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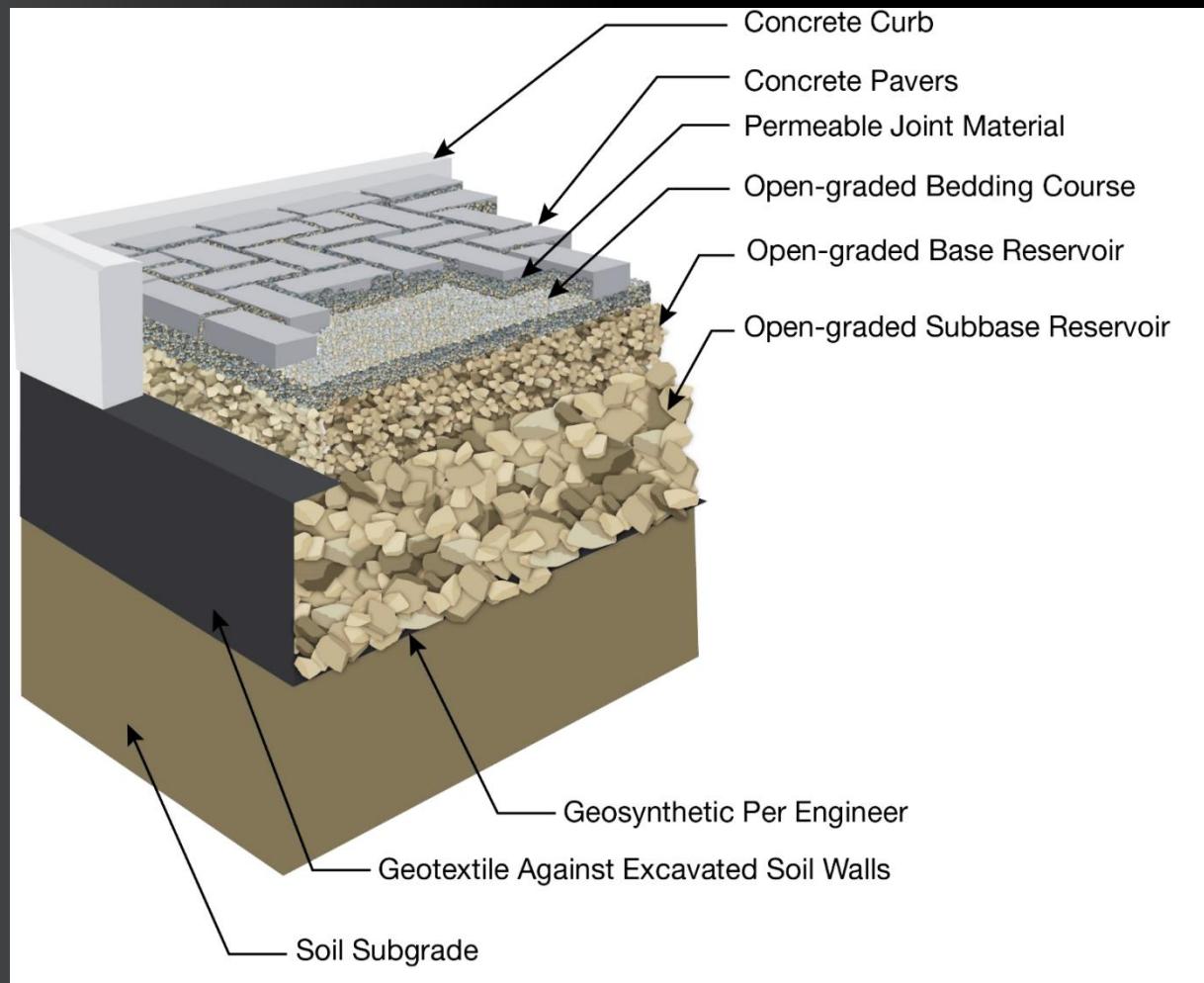


icpi
Interlocking Concrete
Pavement Institute

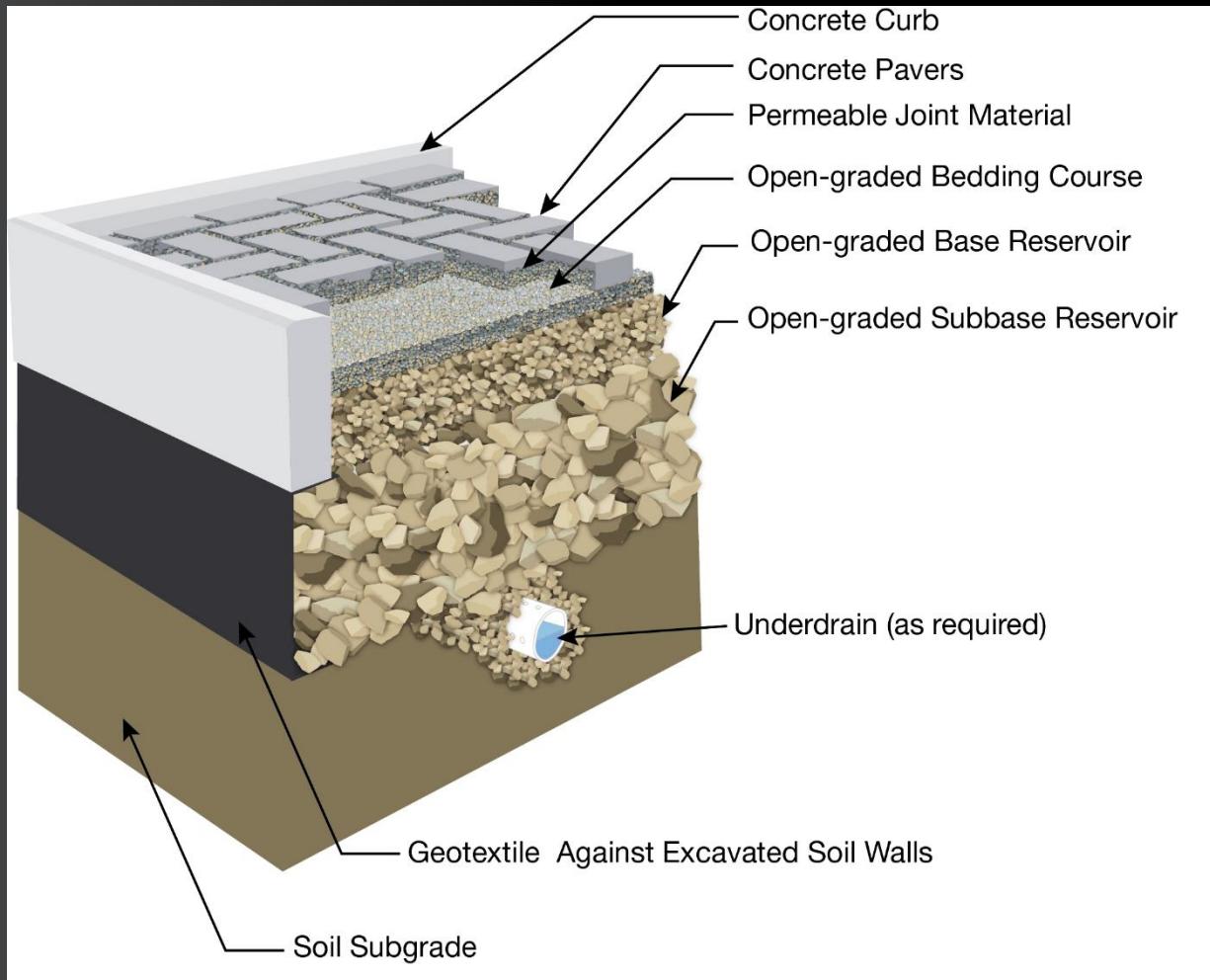
Full-scale Structural Testing and Development of Design Guidelines for PICP

