- Voids in pavement allow water to flow through section
- First installed in 1852 in the UK
- Used in the United States since 1970’s for paving applications, mainly in the Southeast Regions but has spread across U.S.
- Low-volume residential streets

32nd Avenue SW, Seattle, WA

Parking Lot

Applications of Porous Portland Cement Concrete Pavement

- Public sidewalks
- Park walkways
- Noise barriers/walls
- Greenhouse Floors
- Surface Course for Tennis Courts
- Patios, plazas

Serene Way Sidewalk[1]

Photo 1: Courtesy of Randy Sleight, PE, Snohomish County

High Point Public Sidewalk

(4”-5” depth porous PCC

over 4” to 6” depth gravel subbase)

Ernst Park

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Seattle's 32nd Ave SW Porous Cement Concrete Pavement in Snow

- Design Subbase for drainage
- Been installed in cold climates such as Iowa, Pennsylvania, Colorado
- Studies underway in colder climates in areas with high water table

Safeway Parking Lot
Denver, CO – Next AM Following 12” Snow

Sites directly across street

Photos: 5 min. differential max

Pervious Concrete

Conventional Asphalt

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Photos courtesy of National Ready Mixed Concrete Association and Slide courtesy of Center for Portland Cement Concrete Pavement Technology, 2005 via John Kevern at National Concrete Pavement Technology, Iowa State University

Fremont Library/Ernst Park, Seattle, WA

- Porous Cement Concrete Sidewalk
- Hillside Location
- Curvilinear layout

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Snoqualmie Gourmet Ice Cream Parking Lot Paving

Photo and Projects Courtesy of Randy Sleight, PE, Snohomish County from Fall 2006 APWA Conference presentation

Examples of Porous Cement Concrete Pavement Thickness*

- Design Conservatively
- Same Approach as Conventional Concrete Design Software
- Residential Street, 10 Trucks/day, 30 year design life, Soil California Bearing Ratio = 2 (Silt/Clay)*
- Flexural Strength = 350 (fc' = 1250 to 1500 psi)*
  - 6.5 inches for expected life of 35 years
  - 7.0 inches for expected life of 73 years

- Flexural Strength = 375 (fc'=1400 to 1800 psi)*
  - 6.0 inches for expected life of 13 years
  - 6.5 inches for expected life of 46 years
  - 7.0 inches for expected life of 115 years

- Expected Life Estimated to Increase Significantly with Small Increases in Pavement Depth. (Caution: Compaction decreases through section depth).

*Example provided by Andy Marks, Puget Sound Concrete Specifications Council, at 2006 APWA Fall Conference

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Construction Issues for Porous Cement Concrete Pavement

- Method for Installation Varies.
- Place from Chute, Wheeled or by Conveyor.
- No Trowels or Floats.
- Cover Immediately after placement – Voids enhance drying
- No Dowels
- Joint spacing (follow standard but under review)

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Example of Placement of Porous Cement Concrete Sidewalk

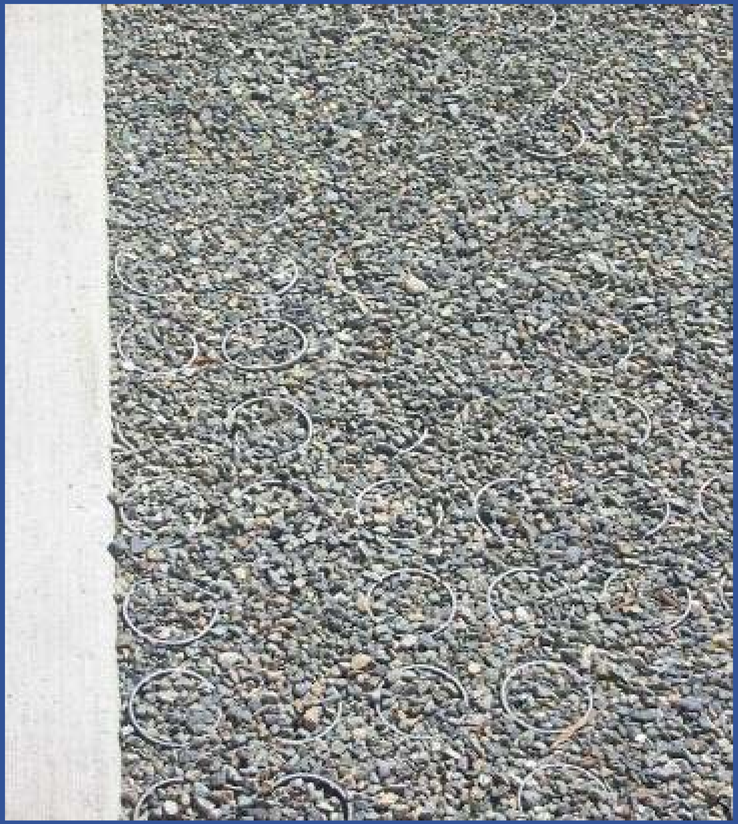
Photos by Randy Sleight, Snohomish County, presented at 2006 Fall APWA Conference.

