Permeable Pavement Design, Elements and Case Studies

David K. Hein, P.Eng., M.ASCE

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David K. Hein, P.E.

- **Principal Engineer, Applied Research Associates, Inc.**
- **Over 35 years of experience in the design, evaluation and management of pavements**
- **Responsible for transportation asset management practice**
- **Extensively involved with ASCE**
  - T&DI Board of Governors, Past President, 2018
  - Chair of the Interlocking Concrete Pavement Committee
  - Chair of the Permeable Pavement Committee
  - Chair of the large element paving slab standards committee (new)
  - Teaching and training through pavement related webinars

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The Problem - Increased Flood Flows

Urban Area Flooding

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The Problem - Massachusetts

Infrastructure Damage

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The Problem - Water Quality

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Permeable Pavements – A Green Solution

- In percolating soils, increases infiltration
- Reduces stormwater volume/peak flows
- Reduces stormwater pollutant load
- Decreases downstream erosion

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Early Permeable Pavements

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Pervious, Porous & Permeable Pavements

Pavement system designed to permit the infiltration of surface water

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Porous Asphalt

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Porous Asphalt

- **Advantages**
  - Cost
  - Materials & construction experience
- **Disadvantages**
  - Materials susceptible to water damage
  - Usually used for short-term storage only
  - Lower relative strength

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Pervious Concrete

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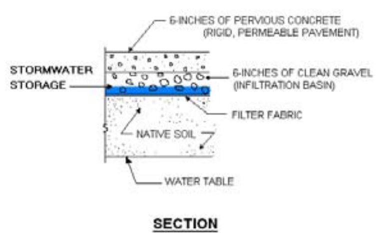
Pervious Concrete

- **Advantages**
  - ➢ Structural strength
  - ➢ Availability of materials
- **Disadvantages**
  - ➢ Slow construction process
  - ➢ Potential material issues
  - ➢ Higher initial cost



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Permeable Interlocking Concrete

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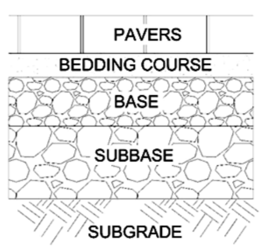
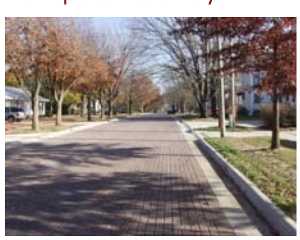
Permeable Interlocking Concrete

- **Advantages**
  - Ease of construction
  - High surface infiltration options
  - Aesthetics
  - Ease of maintenance and repair
- **Disadvantages**
  - Typically higher cost
  - Limited to lower-speed roadways





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Other Permeable Products

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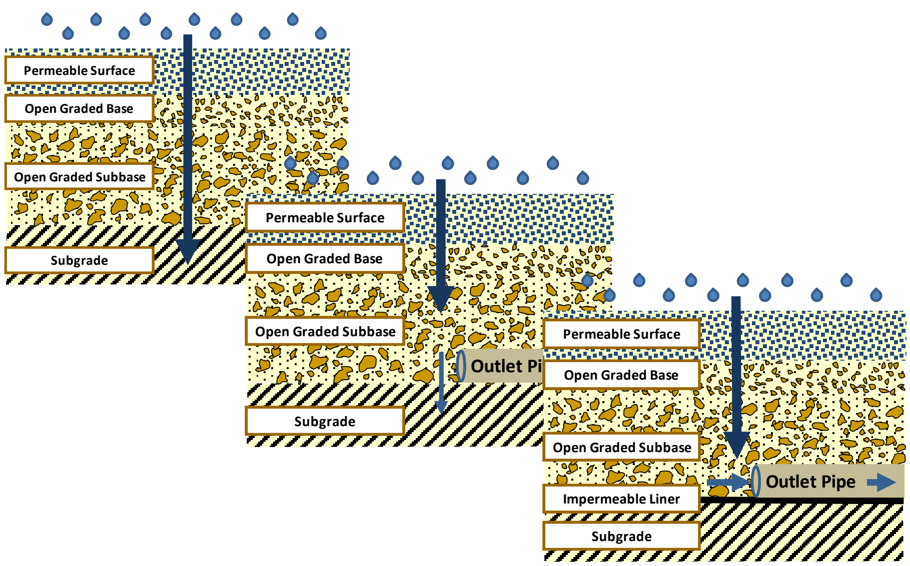
Permeable Pavement Function



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Design Guides

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Variety of Design Software Applications

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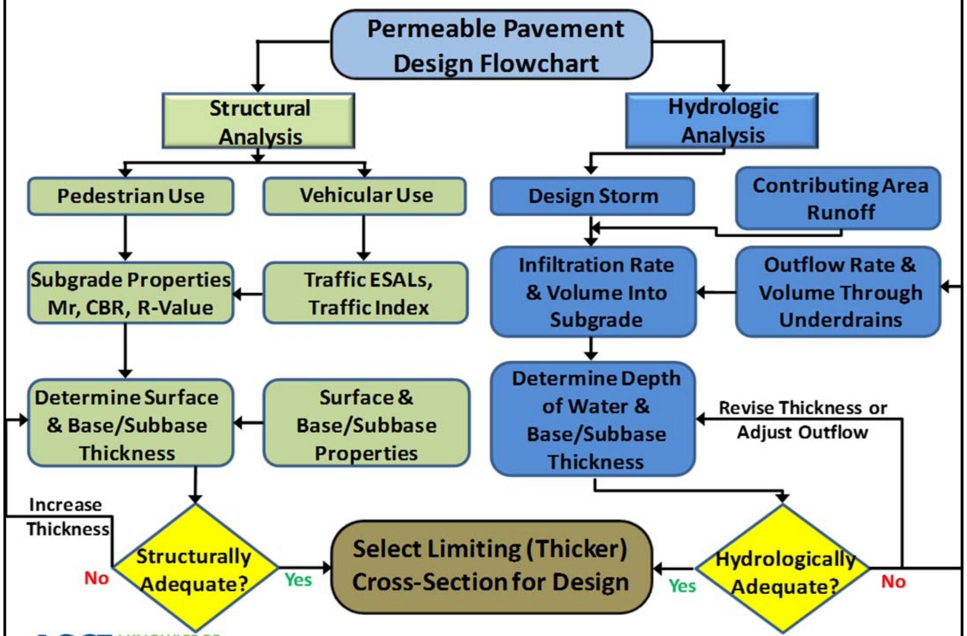