Robert Bowers, P.Eng.
Director of Engineering, ICPI

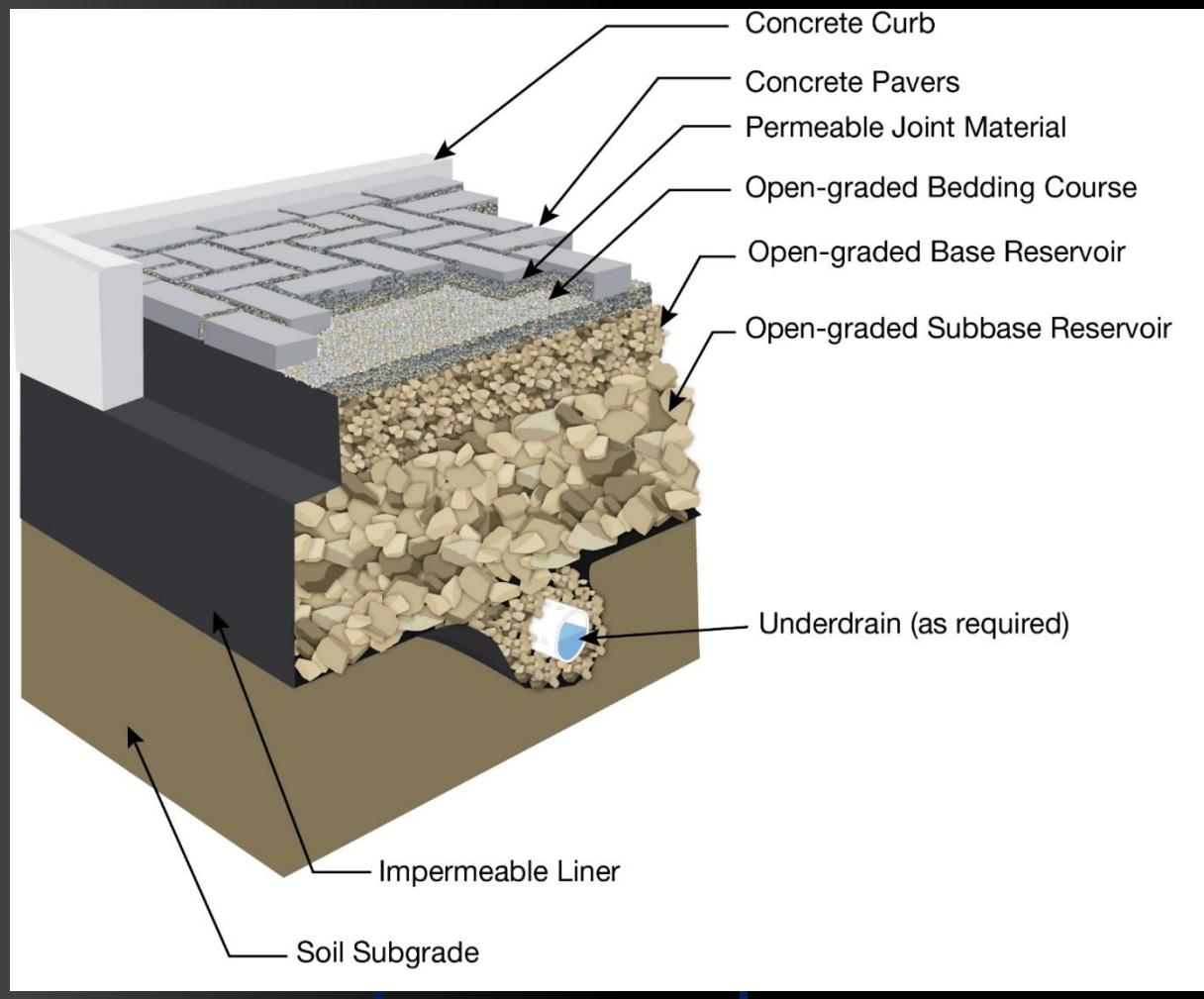
PICP Full-Infiltration



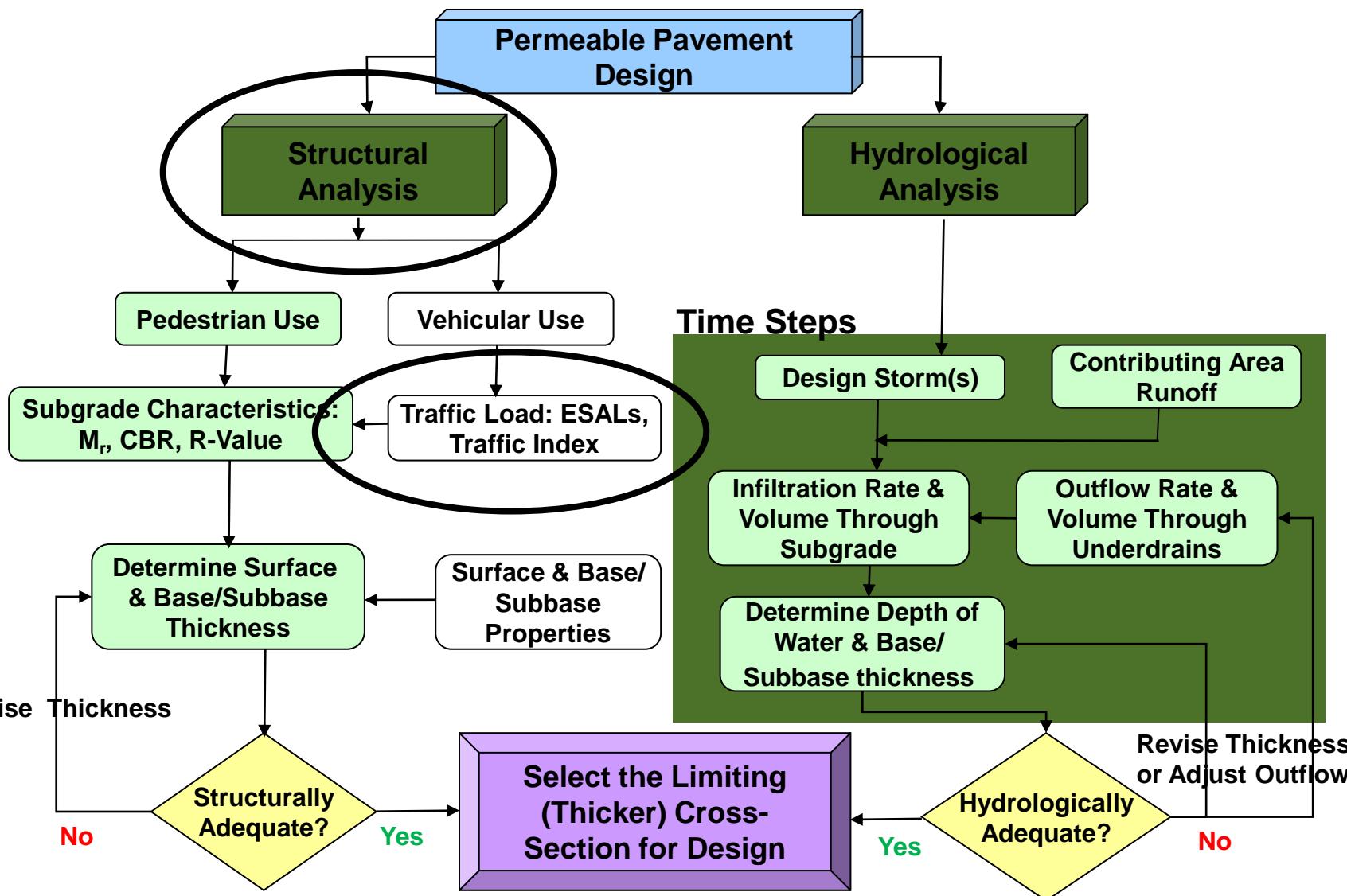
PICP Partial-Infiltration



PICP No-Infiltration