Examples of Porous Pavement Installation

City of Portland Porous Asphalt Concrete Pavement

- N. Gay Avenue
- 8” Porous Asphalt over 6” granular base
- Reused existing curbs and drain collection structures
- Open graded asphalt (no fines)

Geocells - GravelPave^2 System for Parking Stalls



- Invisible Structures, Inc.
- Ring and Grid structures filled with ¼” minus with 6” depth of 5/8” minus gravel subbase
- Mats pinned down per manufacturer installation requirements
- Other: GrassPave^2 for Lawn finish

Permeable Pavers

- Developer: Lyle Homes
- Prime: Mithun
- Private Residential Drive
- Pavers through Mutual Materials
- Pavers over 3” Bedding Course and 10” Base Course for this installation
- Quick Installation 4’x4’ Grids
- Gap at joints

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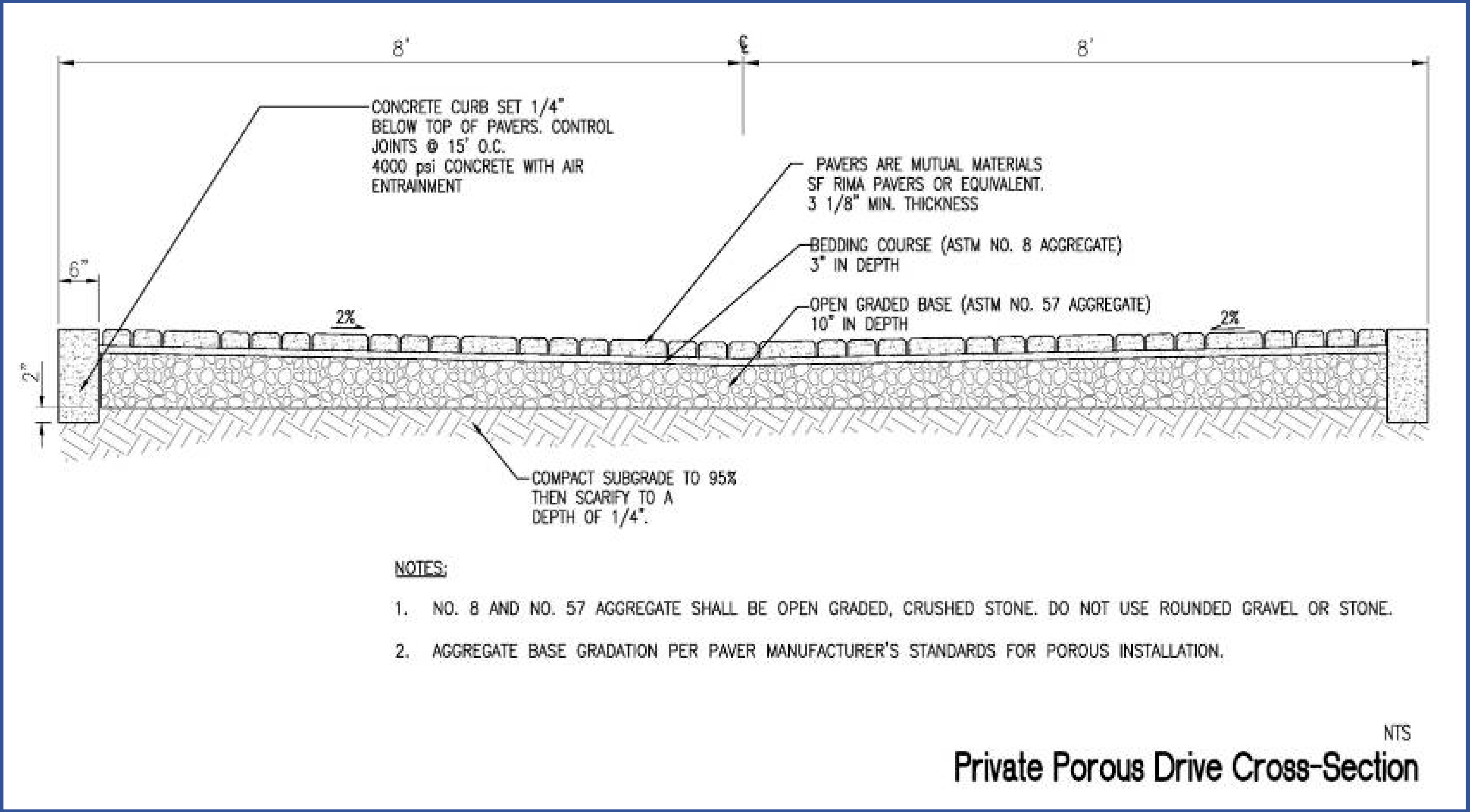
Example Section for Permeable Pavers



