

# Permeable Pavement Design, Elements and Case Studies

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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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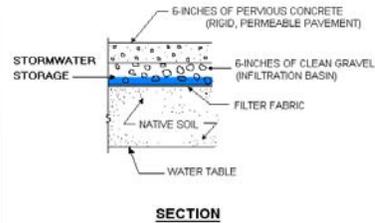
## Pervious Concrete

- **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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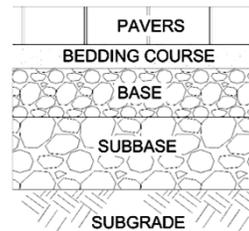
## Permeable Interlocking Concrete

### ▪ Advantages

- Ease of construction
- High surface infiltration options
- Aesthetics
- Ease of maintenance and repair

### ▪ Disadvantages

- Typically higher cost
- Limited to lower-speed roadways



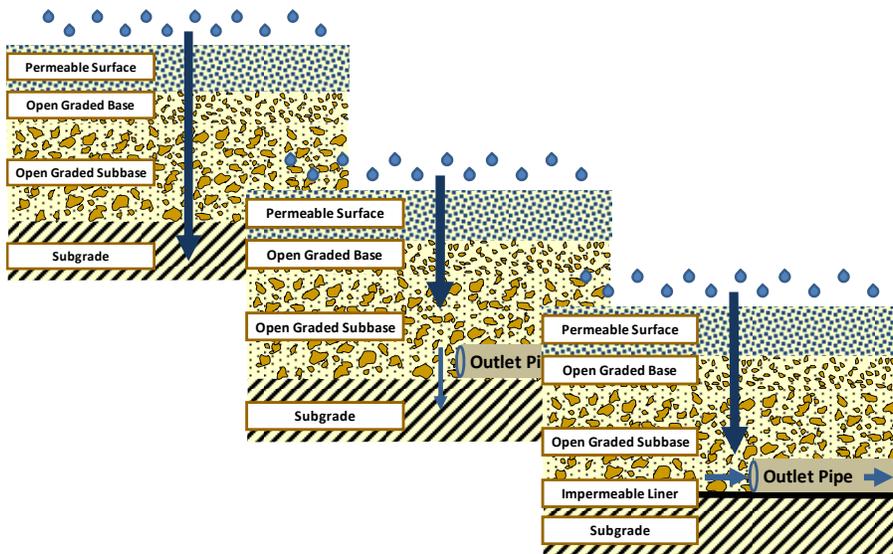
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## Other Permeable Products



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## Permeable Pavement Function



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## Design Guides



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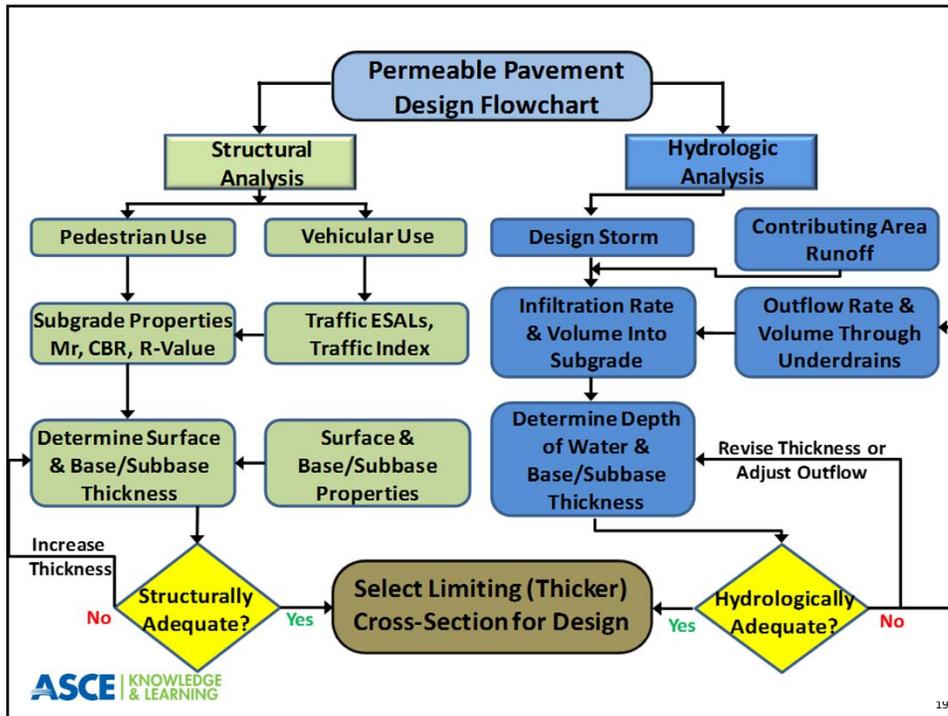
## Variety of Design Software Applications