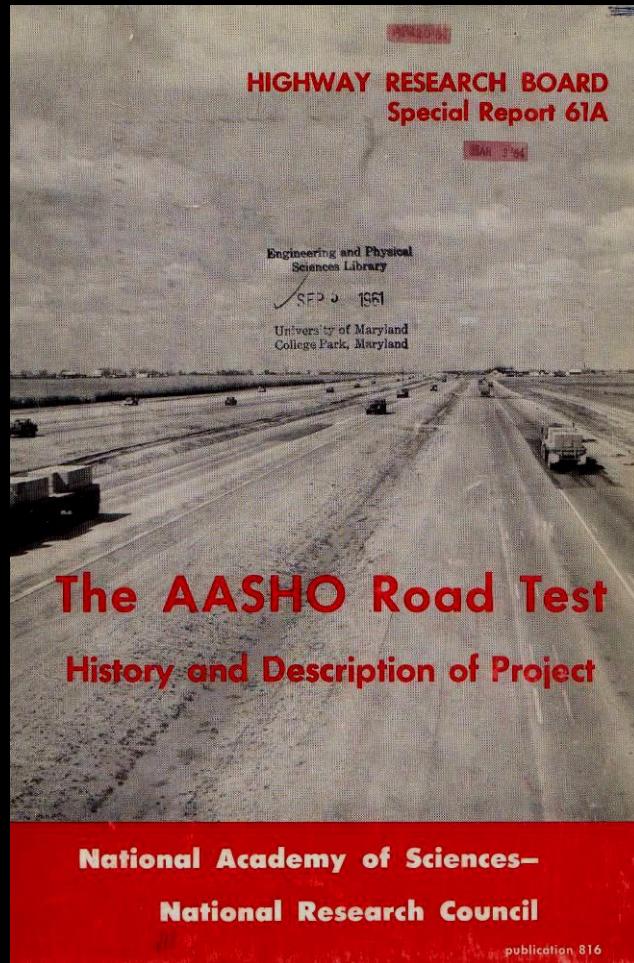


PICP Design

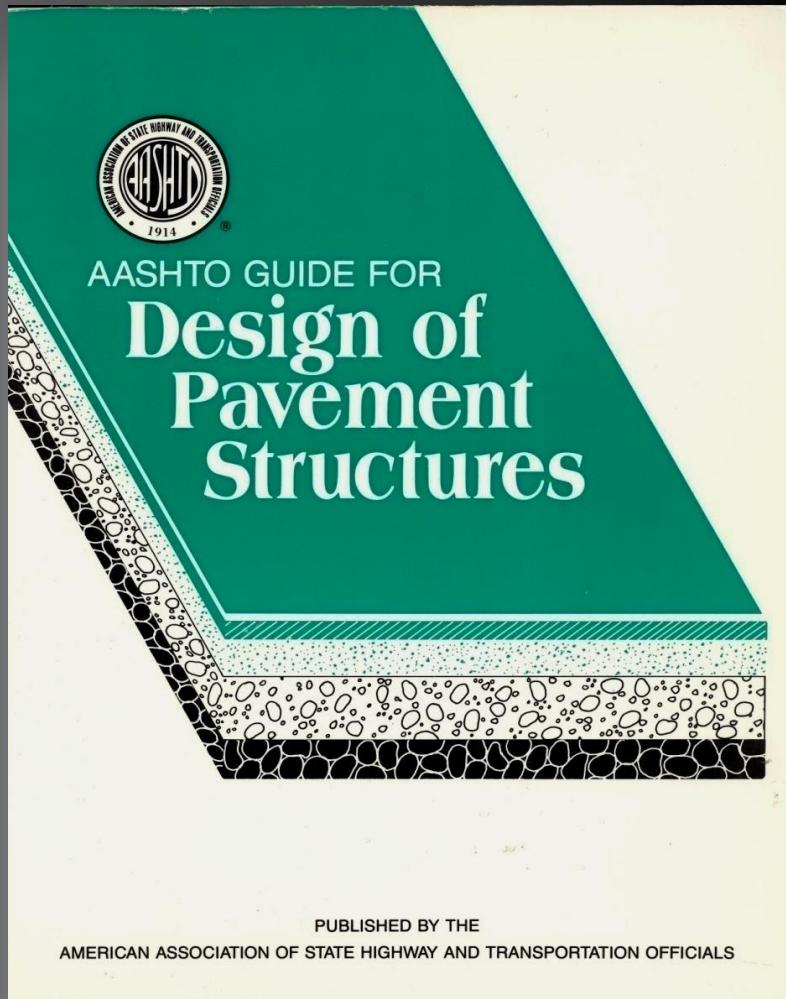


What is an ESAL?

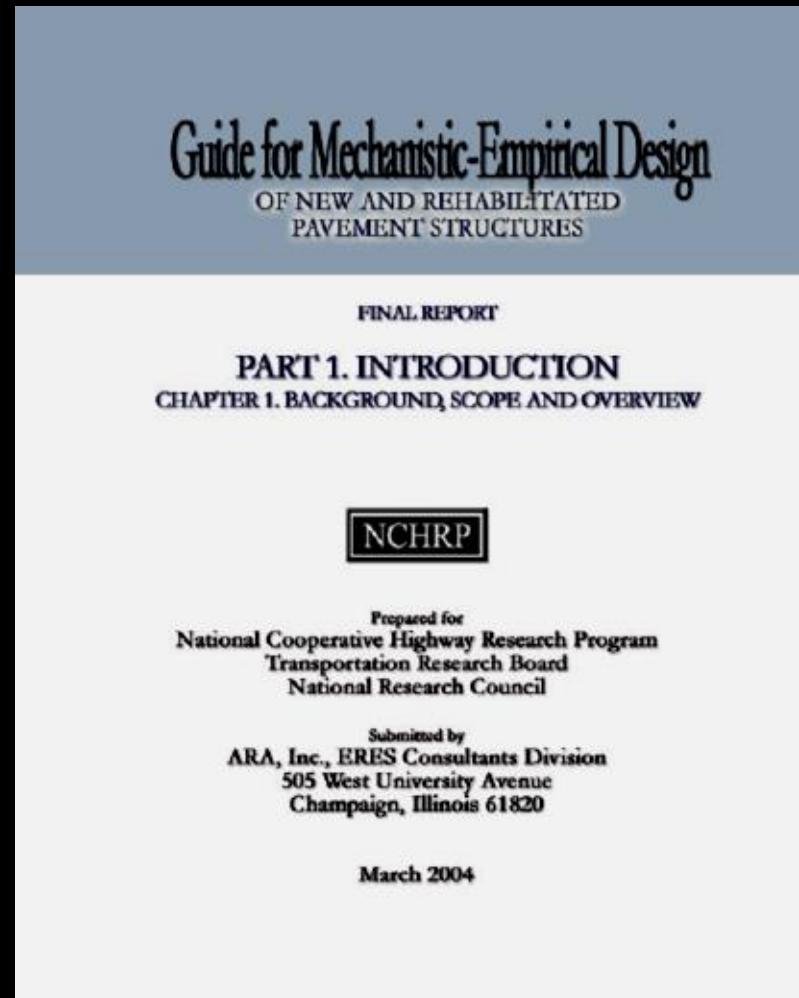
- Equivalent Single Axle Loads
- or 18,000 lb ESALs
- Characterizes performance (rutting)