Open-Celled Paving Grids

- Parking lot
- Fire/Emergency Access Lanes
- Continues Green Planter Strip
- Grid units over bedding sand and base

Fire lane/Maintenance road for housing site.
Geoweb® Cellular Confinement system

Maintenance Road using TurfStone® over 1 ½” to 2” sand and 6” of crushed rock w/o fines

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Open-celled pavers continued – Overflow parking

- During Construction
- After Establishment

Installation of Open-Celled Pavers

Clark County parking lot near La Center – Mutual Materials supplier

Multnomah Arts Center, Portland – Different color pavers to define stalls.

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Photos from http://www.lcrep.org/fieldguide/examples/permeablepavers.htm

Preconstruction & Planning for Porous Pavements

- TESC - Install Sediment and Erosion Control Measures to Redirect Water away from Construction Area Prior to Excavation of Pavement Section.
- Construction Sequencing
- Installer Prequalifications
- For Porous Cement concrete: NRMCA Pervious Concrete "Technician" Certification
- Install Test Panel(s) or Provide Examples of Previous Installations by Crew that will be doing the work.
- Preplanning Meetings between Supplier, Installers, Drivers, Inspectors, Designers
- Preplanning for Construction Sequencing and Truck Deliveries during Placement of Mix (porous cement concrete)

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Post Construction for Permeable Pavements

- Maintain Stabilization of Adjacent Areas BEFORE and AFTER construction.
- Post Construction Testing
  - Infiltration Test
  - Pavement Thickness
- Porous Asphalt & Cement Concrete – check for unraveling and sealing

Maintenance for Pervious Pavements

- Follow Manufacturer recommendations for Proprietary Products (pavers)
- Porous Cement Concrete Pavements and Porous Asphalt - Use Vacuum, Pressure Washer, or combination
- Continuously inform maintenance staff
- Depends on Type of Material
- Develop protection guidelines for future work in area
- Patch with same material

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Photos from Maintenance Memo from Craig Tosomeen, City of Olympia using Leaf/Litter Vacuum (Minuteman Parker Vac-35) September 2006 to clean porous cement concrete sidewalk installed in 1999.