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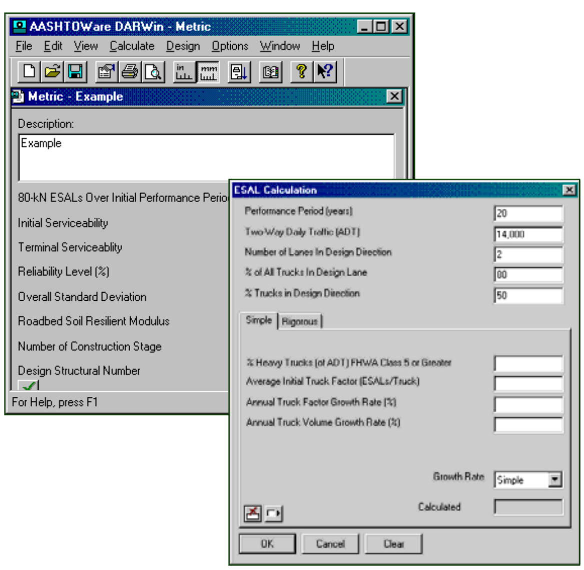
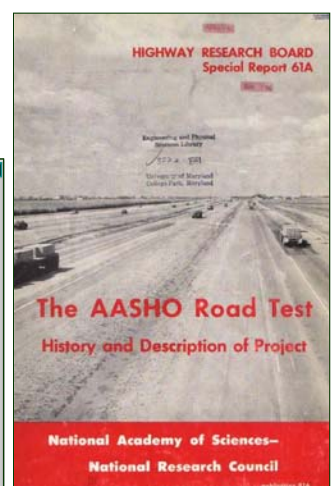
Structural Design - AASHTO





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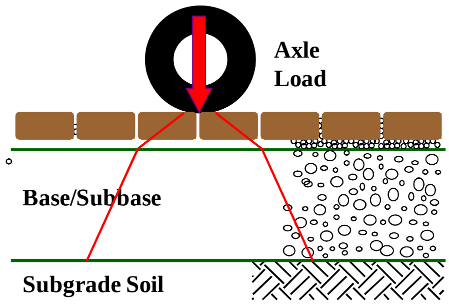
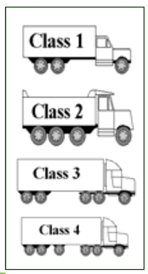
Heavy Vehicle Loading





2- and 3-axle trucks	0.5
4-axle trucks	2.3
5-axle trucks	1.6
6 and + axle trucks	5.5

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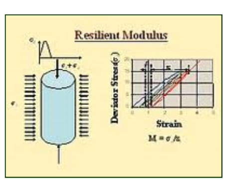
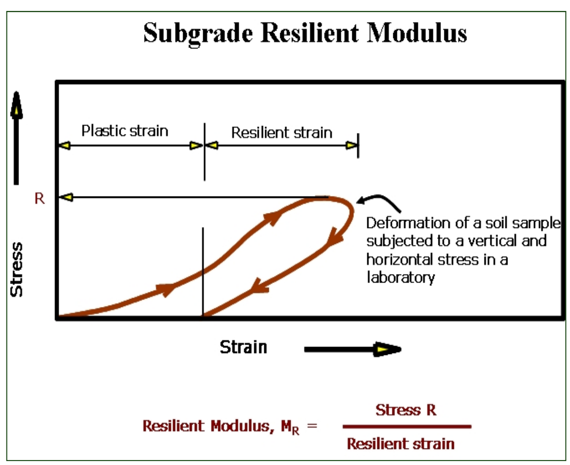
Subgrade Support – Resilient Modulus

- Dynamic stiffness under repeated load
- AASHTO T 294-921
- Permanent Deformation





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Subgrade Infiltration Design Rate

Designation: D 3385 – 03

Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer[1]

This standard is issued under the fixed designation D 3385; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This test method describes a procedure for field measurement of the rate of infiltration of liquid (typically water) into soils using double-ring infiltrometer.

1.2 Soils should be regarded as natural occurring fine or coarse-grained soils or processed materials or mixtures of natural soils and processed materials, or other porous materials, and which are basically insoluble and are in accordance with requirements of 1.5.

1.3 This test method is particularly applicable to relatively uniform fine-grained soils, with an absence of very plastic (fat) clays and gravel-size particles and with moderate to low resistance to ring penetration.

1.4 This test method may be conducted at the ground surface or at given depths in pits, and on bare soil or with vegetation in place, depending on the conditions for which infiltration rates are desired. However, this test method cannot be conducted where the test surface is below the ground water table or perched water table.

1.5 This test method is difficult to use or the resultant data may be unreliable, or both, in very pervious or impervious soils (soils with a hydraulic conductivity greater than about 10^{-2} cm/s or less than about 1×10^{-6} cm/s) or in dry or stiff soils that most likely will fracture when the rings are installed. For soils with hydraulic conductivity less than 1×10^{-6} cm/s refer to Test Method D 5093.

1.6 This test method cannot be used directly to determine the hydraulic conductivity (coefficient of permeability) of the soil (see 5.2).

2. Referenced Documents

2.1 *ASTM Standards:*

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[2]

D 1452 Practice for Soil Investigation and Sampling by Auger Borings[2]

D 2216 Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures[2]

D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)[2]

D 5093 Test Method for Field Measurement of Infiltration Rate Using a Double-Ring Infiltrometer With a Sealed Inner Ring[2]

3. Terminology

3.1 *Definitions:*

3.1.1 *incremental infiltration velocity*—the quantity of flow per unit area over an increment of time. It has the same units as the infiltration rate.

3.1.2 *infiltration*—the downward entry of liquid into the soil.

3.1.3 *infiltration rate*—a selected rate, based on measured incremental infiltration velocities, at which liquid can enter the soil under specified conditions, including the presence of an excess of liquid. It has the dimensions of velocity (that is, $cm^3 cm^{-2} h^{-1} = cm\ h^{-1}$).