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## Structural Design - AASHTO

The screenshot shows the "Metric - Example" window with a list of input parameters on the left and the "ESAL Calculation" dialog box open. The dialog box contains the following fields:

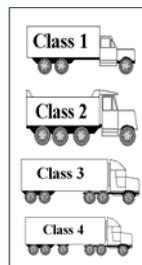
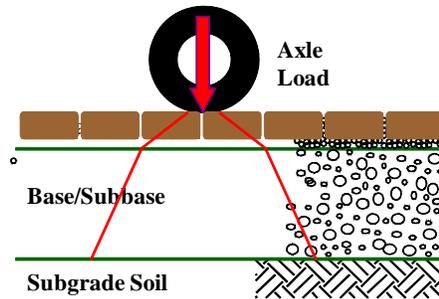
- Performance Period (years): 20
- Two-Way Daily Traffic (ADT): 14,000
- Number of Lanes in Design Direction: 2
- % of All Trucks in Design Lane: 60
- % Trucks in Design Direction: 50
- Simple | rigorous (radio buttons)
- % Heavy Trucks (of ADT) FHWA Class 5 or Greater: [ ]
- Average Initial Truck Factor (ESALs/Truck): [ ]
- Annual Truck Factor Growth Rate (%): [ ]
- Annual Truck Volume Growth Rate (%): [ ]
- Growth Rate: Simple (dropdown)
- Calculated: [ ]

The cover of "Highway Research Board Special Report 61A" features a photograph of a long, straight road stretching into the distance. The title "The AASHTO Road Test" is prominently displayed in red, with the subtitle "History and Description of Project" below it. The report is published by the National Academy of Sciences - National Research Council.

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## Heavy Vehicle Loading

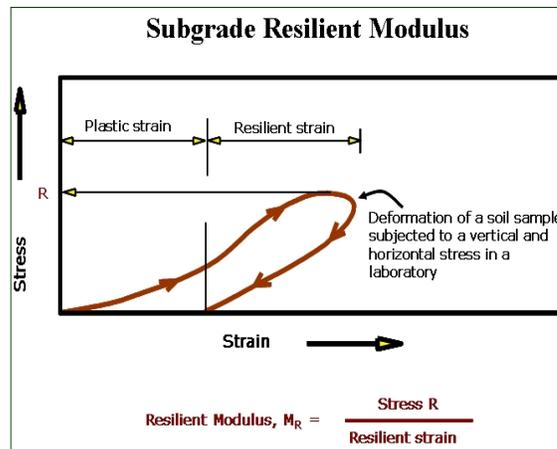
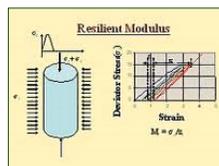


Class 1	2- and 3-axle trucks	0.5
Class 2	4-axle trucks	2.3
Class 3	5-axle trucks	1.6
Class 4	6 and + axle trucks	5.5

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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<sup>1</sup>

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 approval. A superscripted epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or approval.

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 infiltrometers.

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  $1 \times 10^{-6}$  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  $1 \times 10^{-6}$  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 3.2).

### 2. Referenced Documents

- 2.1 *ASTM Standards:*
- D 653 Terminology Relating to Soil, Rock, and Contained Fluids<sup>2</sup>
  - D 1452 Practice for Soil Investigation and Sampling by Auger Borings<sup>2</sup>
  - D 2216 Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures<sup>2</sup>
  - D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)<sup>2</sup>
  - D 5093 Test Method for Field Measurement of Infiltration Rate Using a Double-Ring Infiltrometer With a Sealed Inner Ring<sup>2</sup>

### 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,  $\text{cm}^3 \text{cm}^{-2} \text{h}^{-1} = \text{cm h}^{-1}$ ).