Lessons Learned

- TESC - Adjacent site erosion and flow control is critical.
- Inform users of protection of pavement
- Inform staff (Installers to Inspectors) of expectations and design intent.
- Select locations that will not require vehicular access to adjacent properties during construction. This allows flexibility with the installation due to sequencing, weather and stabilization.
- Require Test Panel or Local Examples of Installations
- Require Installers to have certification & experience
- Inform other subcontractors working in area of protection of the infiltration system & permeable pavements
- Paving around utility vaults should allow for 6 inches minimum. The porous concrete sidewalks seems to have a tendency to crack if less than this width.
- Maintain landscape edges adjacent to porous cement concrete and asphalt concrete (to prevent grass and groundcover intrusion).
- Determine monitoring requirements during design.

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Acknowledgments

Seattle Public Utilities
UW Botanic Gardens

City of Seattle
Washington State Department of Ecology
US Department of HUD
Seattle Housing Authority
Examples from Other Jurisdictions

Puget Sound Concrete Specifications Council
National Ready Mixed Concrete Association
American Concrete Institute

For more information:
www.svrdesign.com and www.seattle.gov/util/naturalsystems .

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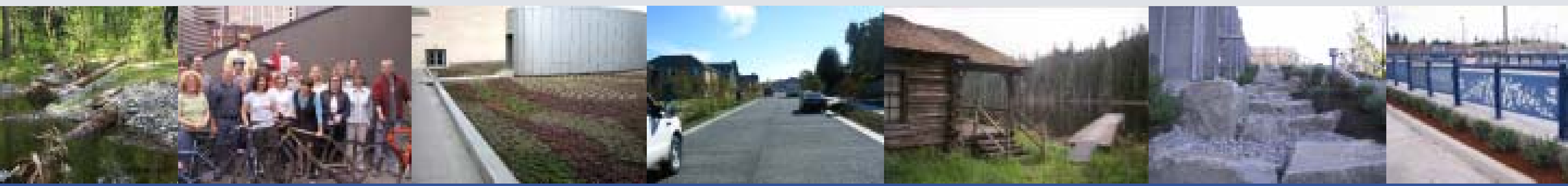
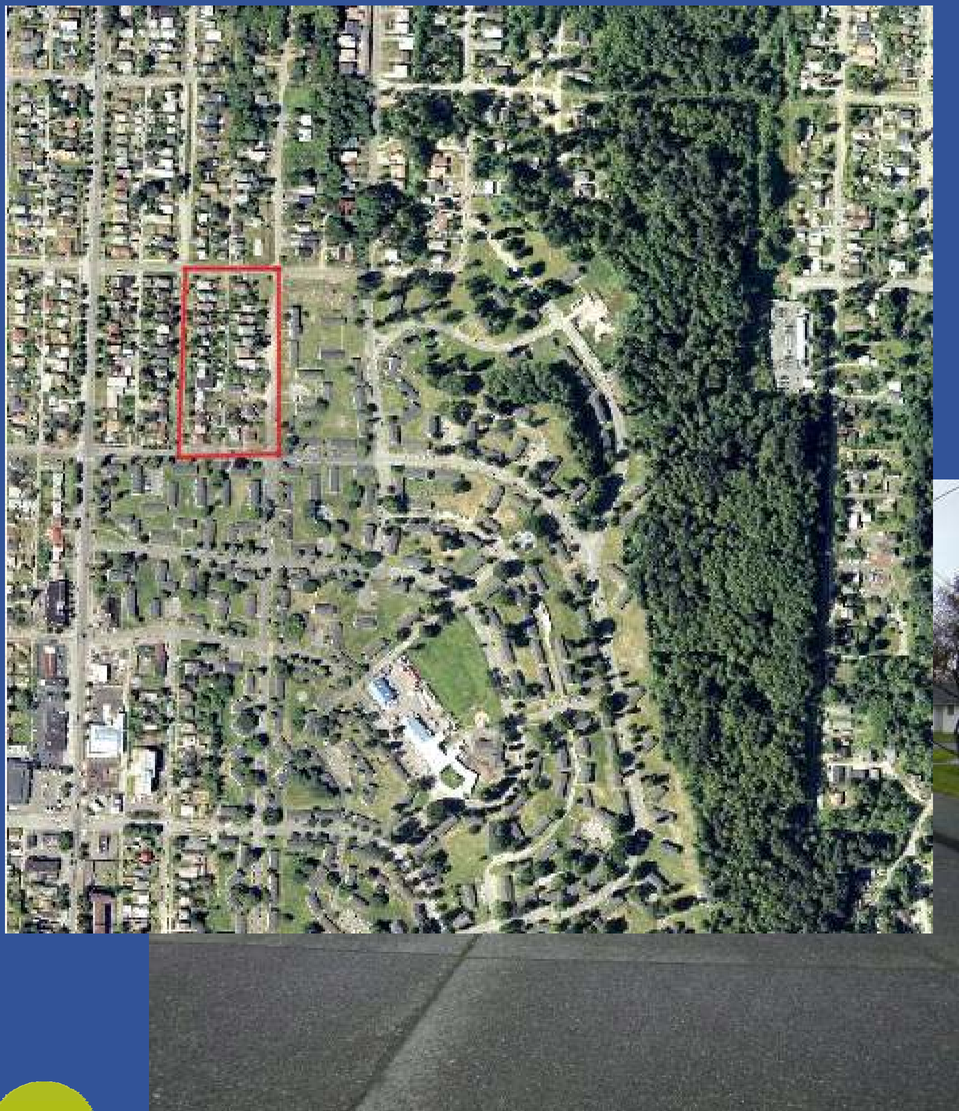