3.1.4 *infiltrometer*—a device for measuring the rate of entry of liquid into a porous body, for example, water into soil.

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Infiltration Test Apparatus

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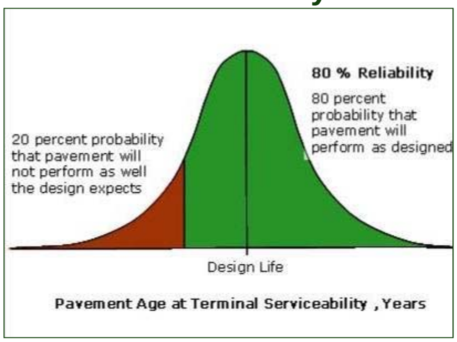
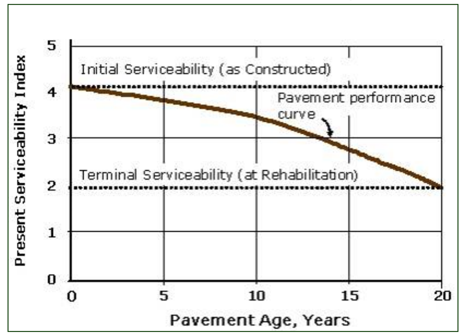
Reliability, Serviceability and Standard Error

Reliability



Serviceability



Standard Error = Typically 0.44 for low-volume roads

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Structural Design Example

- **Structural design for:**
  - 172,000 ESALs
  - Subgrade modulus = 40 MPa (5,800 psi)
  - Initial serviceability = 4.1
  - Terminal serviceability = 2.2
  - Reliability = 70 percent
  - Standard error = 0.44
- **Calculated required structural number from the AASHTO design equation = 63 mm (2.5 in)**

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Thickness Required

Layer	Required Layer Thickness		Structural Layer Coefficient		Structural Equivalency Number
Paving	130 mm	x	0.30	=	39 mm
Base	100 mm	x	0.06	=	6 mm
Subbase	300 mm	x	0.06	=	18 mm
Total (SN)					63 mm
Paving	5 1/8 in	x	0.30	=	1.54 in
Base	4 in	x	0.06	=	0.25 in
Subbase	12 in	x	0.06	=	0.72 in
Total (SN)					**2.5 in**

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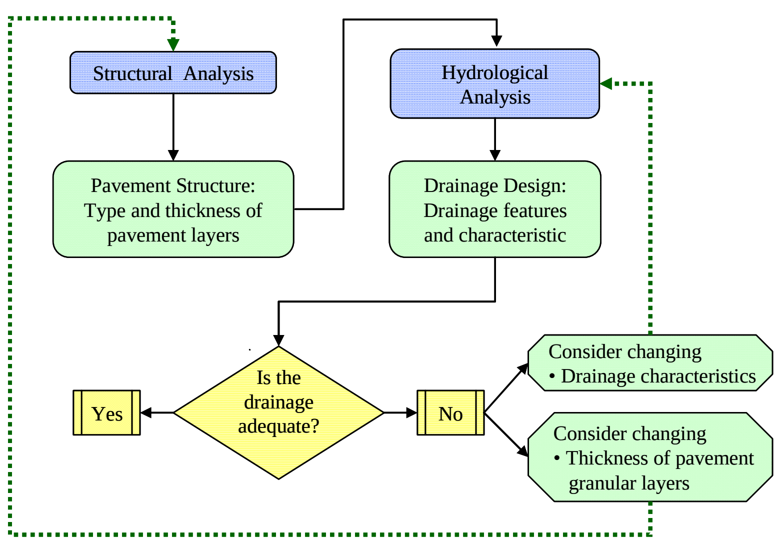
Tools for Hydrologic and Structural Design



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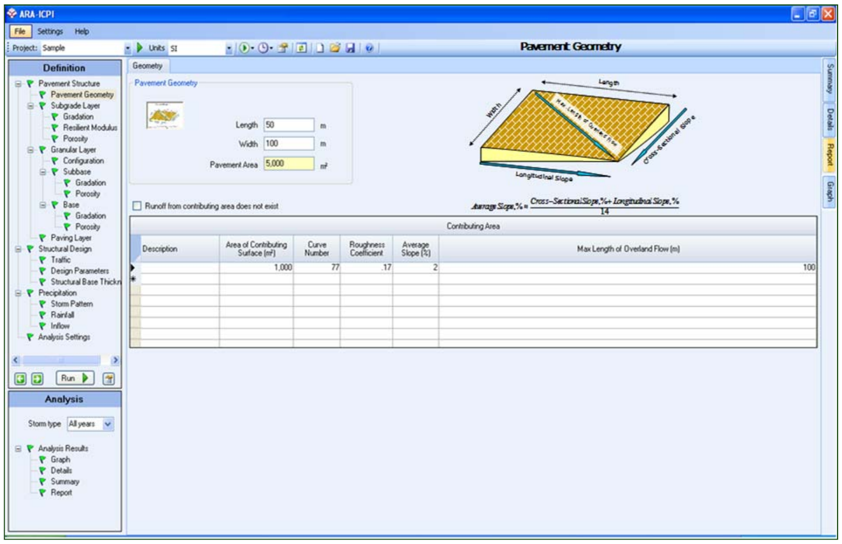
Define the Pavement and Surrounding Area



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Site Design

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Site Design

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Sources of Water – Contributing Area