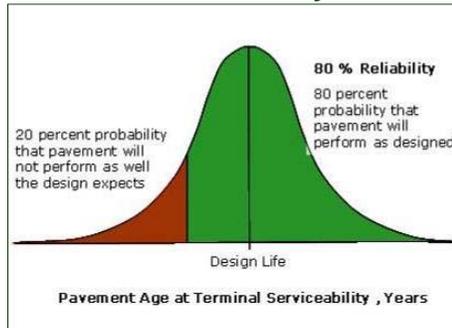
3.1.4 *infiltrometer*—a device for measuring the rate of entry of liquid into a porous body, for example, water into soil.

# Infiltration Test Apparatus



## 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)**

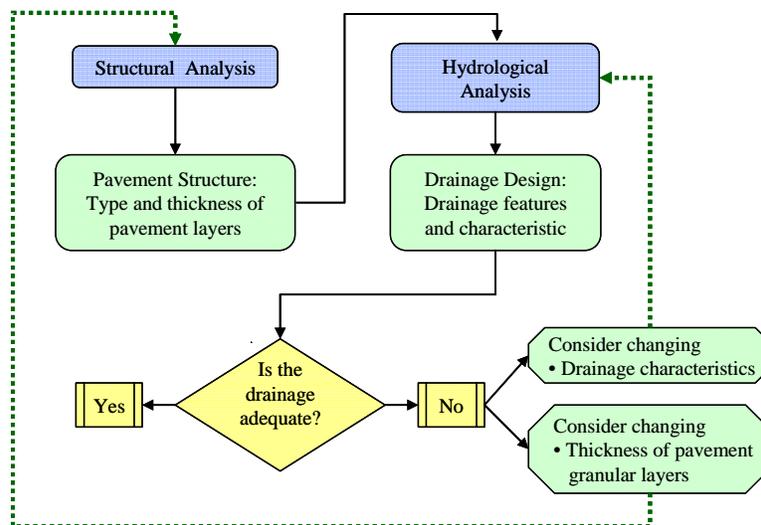
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## Thickness Required

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
<b>Total (SN)</b>					<b>63 mm</b>
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
<b>Total (SN)</b>					<b>2.5 in</b>

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## Tools for Hydrologic and Structural Design



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## Define the Pavement and Surrounding Area

Description	Area of Contributing Surface [m <sup>2</sup> ]	Curve Number	Roughness Coefficient	Average Slope [S]	Max Length of Overland Flow [m]
	1,000	77	17	2	100

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## Site Design

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## Site Design



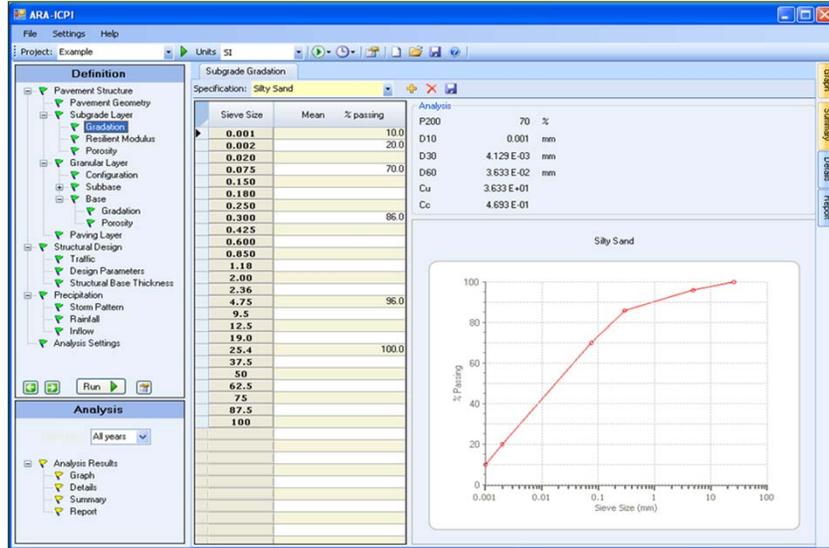
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## Sources of Water – Contributing Area



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## Define Pavement Material Properties



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## Material Properties – Pervious Pave

The screenshot shows the 'PerviousPave' software interface. It has a menu bar (File, Units, About) and a tabbed interface with 'Project', 'Traffic', 'Structural Properties', 'Hydrological Properties', and 'Design' tabs. The 'Design' tab is active, showing several input fields and buttons for material properties.