Questions? Answers and Next

Example: Seattle's First Public Porous Pavement Street
Existing Conditions of 32nd Avenue SW



prior to redevelopment

- Project: Seattle Housing Authority's High Point Redevelopment
- Longitudinal Slope 3% +/-
- Drainage basin 4.6 acres
- Existing developed basin with 8 dwelling units per acre
- Existing Road 32' wide
- Sidewalk on one side of street
- Parking on grass areas
- 40% impervious
- 60% pervious

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Example: Design Goals for 32nd Ave SW

- Pilot Porous Pavement Street for City of Seattle
- Infiltrate the 6-month Storm Event for the Roadway Section only
- Reduce the Existing Developed Peak Flow Rate up to the 2-year Storm Event
- Integration of Redevelopment into Existing Neighborhood
- Traffic Calming
- Provide Service for Residential Street Loading Condition

Example: Design Parameters for Seattle's First Public Porous Cement Concrete Pavement Residential Street

- 8" Compacted Thickness for Road over 18" Gravel Subbase
  - Designed for Residential Street Loading
- Cement Content (Two Mix designs 564 & 582 lbs/cy were chosen for comparison based on test panel results)
- Mix Aggregate: AASHTO No. 8* (3/8" to No 16) or No. 89 (3/8" to 50)
- Mix Design Non-Proprietary
- Water Cement Ratio 0.27 to 0.35*
- Voids 15% to 21% (ASTM D-1188)
- Field Infiltration Rate 200 in/hr through Pavement
- Design Flexural Strength 450 psi
- No Dowels (Corrode with Water in Pavement)
- Joints every 15-feet (Depth1/3 Pavement Thickness)

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Example: Design Assumptions/Parameters for 32nd Ave SW Subbase and Subgrade

- 20% Voids for Gravel Storage Subbase ¾” to 1 ½” Washed Crushed Aggregate for Road Subbase
- 3/8” to ¾” Washed Crushed Aggregate for Sidewalk Subbase
- Compaction 92% for Roadway Subbase
- Scarify Existing Subgrade to Prevent Sealing of Subgrade
- Geotextile between Existing Subgrade and Gravel Subbase
- Maximum Ponding Depth within Gravel Storage Subbase 1-foot
- Gravel Storage Subbase below Freeze/Thaw Depth (10” to 12”)
- Existing Subgrade Design Infiltration Rate 0.25 in/hr (silty fine sand to fine sandy silts) per Geotechnical Review.