Structural Design - AASHTO



1993



ME PDG 2004

Truck Factor = ESAL per Truck



2 x 80kN

2 x 70 kN

50 kN

$$\text{LEF} = \left(\frac{80}{80}\right)^4$$

$$\text{LEF} = \left(\frac{70}{80}\right)^4 \cdot 0.6$$

$$\text{LEF} = \left(\frac{50}{80}\right)^4 \cdot 0.15$$

$$\text{TF} = 2 \times 1 + 2 \times 0.6 + 0.15 = 3.35 \text{ ESALs}$$

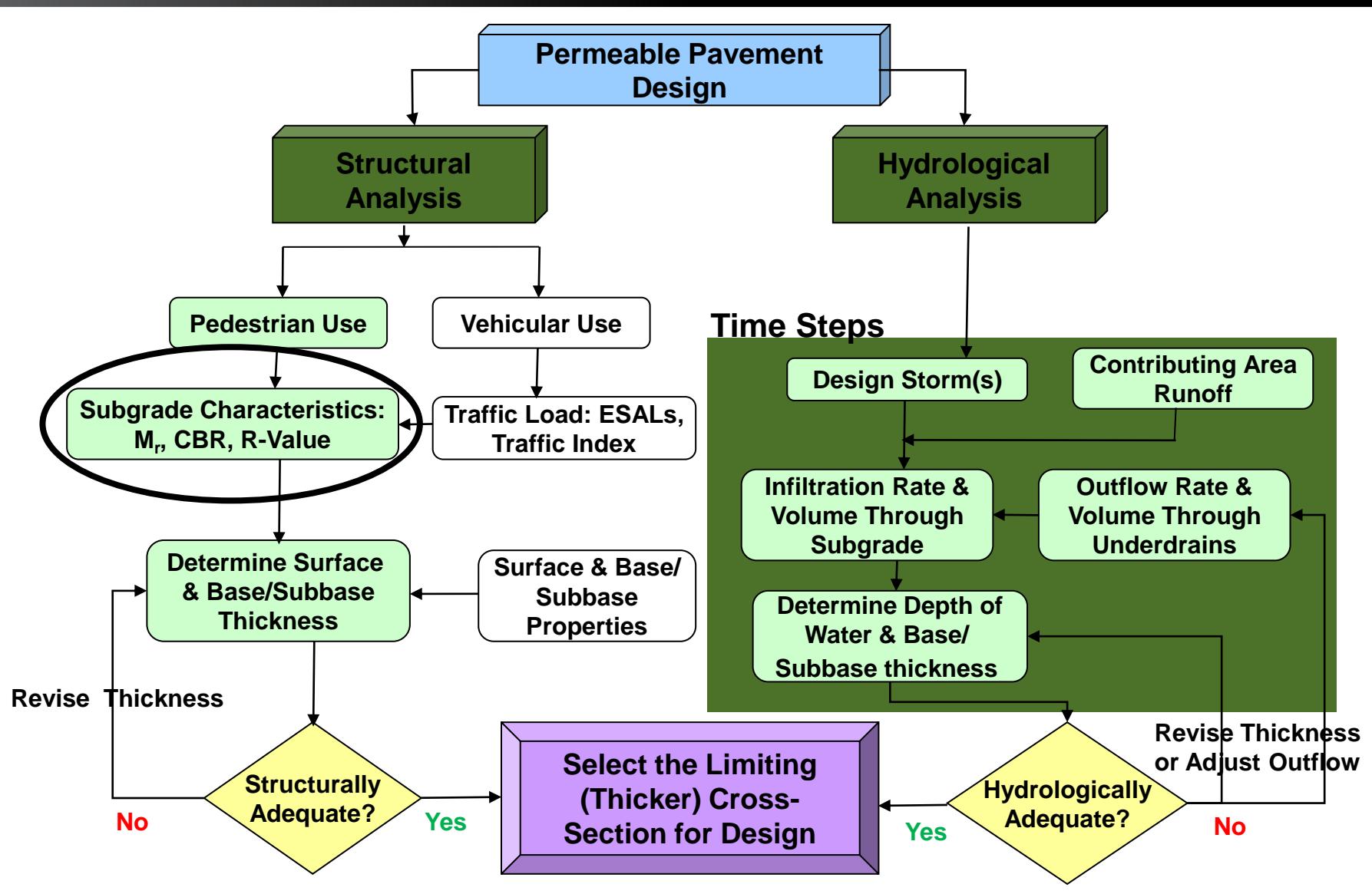
How many ESAL does one pass of a car equal?

*Assuming 1 axle = 9 kN, a car is 0.0003 ESAL
or 1 truck equals more than 3,000 cars*

AASHTO Typical ESALs by Road Class

Road Class	Urban	Rural
Arterial or Major Streets	7,500,000	3,600,000
Major Collectors	2,800,000	1,450,000
Minor Collectors	1,250,000	550,000
Commercial/Multi-Family/ Locals	425,000	275,000
Parking Lots		< 275,000

PCIP Design



Characterization of soil strength using AASHTO, ASTM, or State DOT lab tests

- Resilient Modulus or M_r (PSI or MPa)
- Measures stiffness (resistance to loads)
- Dynamic test (repeated loads) on a soil or base sample under simulated confining stresses (from field tests)
- California Bearing Ratio (CBR in percent)
 - Tests vertical bearing capacity compared to a high-quality compacted aggregate base
- Resistance or R-value (dimensionless number)
 - Tests vertical bearing and horizontal shear
 - Used in California & a few other states
- Strengths correlate to each other