Resilient Modulus of the Subgrade (MRSD)  psi

Composite Modulus of Support (k-value)

Calculate composite k-value with anticipated reservoir layer(s)   pci

User-defined k-value  pci

Pervious Concrete Properties

28-Day Flexural Strength (MR)  psi

Modulus of Elasticity (E)  psi

Edge Support Provided (e.g., placed in median, concrete curb and gutter provided, etc.)

yes  no

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## Porosity and Permeability

The screenshot shows the 'Permeable Design Pro' software interface. The 'Definition' pane on the left lists various pavement layers, with 'Porosity' selected under the 'Base' layer. The main window displays the 'Base Porosity' settings for 'ASTM No. 57 Stone'. The 'Porosity' value is set to 0.200, and the 'Void Ratio' is 0.4. The resulting 'Permeability' is 108.791 in/hr, which is equivalent to 217.58 h/day. The 'Analysis' pane at the bottom shows the 'Analysis period' set to 'All years'.

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## Traffic Analysis for Structural Design

The screenshot shows the 'ARA-ICPI' software interface. The 'Definition' pane on the left lists various pavement layers, with 'Traffic' selected under the 'Structural Design' layer. The main window displays the 'Traffic' settings. The 'Traffic Type' is set to 'Parking Area'. The 'Traffic Category' is set to 'Category III - Cars and Occasionally Heavy Vehicles'. The 'ESALs' value is 75,000. The 'Design Life' is 15 years, and the 'AADT' is 1,000. The 'Directional Distribution' is 50%, 'Lane Distribution' is 100%, 'Commercial Vehicles' is 10%, 'Equivalency Factor' is 2, 'Traffic Growth' is 2%, and 'Traffic Days' is 312 days/year. The resulting 'ESAL' value is 539,555. The 'Analysis' pane at the bottom shows the 'Analysis period' set to 'All years'.

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# Traffic Analysis – Pervious Pave

The screenshot shows the PerviousPave software interface. On the left, under 'Application (Load Spectra)', 'Residential/Parking Lot' is selected. Under 'Average Daily Truck Traffic', 'ADT (average daily truck traffic, one-way)' is selected with a value of 2. The 'Percent of Traffic on Design Section' is 100% and 'Annual Truck Traffic Growth' is 2%. On the right, there are two tables for traffic analysis.

Traffic Category: Residential/Parking Lot	
Axle load, kips	Axes / 1000 trucks
<b>Single Axles</b>	
32	0.96
20	4.23
18	15.81
16	38.02
14	56.11
12	124
10	204.96
8	483.1
6	712.28
4	1691.11
<b>Tandem Axles</b>	
36	4.19
32	69.59
28	66.48
24	39.18
20	57.1
16	75.02
12	139.3
8	85.59
4	31.9
<b>Tridem Axles (User Defined Only)</b>	
46	0
40	0
34	0
28	0
22	0
16	0
10	0
4	0
0	0

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# AASHTO Structural Design Analysis

The screenshot shows the ARA-ICPI software interface for AASHTO Structural Design Analysis. The 'Definition' pane on the left shows 'Structural Base Thickness' selected. The main window displays the 'Structural Number of the Pavement' analysis results.