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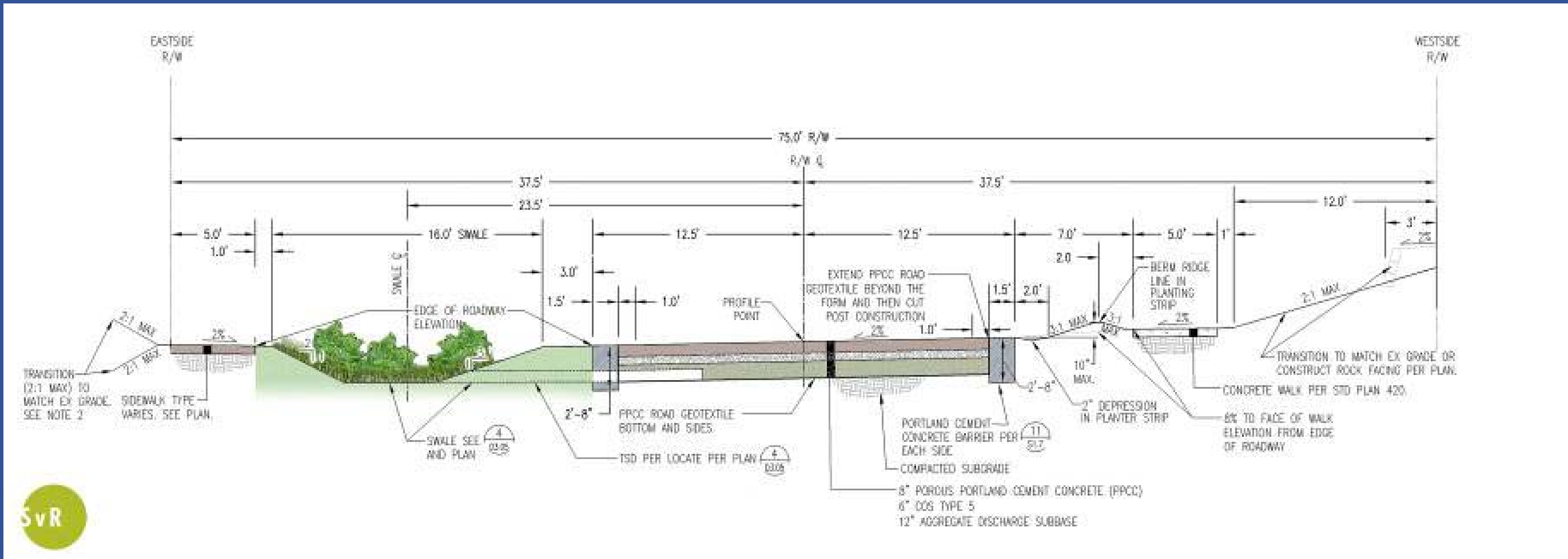
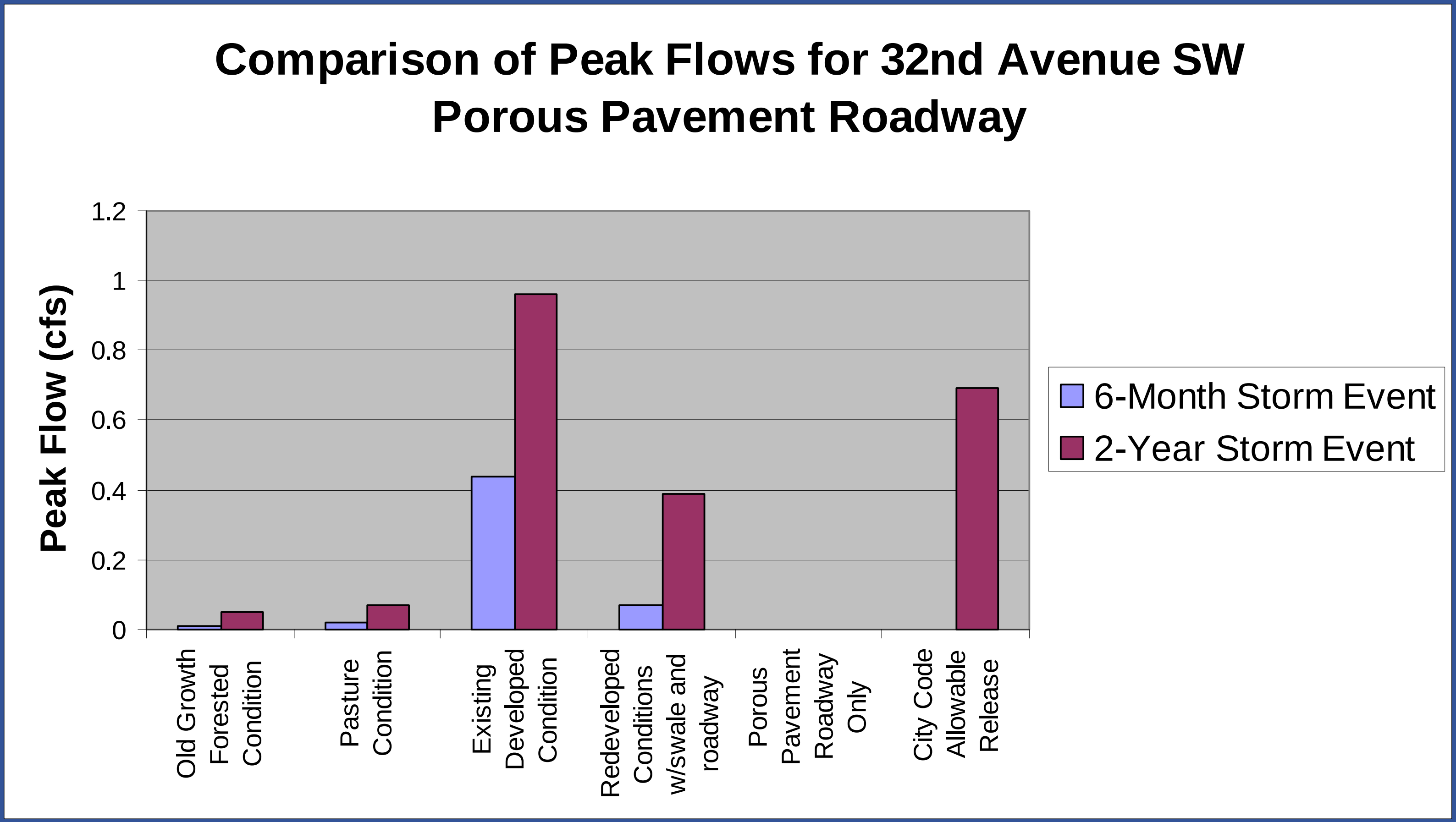
Example: Cross-Section for 32nd Ave SW