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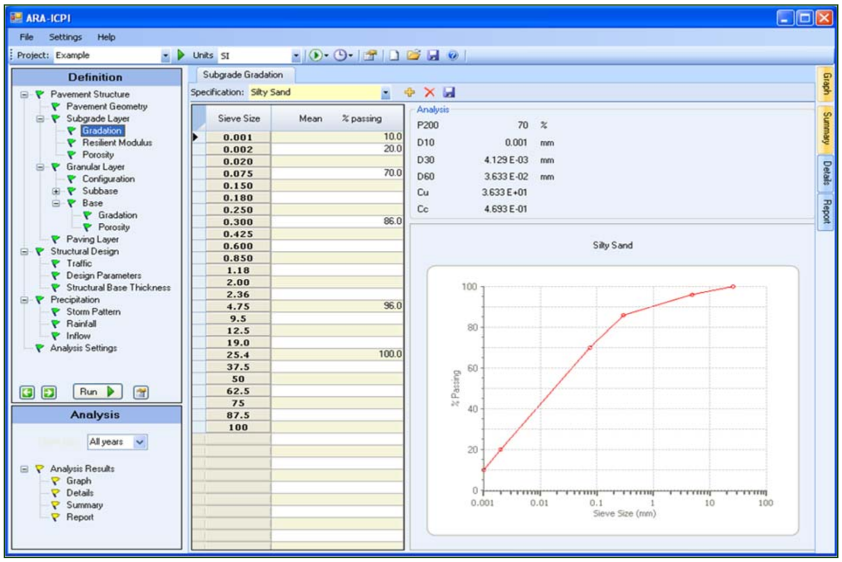
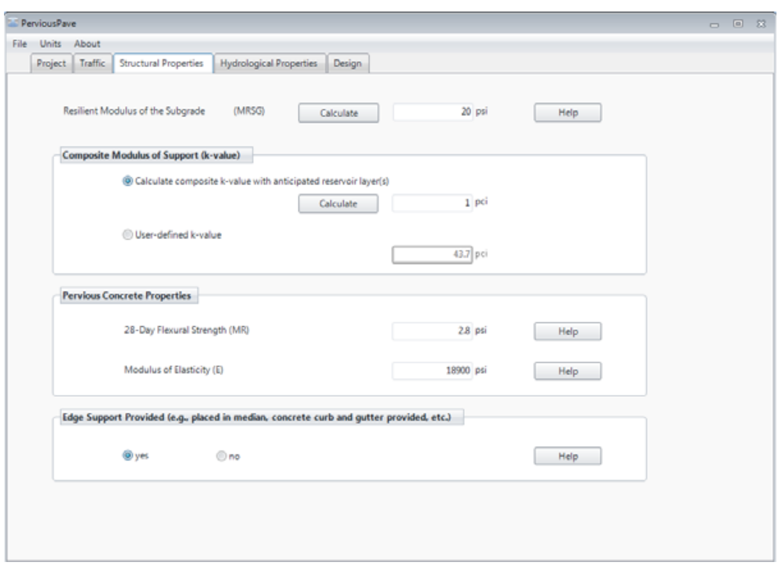
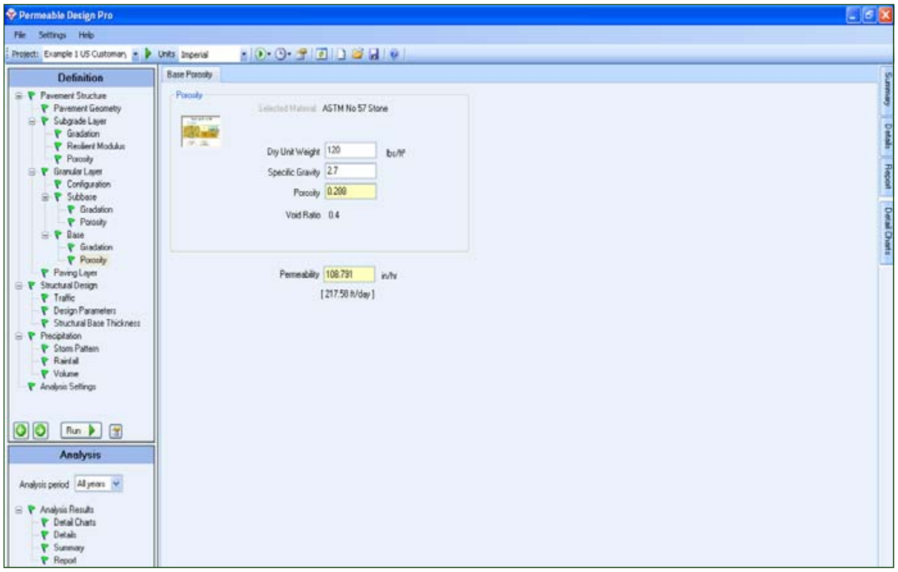
Define Pavement Material Properties



Material Properties – Pervious Pave



Porosity and Permeability



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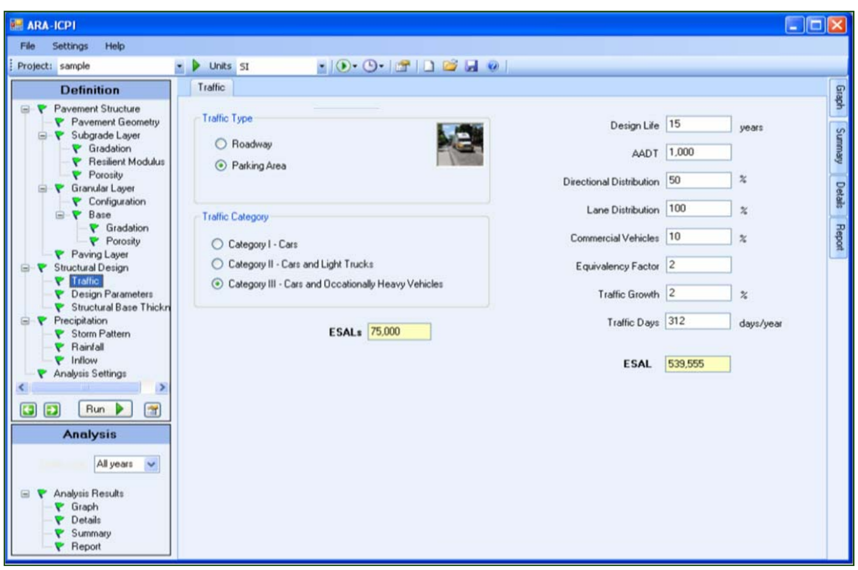
Traffic Analysis for Structural Design