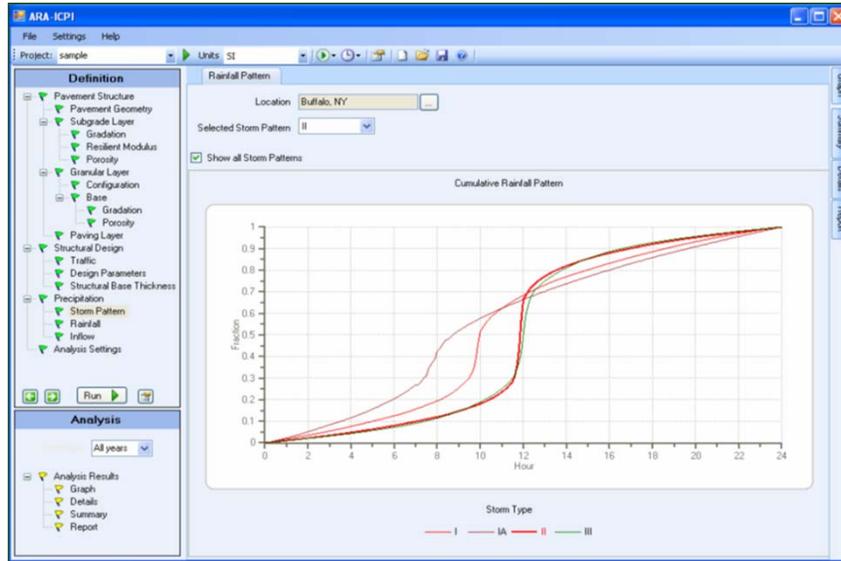
Structural Number of the Pavement			
	Thickness	Structural Layer Coefficient	Structural Number
Paving Layer	105 mm	X 0.30	= 31.5 mm
Base Layer	100 mm	X 0.16	= 16 mm
Subbase Layer	100 mm	X 0.16	= 16 mm
<b>Total</b>			<b>= 63.5 mm</b>

Structural Number of the Pavement			
	Thickness	Structural Layer Coefficient	Structural Number
Paving Layer	4 1/8 in	X 0.30	= 1 1/4 in
Base Layer	4 in	X 0.16	= 5/8 in
Subbase Layer	4 in	X 0.16	= 5/8 in
<b>Total</b>			<b>= 2.5 in</b>

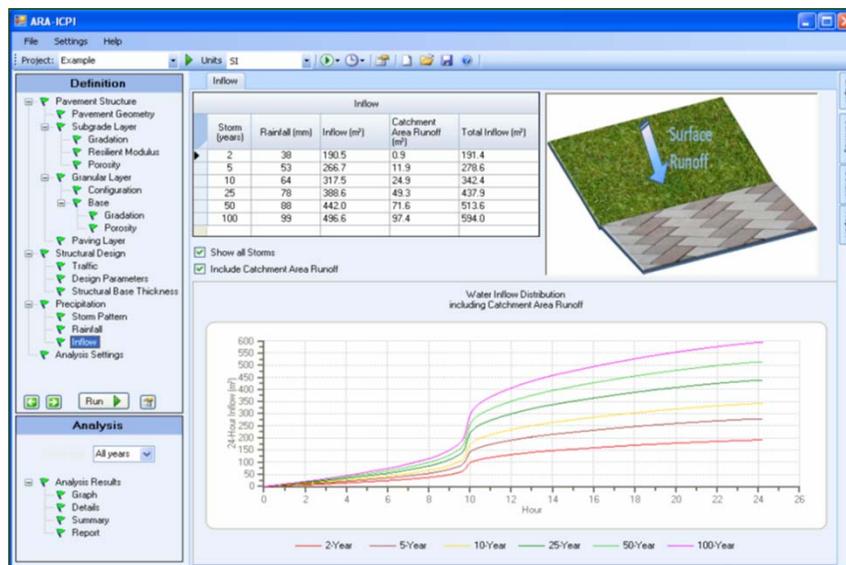
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# Hydrologic Conditions and Design Storms



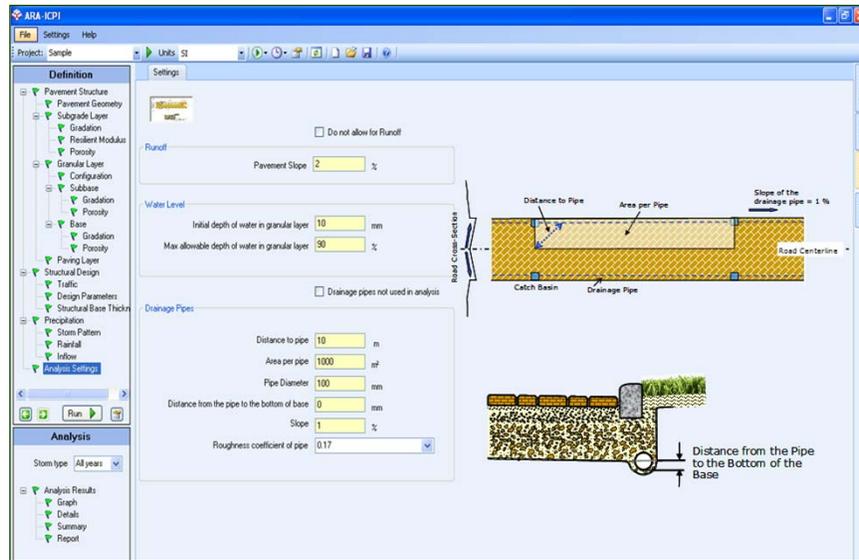
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# Calculate Total Water In-Flow