- Sloped Subgrade with Roadway Longitudinal Slope to Minimize Amount of Excavation
- Impermeable Check Dams across Roadway for Every One-Foot Drop in Elevation/Gravel Storage
- Gravel Storage Subbase Set above other Underground Utilities
- Back-Up System (CB and Swale) for Overflow during Large Storms
- Depression on Upslope Side for Collection of Fines
- Coordination with other New Underground Utilities

Example: Modeling Results for 32nd Ave SW



- In comparison, with impervious roadway, to meet same goal for developed basin during 6-month storm event approx. 533 ft of 36" detention pipe would have been required plus water quality treatment.

Construction of 32nd Ave SW

Before

Side Barriers

Installing Dams for Cells

Fabric at Subgrade

Gravel Storage Subbase

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Example of Placement of Porous Cement Concrete for Roadway – 32nd Ave SW

Moisten Subbase, Place Mix & Strikeoff

Cut in joints

Roller for compaction

Protect & cover

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Example: Seattle's First Public Porous Pavement Street
Redeveloped Conditions of 32nd Avenue SW

- Designed 2003-04
  Constructed 2005
- Drainage Basin 4.6 ac (Road and Housing)
- 25' Wide Road with Sidewalks on both Sides and No Curbs
- Westside Landscape Treatment to Encourage On-Street Parking
- New Utilities
- 30% Impervious
- 60% Pervious
- 10% Porous Paving