Soil Strength

Resilient Modulus, M_r

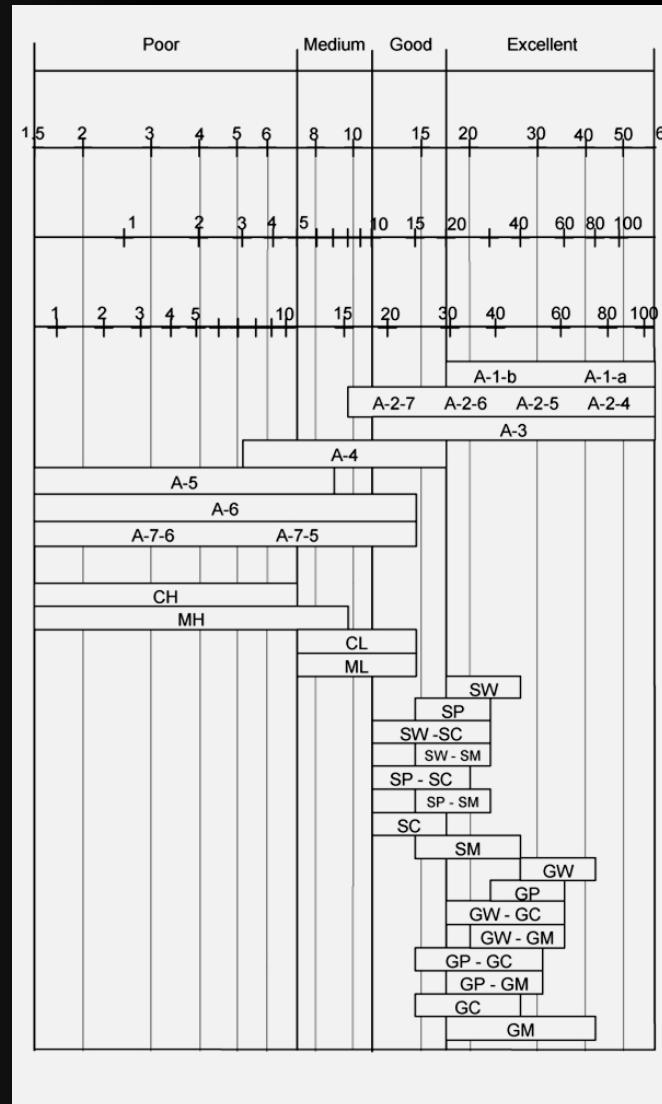
AASHTO T-307

CBR ASTM D1883

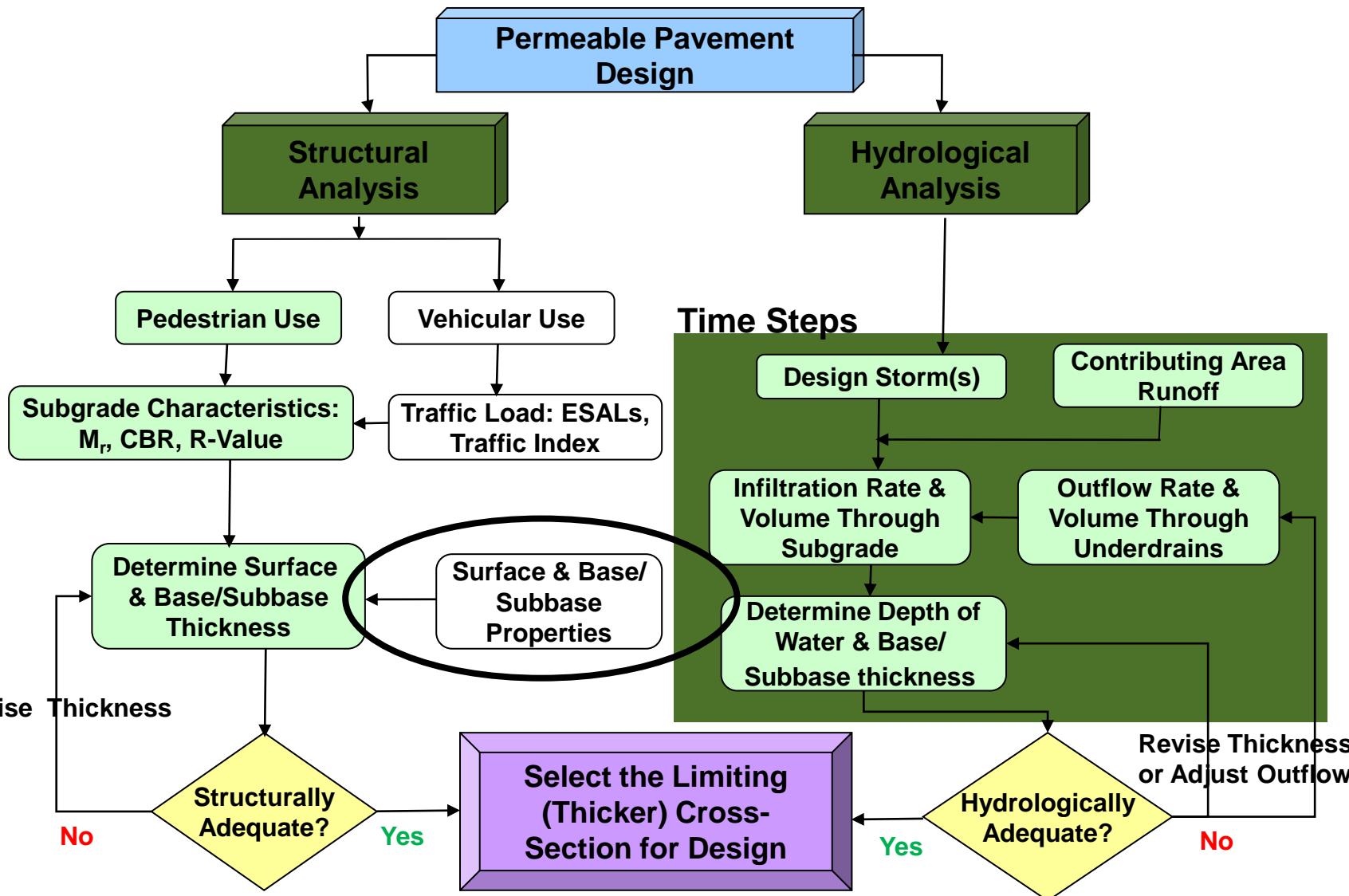
R-value ASTM D2844

**AASHTO Soil
Classification
AASHTO M-45**

**Unified Soil
Classification
ASTM D2487**



PCIP Design



AASHTO 1993 Flexible Pavement Design

AASHTO Equation used to solve Structural Number (SN)

Equation Inputs:

- Estimated lifetime ESALs (20 years typical)
- Characterization of soil strength using lab tests
 - Resilient Modulus (Mr) (or R-value or CBR converted to Mr) then use AASHTO equation to calculate required SN based on serviceability (smoothness) & reliability
- Designer finds mix of base layer coefficients that satisfy the required SN
 - Layer coefficients: dimensionless numerical characterization of material stiffness per inch of thickness (higher means stiffer)
 - Each pavement layer assigned a layer coefficient
 - Sum of coefficients x layer thickness > required SN

PICP Structural Design Assumptions

Minimum soil strength

- 4% soaked CBR, R-value = 9 or min. resilient modulus = 6,200 psi (43 MPa)

Layer coefficients

Typical dense-graded base 0.12 to 0.14 per inch thickness

- 3 1/8 in. thick pavers + 2 in. bedding = 0.3
- 4 in. thick ASTM No. 57 stone base = 0.09
- Variable ASTM No. 2, 3 or 4 stone subbase = 0.06
- Low coefficients used = conservative approach
- No frost protection layer required

Structural Calculation Example

300,000 ESALs design life, soaked CBR = 6%

AASHTO Equation Yields Required SN = 2.5

Layer	Required Layer Thickness		Layer Coefficient		Structural Number
Required SN					2.50
Paving	5 1/8 in.	x	0.30	=	1.53
No. 57 Base	4 in.	x	0.09	=	0.36
No. 2 Subbase	?	x	0.06	=	0.61

No. 2 Subbase must be more than 10 in.

PEDESTRIAN	Soaked CBR (R-value)	4 (9)	5 (11)	6 (12.5)	7 (14)	8 (15.5)	9 (17)	10 (18)
	Resilient Modulus, psi (MPa)*	6,205 (43)	7,157 (49)	8,043 (55)	8,877 (61)	9,669 (67)	10,426 (72)	11,153 (77)
	Base thickness, in. (mm) ASTM No. 57	6 (150)						

VEHICULAR	Soaked CBR (R-value)	4 (9)	5 (11)	6 (12.5)	7 (14)	8 (15.5)	9 (17)	10 (18)
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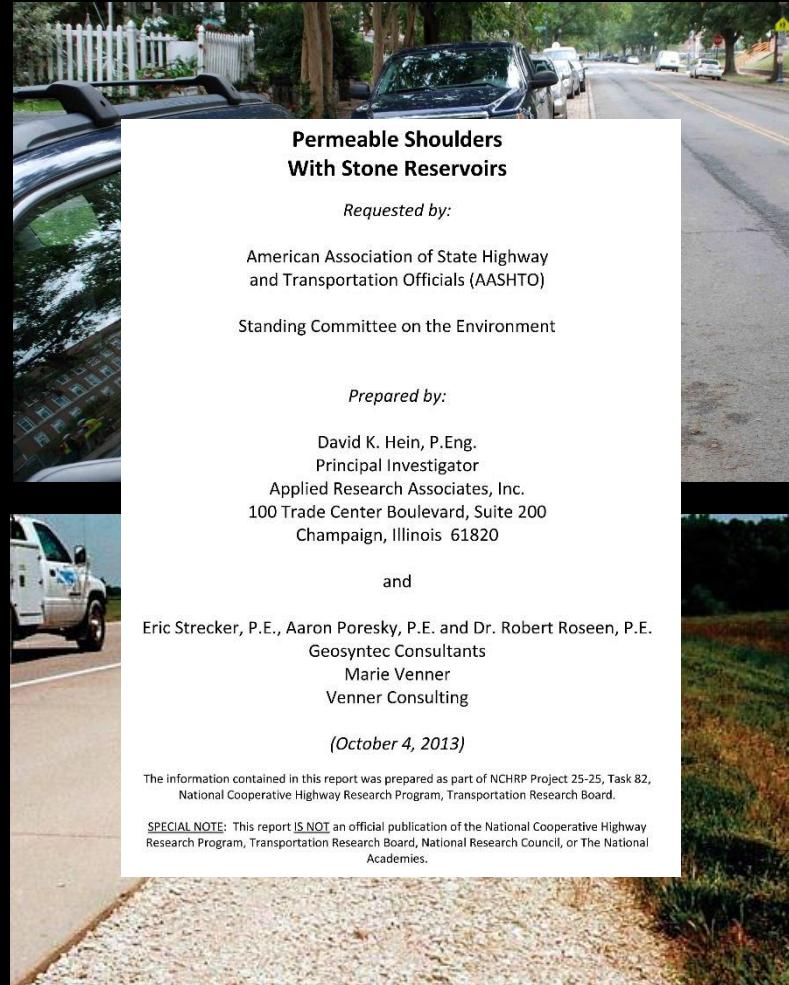
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50,000 (6.3) and Residential Driveways	Base thickness, in. (mm) ASTM No. 57	4 (100)						
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200,000 (7.4)	Base thickness, in. (mm) ASTM No. 57	4 (100)	4 (100)					
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300,000 (7.8)	Base thickness, in. (mm) ASTM No. 57	4 (100)	4 (100)	4 (100)	4 (100)	4 (100)		
	Subbase thickness in. (mm) ASTM No. 2	16 (400)	14 (350)	12 (300)	10 (250)	9 (225)	8 (200)	7 (175)
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1,000,000 (9)	Base thickness, in. (mm) ASTM No. 57	4 (100)	4 (100)	4 (100)	4 (100)	4 (100)	4 (100)	4 (100)
	Subbase thickness in. (mm) ASTM No. 2	27 (675)	24 (600)	21 (525)	19 (475)	18 (425)	16 (400)	15 (375)