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## Select Drainage Parameters and Conditions



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## Results

### Layer Information

<b>Paving Layer</b>	<b>Concrete Pavers + ASTM No 8 Stone</b>	
	Structural Coefficient	0.3
	Structural Number	1.54 in
	Thickness	5.125 in
<b>Base Material</b>	<b>ASTM No 57 Stone</b>	
	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
<b>Subbase Material</b>	<b>ASTM No 2 Stone</b>	
	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
<b>Subgrade Material</b>		
	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

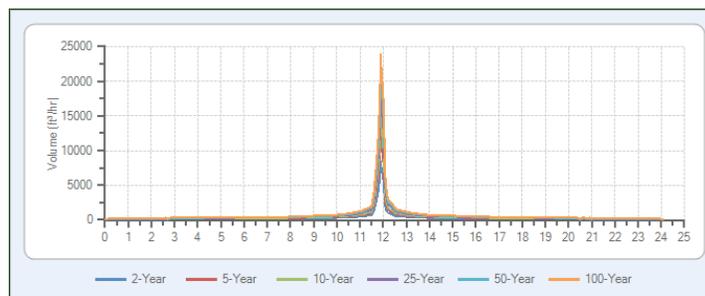
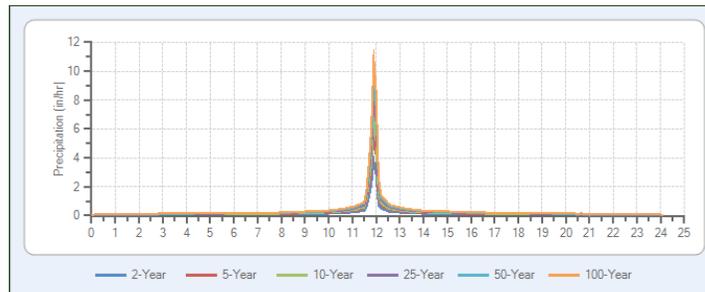
Rainfall Location Midland, TX  
 Storm Type II

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

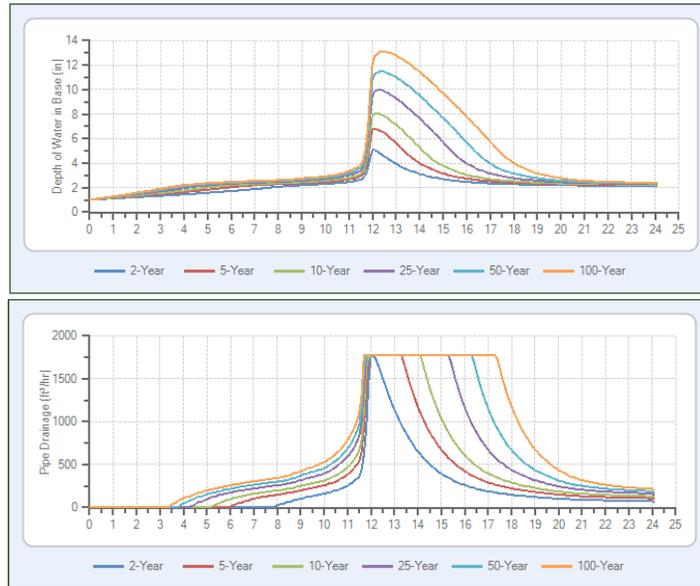
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# Results