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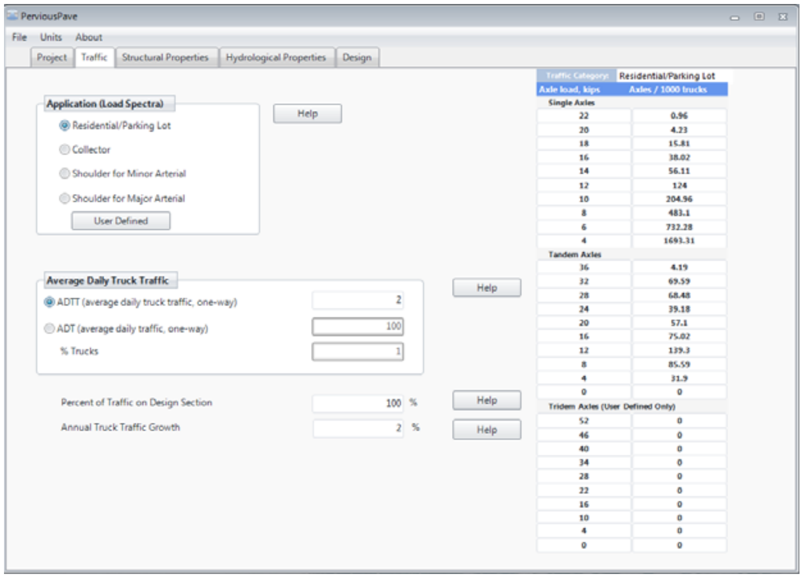
Traffic Analysis – Pervious Pave



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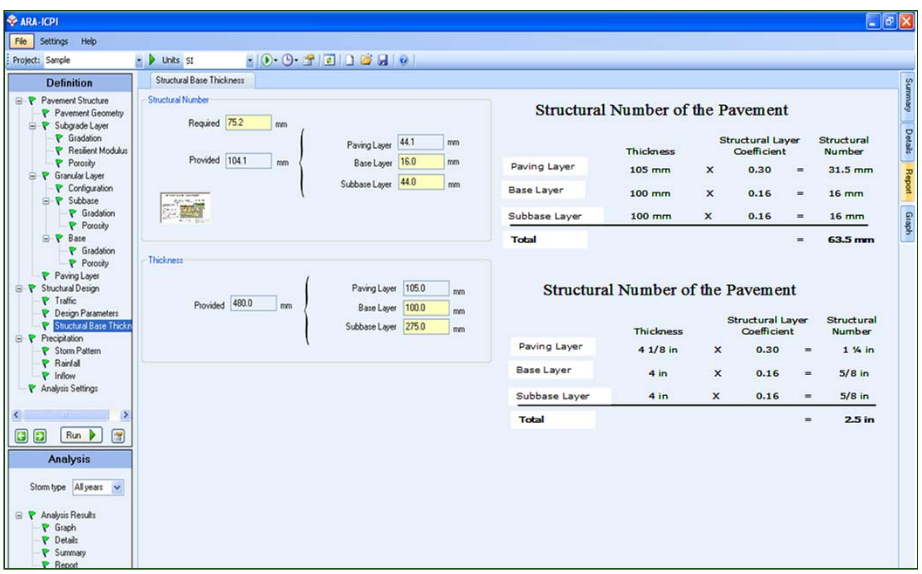
AASHTO Structural Design Analysis



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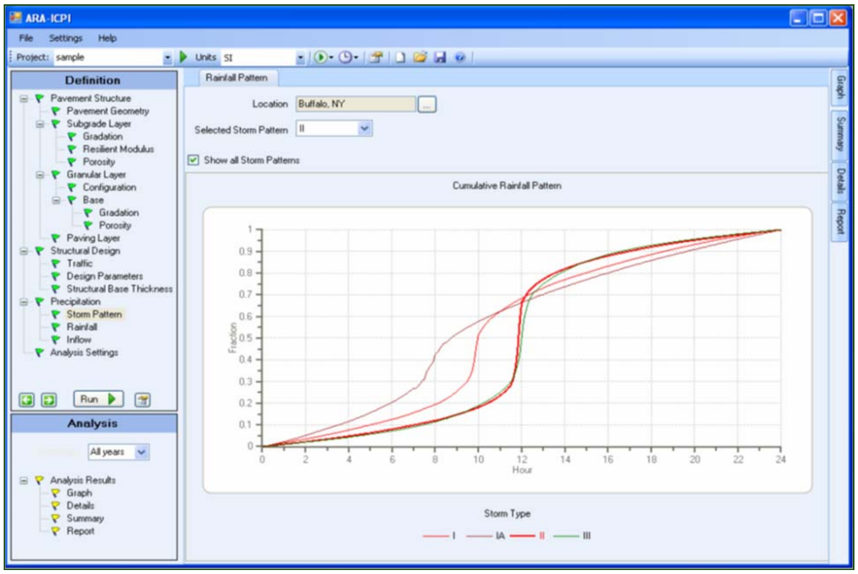
Hydrologic Conditions and Design Storms



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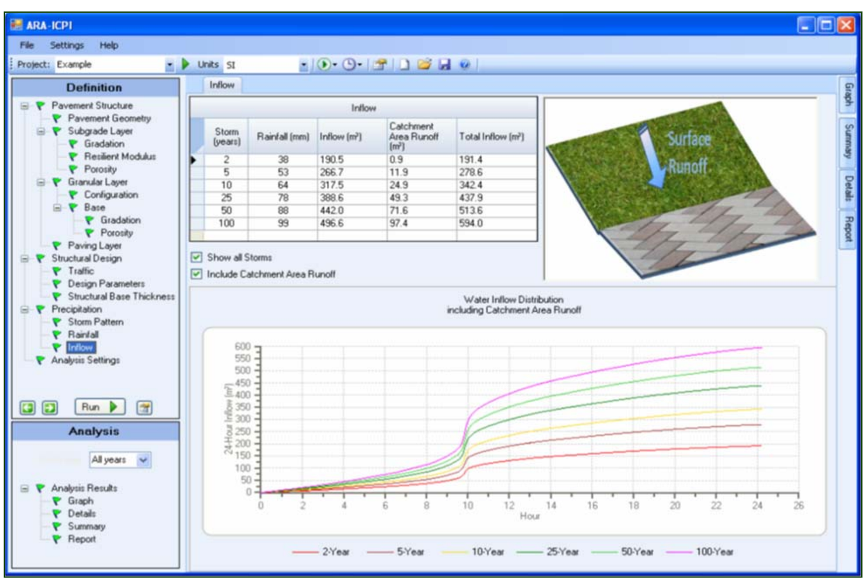
Calculate Total Water In-Flow