Why Do Structural Research?

- AASHTO flexible pavement equation developed for dense-graded bases
- What about open-graded bases ($n > 0.3$)
 - Highly stress-dependent
 - Extended subgrade saturation time for stormwater management
 - Almost no full-scale load testing data
- Validate/extend ICPI design charts
- Resolve “water-is-the-enemy-of-pavements”
- Raise designer confidence

Research Need - Permeable Pavement Road Shoulders

- NCHRP 25-25 task 82 report:
- Permeable Shoulders with Stone Reservoirs
- Requested by AASHTO Standing Committee on the Environment
- Feasibility, Design, Construction, Maintenance
- Highest benefit in urban areas – better structural design needed



UC Davis Pavement Research Center Tasks

- Literature review - identify critical responses, failure mechanisms, performance transfer functions, & modeling assumptions
 - Key resource: Univ. of Illinois – RR ballast modeling
- Measure pavement deflection in the field & characterize
 - effective stiffness of the different layers in PICP for modeling



Deflection
Measurement
Device



UC Davis Pavement Research Center Tasks

- Perform mechanistic analyses of PICP to develop tentative design tables for validation via full-scale load testing
- Shear stress to shear strength ratios at the top of the subbase and top of the subgrade for modeling rut development

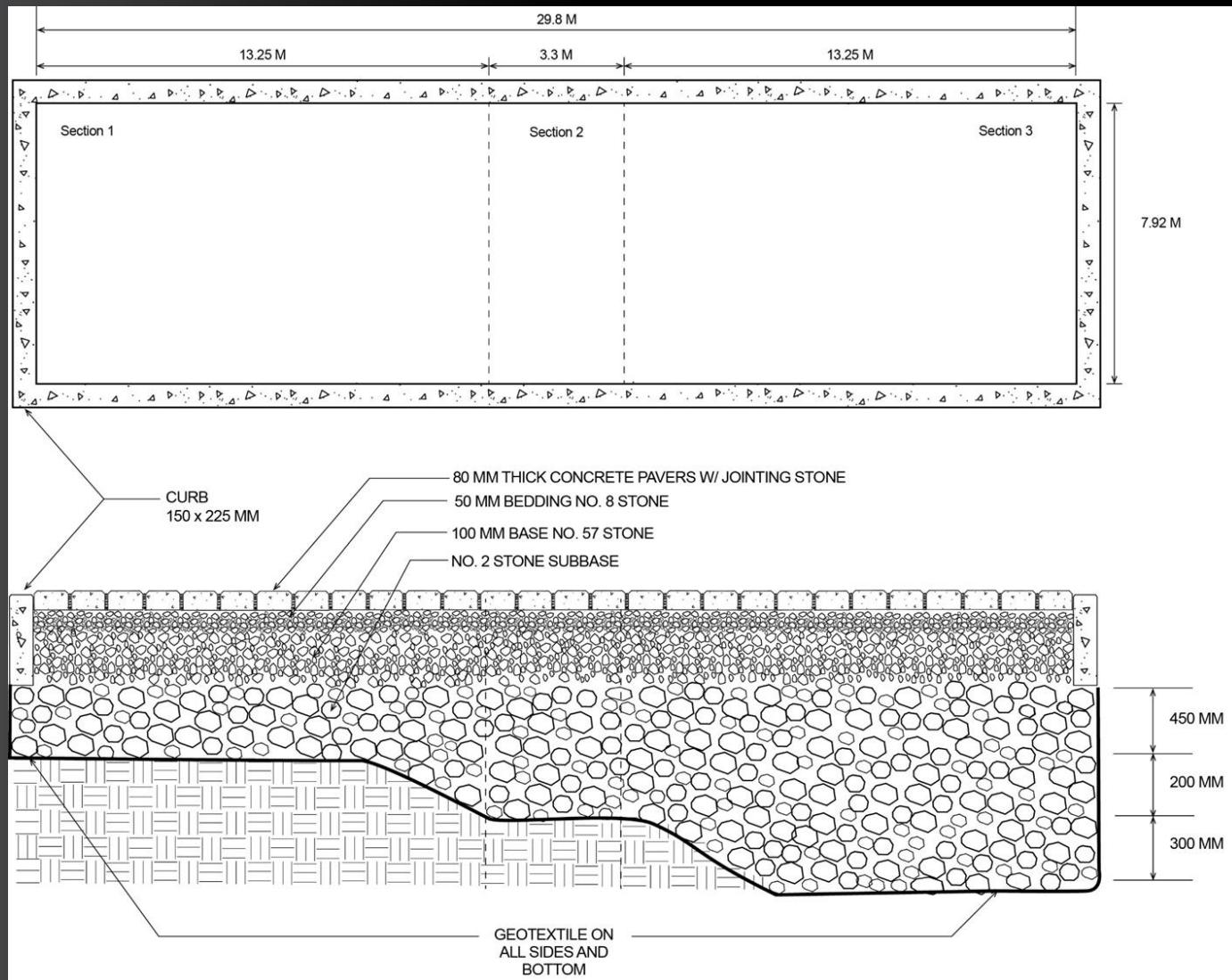


UC Davis Pavement Research Center Tasks

- Prepare accelerated load testing plan based on the results of the mechanistic analysis
- Test responses/failure of three PICP structures in dry and wet condition with a Heavy Vehicle Simulator (HVS).
- Analyze the results revise/update ICPI structural design tables as needed



PICP Test Profile



PICP Test Track Construction



UC Davis - Heavy Vehicle Simulator (HVS)



Worst, Worst Case



Native Soil Subgrade Moisture

Wheel Load (kN)	Load Repetition s	ESALs	Surface Rut Depths, mm		
			450 mm Subbase	650 mm Subbase	950 mm Subbase
25	100,000	13,890	8.6	7.7	9.4
40	100,000	100,000	13.6	12.9	13.7
60	140,000	768,619	23.7	22.0	20.4
Total	340,000	882,509			



Saturated Subbase & Soil

Wheel Load (kN)	Load Repetition s	ESALs	Surface Rut Depths, mm		
			450 mm Subbase	650 mm Subbase	950 mm Subbase
25	100,000	13,890	13.7	11.8	11.2
40	100,000	100,000	25.2	20.8	20.3
60	140,000	768,619	47.2	37.9	34.8
80	40,000	735,167	58.0	46.9	40.8
Total	380,000	1,617,676			



Drained Subbase & Soil

Wheel Load (kN)	Load Repetition s	ESALs	Surface Rut Depths, mm		
			450 mm Subbase	650 mm Subbase	950 mm Subbase
25	100,000	13,890	9.5	9.1	9.1
40	25,000	25,000	11.0	10.6	10.6
Total	140,000	38,890			