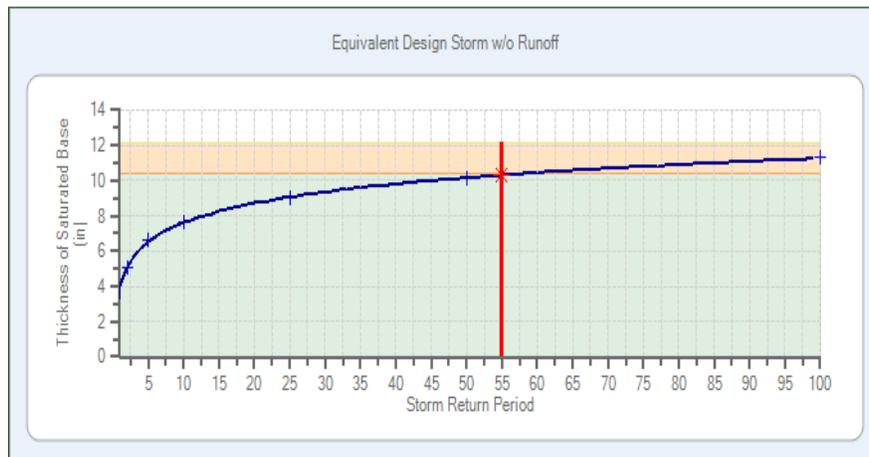
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## Results



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## Results



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## Results – Pervious Pave

The screenshot shows the 'Design' tab of the PerviousPave software. It displays the following results:

- 1. Run Structural Analysis**
  - Anticipated Thickness of Reservoir Layer(s) used in Structural Design = 24 in.
  - Composite k-value for the Subgrade and Reservoir Layer(s) = 836 pci
  - Required Pervious Concrete Surface Course Thickness = 15.00 in.
- 2. Run Hydrological Analysis**
  - Calculated Volume of Water Processed in the Hydrological Design = 25933.3 ft<sup>3</sup>
- Recommendation**

The above volume of water represents the stormwater runoff needs of your facility. Your defined reservoir layer thickness is sufficient to process this volume of water within the specified detention time. You may choose to decrease your reservoir layer thickness. If you do, please re-run your structural analysis. The minimum reservoir layer thickness required is:

  - 21.2 in. [Show Consideration](#)
- 3. View Design and Analysis Summary Report**

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## Repeat Analysis to Fine Tune the Design

The screenshot shows the HRA-ICPI software interface with the following components:

- Definition Panel:** Lists project parameters such as Location (Annapolis, MD), Selected Storm Pattern, and various pavement layers (Subgrade, Drainage, Subbase, Base, Paving, Traffic, etc.).
- Graphs:**
  - Retention Function:** A graph showing the fraction of water retained over a 24-hour period, with a curve rising from 0 to 1.0.
  - Equivalent Design Storm with Runoff:** A graph showing the thickness of the design storm (in inches) over a 100-hour storm duration period.
  - Graph:** A graph showing the depth of water (in feet) over a 24-hour period, with multiple curves representing different design scenarios.
  - Pipe Discharge:** A graph showing the pipe discharge (in cfs) over a 24-hour period, with multiple curves representing different design scenarios.
  - Deep Penetration:** A graph showing the deep penetration (in feet) over a 24-hour period, with multiple curves representing different design scenarios.
- Summary Panel:** Provides a high-level overview of the design, including the estimated structural design for a 100-year storm return period.

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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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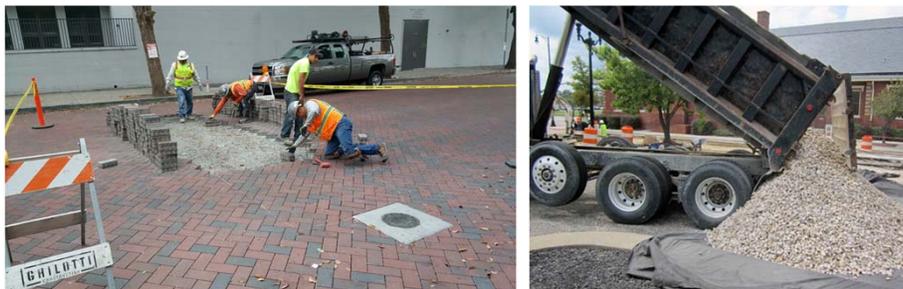
## Joint Filler Replacement

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



## 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



## 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

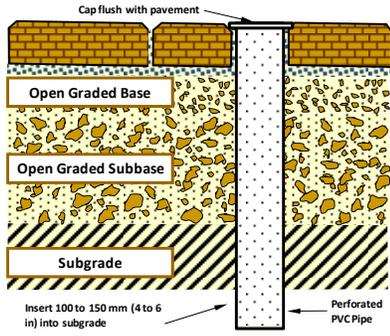


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# Subsurface Inspection Monitoring Well