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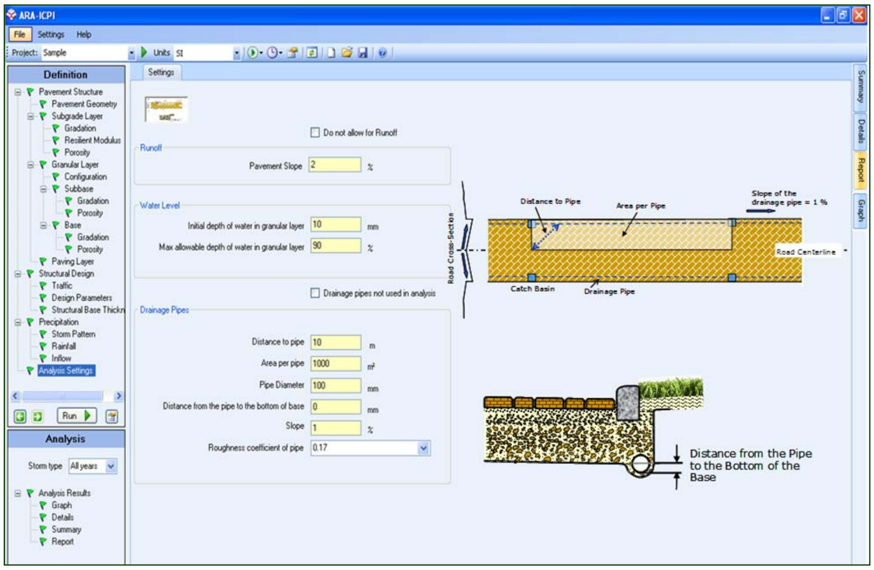
Select Drainage Parameters and Conditions



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Results

Layer Information

Paving Layer	**Concrete Pavers + ASTM No 8 Stone**	
	Structural Coefficient	0.3
	Structural Number	1.54 in
	Thickness	5.125 in
Base Material	**ASTM No 57 Stone**	
	Structural Coefficient	0.09
	Structural Number	0.2 in
	Thickness	4.0 in
	Porosity	0.347
	Void Ratio	0.53
	Permeability	2,720 in/hr
Subbase Material	**ASTM No 2 Stone**	
	Structural Coefficient	0.06
	Structural Number	0.66 in
	Thickness	11.0 in
	Porosity	0.318
	Void Ratio	0.47
	Permeability	31,051 in/hr
Subgrade Material		
	Subgrade Strength	7,200 psi
	Porosity	0.353
	Void Ratio	0.55
	Permeability	0 in/hr

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Results

Structural Design Information

Average Annual Daily Traffic	
Design ESALs	75,000
Design Structural Number	2.13
Pavement Structural Number	2.4
Structurally Adequate	Yes

Hydrological Design Information

Rainfall Location	Midland, TX
Storm Type	II

Storm Return Period (Years)	24-hour Rainfall Intensity in	Satisfies Infiltration Capacity	Satisfies Storage Goal	Satisfies Storage Capacity
2	2.6	Yes	Yes	Yes
5	3.7	Yes	Yes	Yes
10	4.5	No	Yes	Yes
25	5.6	No	Yes	Yes
50	6.4	No	No	Yes
100	7.2	No	No	No

Storage goal represents 85 percent of maximum water storage capacity

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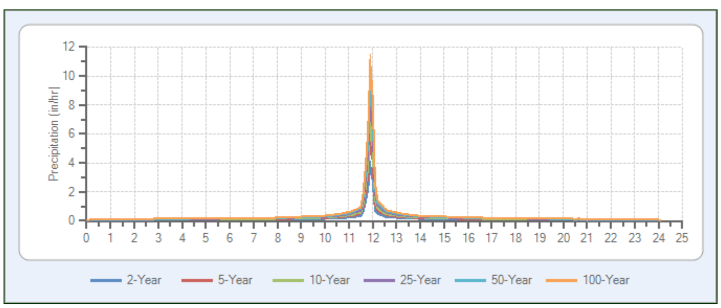

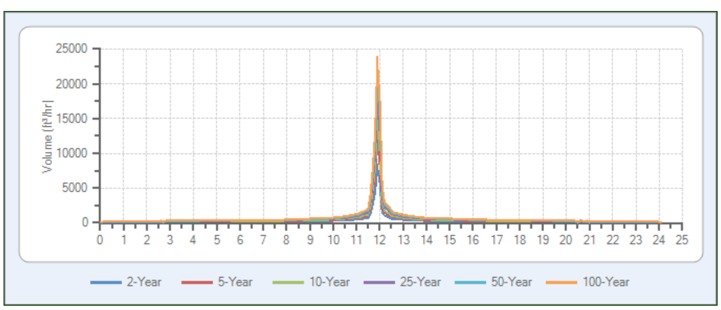

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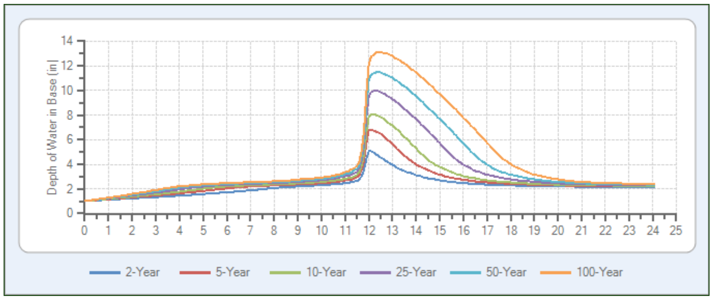
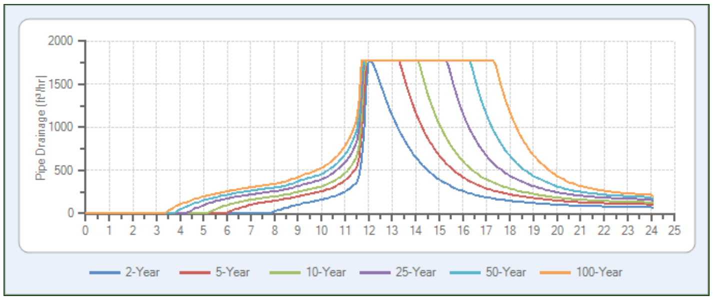
Results