Number of Days in a Year When the Subbase has Standing Water (Wet Days)		0				10				30			
Resilient Modulus of Subgrade MPa (CBR)	Dry	40	60	80	100	40	60	80	100	40	60	80	100
	Wet	24	36	48	60	24	36	48	60	24	36	48	60
Cohesion (kPa), Internal Friction Angle of Subgrade (°)	Dry	10,20	15,25	20,30	25,35	10,20	15,25	20,30	25,35	10,20	15,25	20,30	25,35
	Wet	6,12	9,15	12,22	15,25	6,12	9,15	12,22	15,25	6,12	9,15	12,22	15,25
Lifetime ESALs (Traffic Index)													
50,000 (6.3)		150	150	150	150	150	150	150	150	150	150	150	150
100,000 (6.8)		150	150	150	150	210	150	150	150	260	150	150	150
200,000 (7.4)		230	150	150	150	315	210	150	150	365	255	160	150
300,000 (7.8)		290	180	150	150	375	265	170	150	425	315	215	150
400,000 (8.1)		330	220	150	150	420	305	210	150	470	350	255	175
500,000 (8.3)		360	250	160	150	450	335	240	160	500	380	280	205
600,000 (8.5)		385	275	185	150	475	360	260	180	525	405	305	225
700,000 (8.6)		410	295	205	150	495	380	280	200	550	425	325	245
800,000 (8.8)		425	310	220	150	515	395	295	215	565	440	340	260
900,000 (8.9)		440	325	235	155	530	410	310	230	585	455	355	270
1,000,000 (9.0)		455	340	250	165	545	425	325	240	600	470	365	285

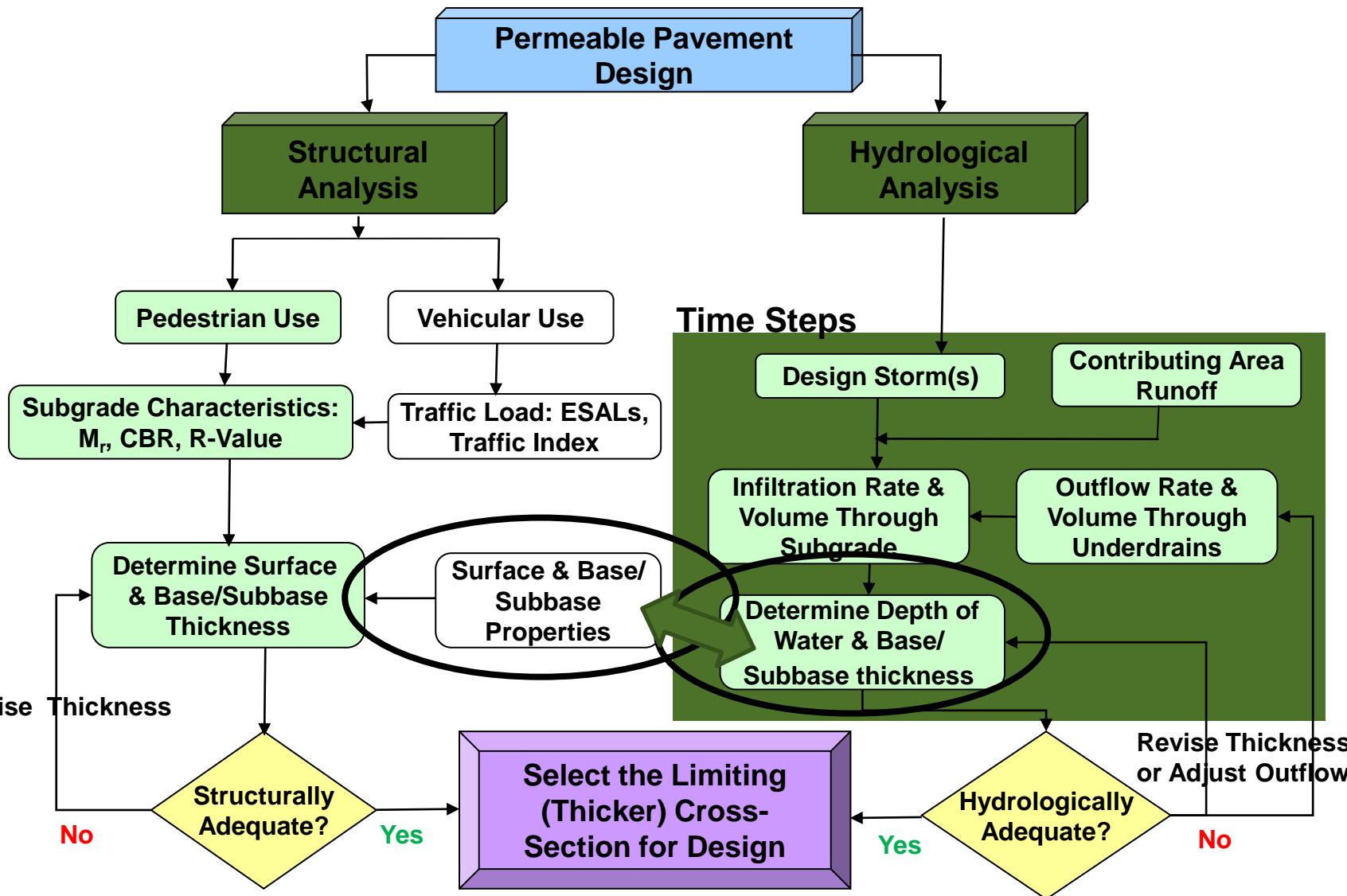
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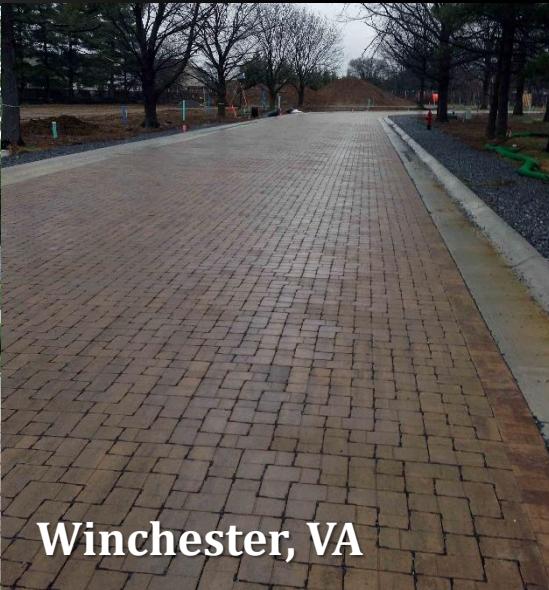
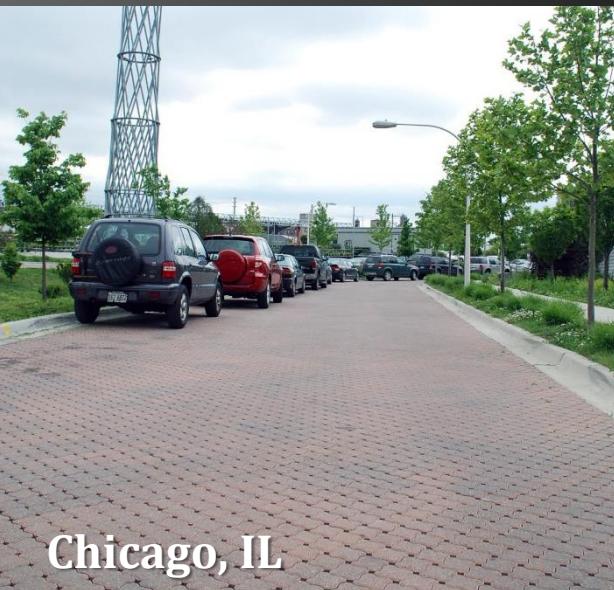
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	Wet	6,12	9,15	12,22	15,25	6,12	9,15	12,22	15,25	6,12	9,15	12,22	15,25
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PICP Design