Resources (1 of 2)

- American Concrete Institute 522R-06 on Pervious Concrete May 2006 http://www.aci-int.org/PUBS/newpubs/522.htm
- National Ready Mixed Concrete Association Pervious Concrete Publications www.nrmca.org
- "Freeze Thaw Resistance of Pervious Concrete," National Ready Mixed Concrete Association, May 2004. www.nrmca.org
- "Pervious Concrete Contractor Certification," National Ready Mixed Concrete Association, August 2005. www.nrmca.org
- City of Seattle Department of Planning and Development Client Assistance Memo #515. http://www.ci.seattle.wa.us/dclu/Publications/cam/CAM515.pdf
- LID Technical Guidance Manual for Puget Sound, http://www.psat.wa.gov/Publications/LID_tech_manual05/lid_index.htm
- Lower Columbia River Field Guide to Water Quality Friendly Development http://www.lcrep.org/fieldguide/examples/permeablepavers.htm
- City of Olympia www.olympiawa.gov/cityutilities/stormwater/scienceandinnovations/porouspavement.htm
- Jim Powell from Northwest Chapter from American Concrete Pavement Association, 360-956-7080.
- Local Suppliers: Greg McKinnon at Stoneway provided consultation for High Point, 425-226-1000. Glacier Northwest, 206-764-3000, www.glaciernw.com.
- "Porous Pavements," by Bruce K. Ferguson, Taylor & Francis Group, 2005.
- Sample specifications from Florida, Tennessee and Georgia Concrete and Products Associations
- Andrew Marks from Puget Sound Concrete Specifications Council, andrew.marks@comcast.net
- Bruce Chattin from Washington Aggregates and Concrete Association, http://www.washingtonconcrete.org

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Resources (2 of 2)

- "Pervious Concrete Pavement" by Paul D. Tennis, Michael L. Leming and David J. Akers and Portland Cement Association and National Ready Mixed Concrete Association, 2004.
- "Villanova Urban Stormwater Partnership: Porous Concrete" By Robert Traver, Andrea Welker, Clay Emerson, Michael Kwiatkowski, Tyler Ladd, and Leo Kob in Stormwater magazine July/August 2004, pages 30-45.
- Charger Enterprises, http://www.chargerconcrete.com/SPECIFICATION.pdf
- Brett Kesterson from City of Portland
- "NC State University Permeable Pavement Research: Water Quality, Water Quantity, and Clogging," Eban Z. Bean, EL, PhD Candidate and William F. Hunt, PhD, PE, NWQEP Notes, North Carolina State University, Number 119, November 2005.
- "Long-Term Stormwater Quantity and Quality Performance of Permeable Pavement Systems," by Benjamin O. Brattebo and Derek B. Booth, July 1, 2003, Center for Water and Watershed Studies, Department of Civil and Environmental Engineering, University of Washington at http://depts.washington.edu/cwws/Research/Reports/permeableparking.pdf
- Pervious pavement in cold climates: http://www.perviouspavement.org/asphalt%20vs.concrete.htm
- SvR Design Company www.svrdesign.com

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Industry Trends for Porous Cement Concrete Pavement

- Industry is developing Standard Testing Specifications.
- Equipment is being developed to make it more automated for placement and installation.
- NRMCA Certification for Technicians and Installers
- Mix Design - Smaller aggregate for walkways as opposed to roads?
- Costs expected to go down as Quantity & Experience goes up
- Standard Specifications for public works are being developed by Cities & Counties for implementation.

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Other Examples

Photo courtesy of www.invisiblestructures.com

Bricks inside the Grasspave2 system delineate spaces for the parking lot

Salty's on Alki – Overflow Parking

With open celled concrete pavers

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Portland's Porous Portland Cement Concrete Roadways

- Constructed in Fall 2005
- N. Gay Avenue
- 10" Porous Concrete over 6" Subbase
- Full Street Section w/porous cement concrete (PPCC)
- One Street with PPCC in parking lanes only
- Reused existing curb and drain collection structures for emergency overflow