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**Jenner California**

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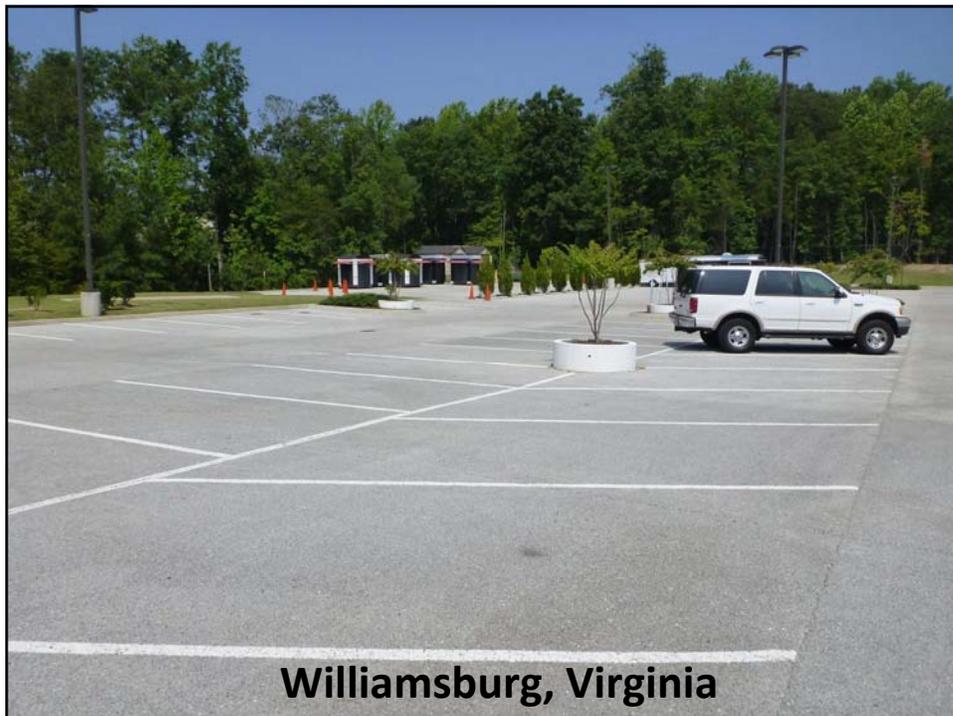
**Permeable Clay Brick Pavement**

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**Burnaby British Columbia**

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**Williamsburg, Virginia**

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**Pringle Creek Subdivision, Salem Oregon**

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**Subdivision Roads – Portland, Oregon**

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**Charles City, Indiana**

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**San Diego County  
Operations Center**

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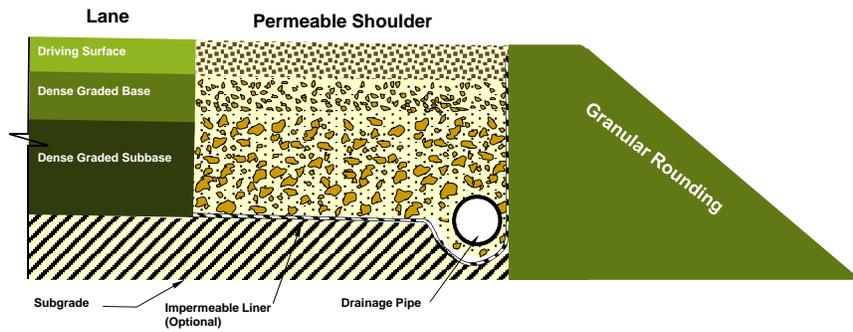


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## Permeable Roadway Shoulders



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Heavy Loads

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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

**Permeable Pavements**  
Recommended Design Guidelines

Prepared by:  
The Permeable Pavements Technical Committee  
Low Impact Development Task-By Committee  
Urban Water Resources Research Council  
Environmental and Water Resources Institute  
ASCE, American Society of Civil Engineers

Edited by:  
Anthony Santolucito, LEED AP  
July 2016, 74  
Over 2,000

ASCE STANDARD  
ASCE/STANDARD  
**68-18**

**Permeable  
Interlocking  
Concrete Pavement**

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