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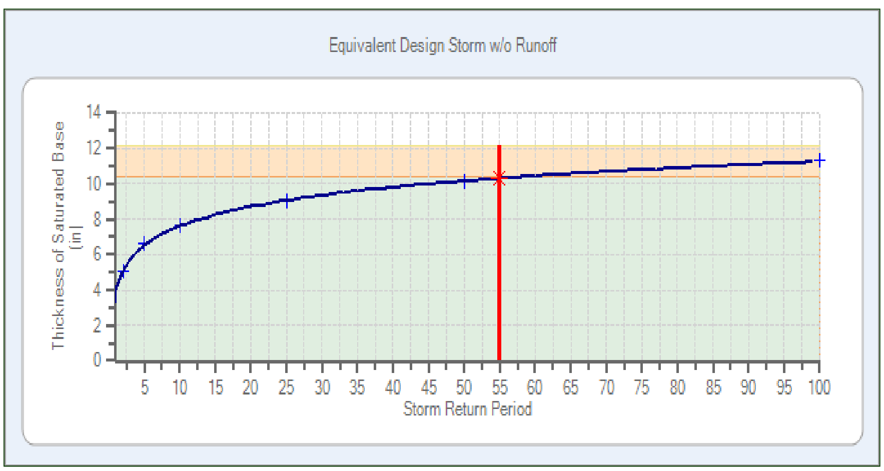
Results



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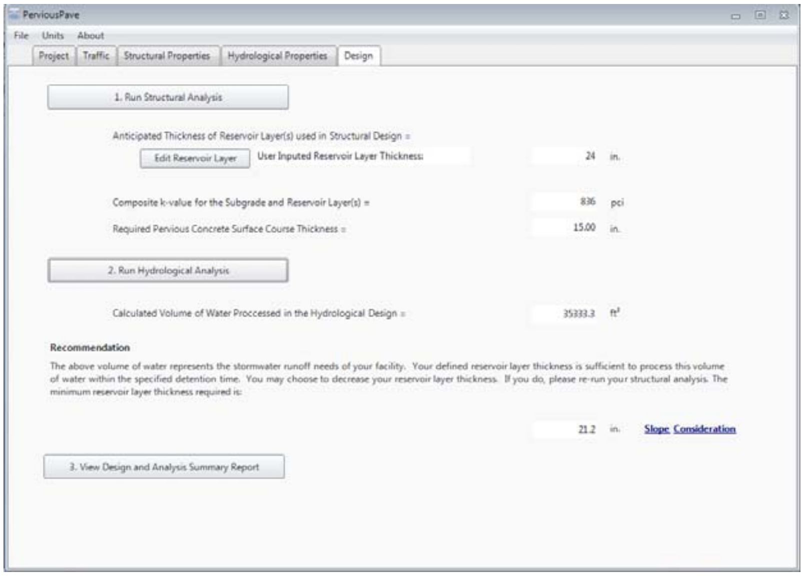
Results – Pervious Pave



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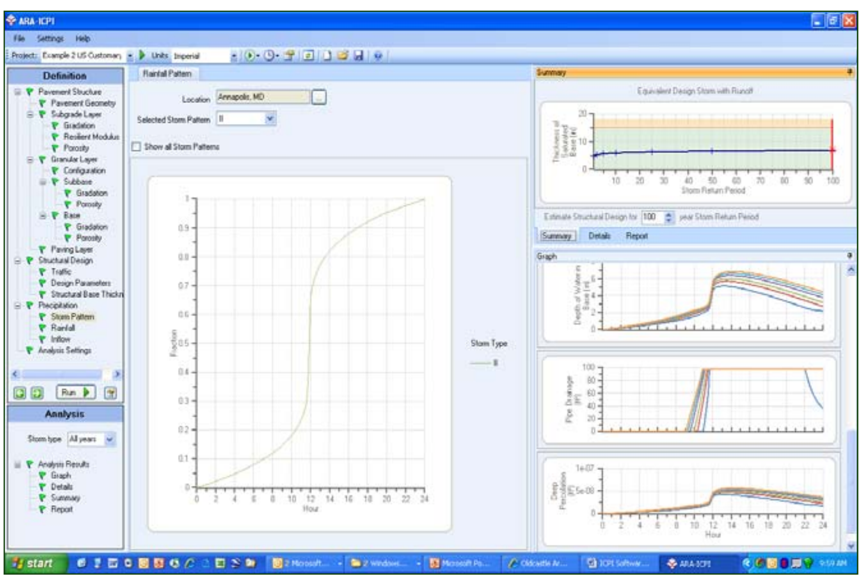
Repeat Analysis to Fine Tune the Design



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Evaluate Site Suitability
Will It Really Work??

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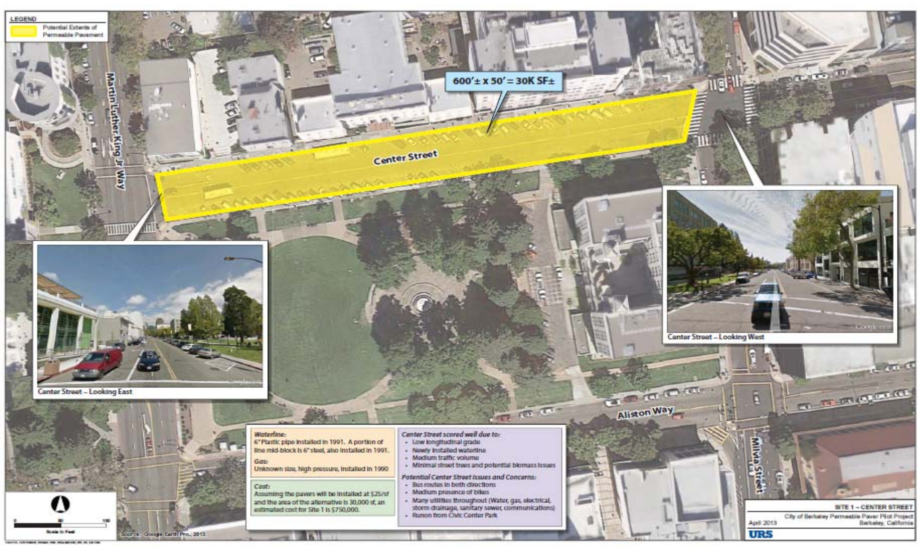
Evaluate Site Suitability
Will It Really Work??



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Construction

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Porous Asphalt Installation

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Pervious Concrete Installation

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Pervious Concrete Installation

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Pervious Concrete

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Permeability Improvements

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Larger Scale Maintenance

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Joint Filler Replacement

- Replenish jointing material 6 months after construction and yearly as needed

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Utility Restoration Guidelines

- Keep all materials clean and free of sediment and debris
- Minimize excess debris from construction activities and equipment entering the permeable surface
- Store all materials away from the permeable surface, otherwise separate materials from the permeable surface with a protective barrier

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Utility Restoration Guidelines

- Cuts located parallel and close to the wheel path should be extended to include the wheel path
- Cuts located within 3 ft of a curb or construction joint, should include the removal of the adjacent road base to the edge of the curb or construction joint

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Winter Maintenance

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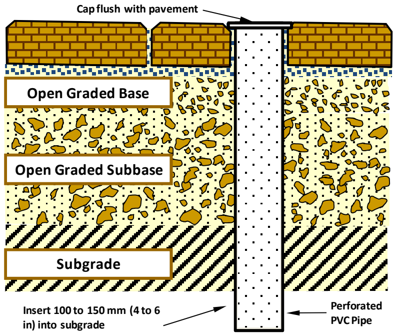
Subsurface Inspection Monitoring Well



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STOP
Burnaby British Columbia

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Williamsburg, Virginia

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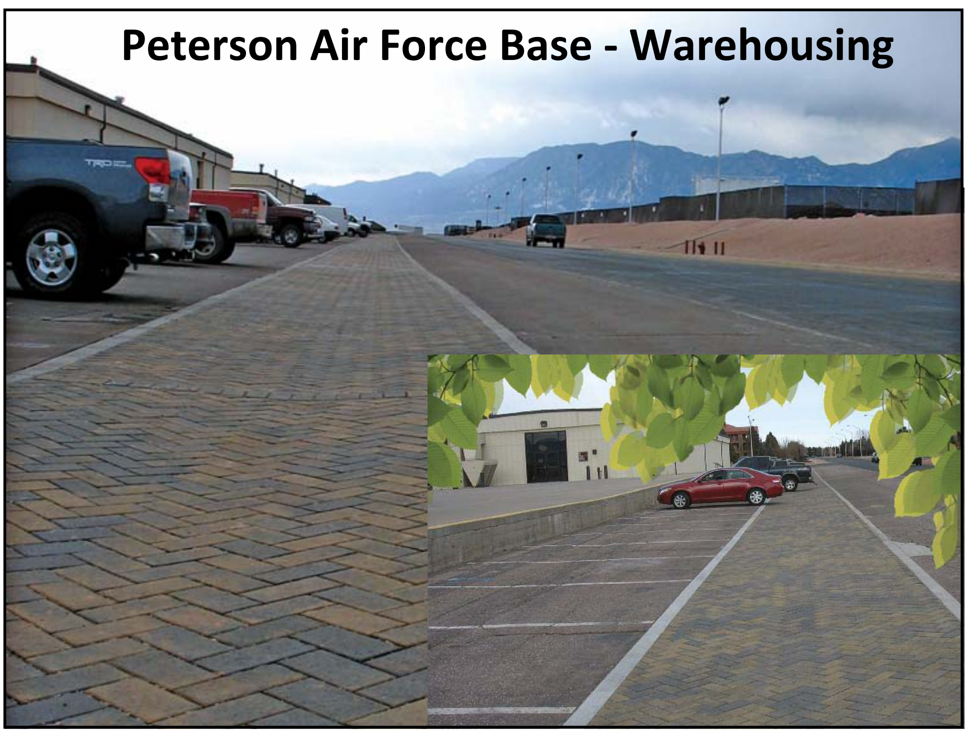

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Pringle Creek Subdivision, Salem Oregon

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Subdivision Roads – Portland, Oregon

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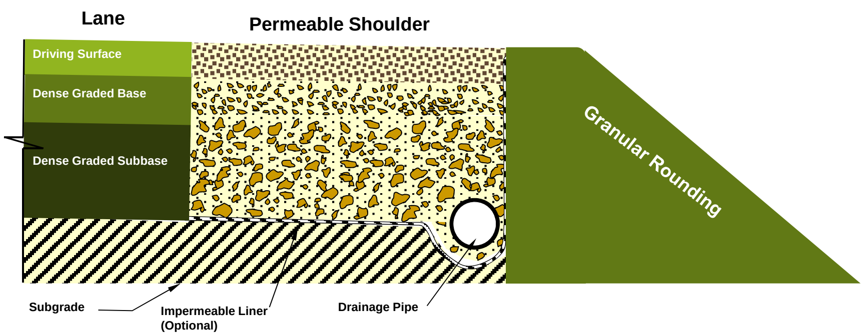
Permeable Roadway Shoulders



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Conclusions

- Permeable pavements can be an integral component of low impact design procedures
- Ability to infiltrate and detain stormwater
- Design features permit reduction in water borne chemicals and contaminants
- Contributes substantially to “green” sustainable design
- Not for use everywhere
- Requires careful consideration of vehicular and contaminant loading

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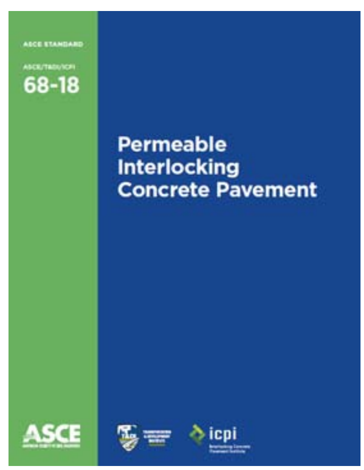
ASCE Resources



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