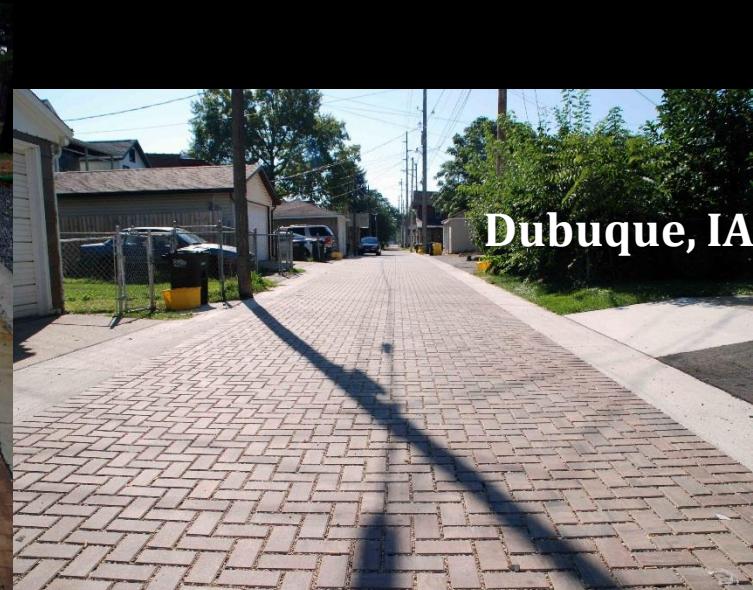


Deployment/Institutionalization

- TRB, ASCE & stormwater conference presentations
- Propose design guidelines & specs for PICP roads & shoulders to DOTs, LTAPs & municipal specs
- Include design charts in ASCE PICP design standard



Winchester, VA



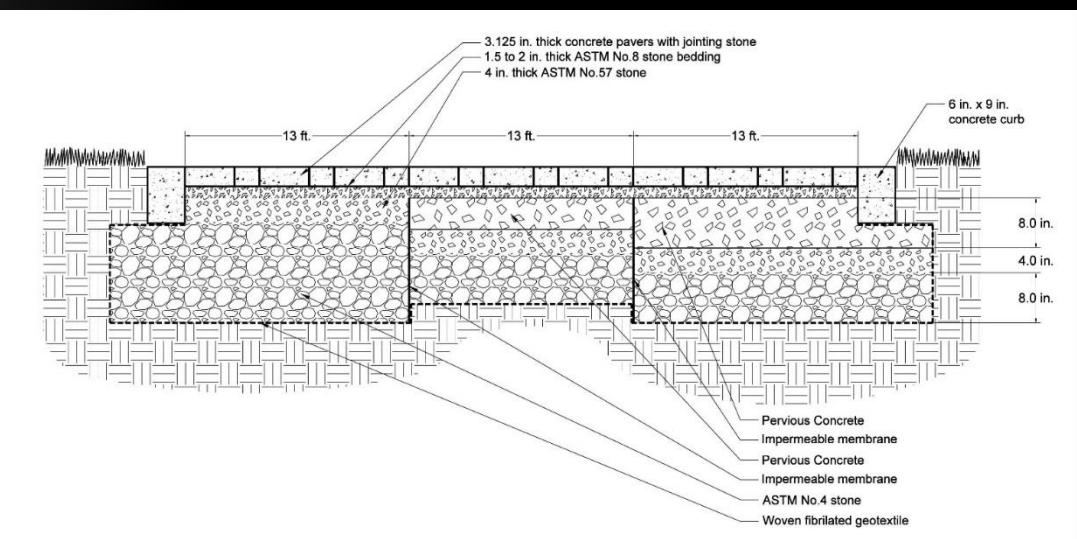
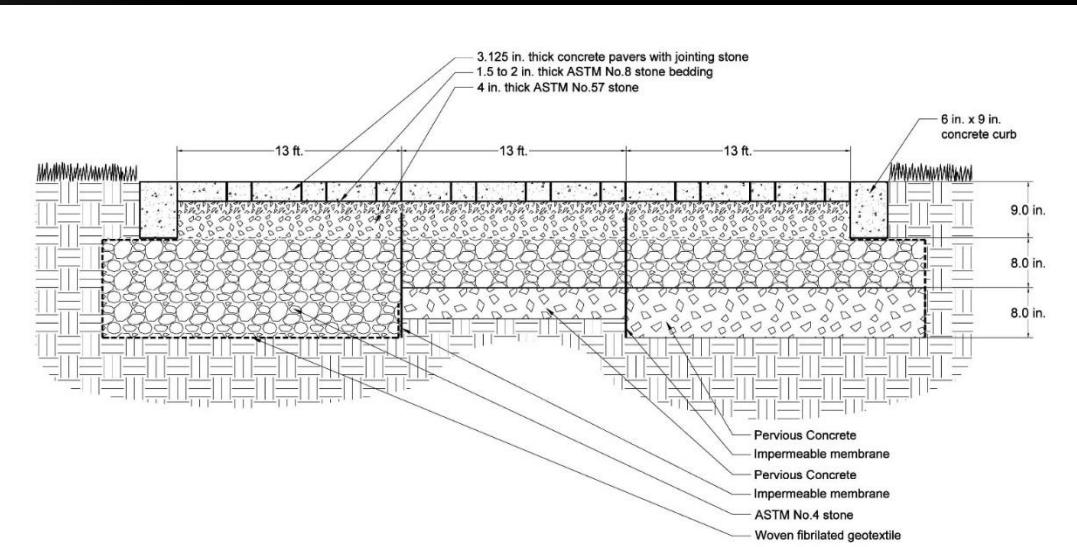
Dubuque, IA

Chicago, IL

Next Test Tracks

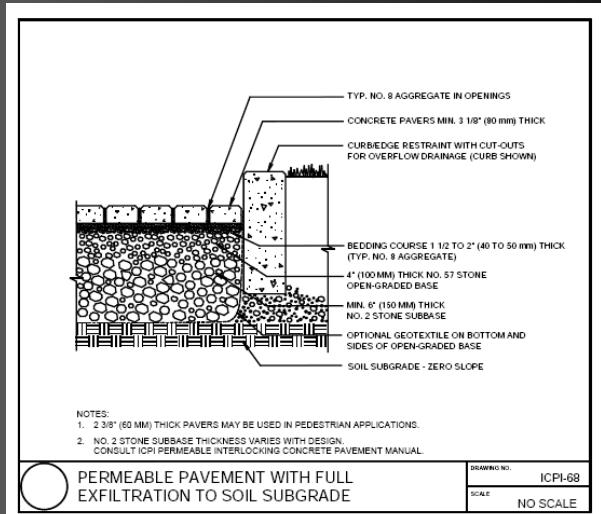
- PICP & bedding
- Base
- Subbase
- Pervious concrete
- Geotextile
- Weak subgrade

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ICPI Resources

- Interlock Design Magazine
- Tech Specs
- Specs & Details
- www.icpi.org



Tech Spec 18

Construction of Permeable Interlocking Concrete Pavement Systems

This spec bulletin provides a summary of PCP construction techniques outlined in the manual, as well as further guidance on best construction practice (BMP) and Low Impact Development (LID) measures to reduce runoff volume in addition to infiltration, infiltration opportunities for addressing combined sewer overflow with green alleys and streets, as well as use in parking lot and pedestrian surfaces. Traditional stormwater management solutions focus on collecting, conveying and treating runoff discharge of stormwater. As a key part of the ICPI mission, PCP has disconnected, decentralized and more widely distributed runoff through infiltration, detention, filtering and treatment.

The International Interlocking Concrete Pavement Institute (ICPI) provides comprehensive, up-to-date information on permeable interlocking concrete pavements, which covers design, specification, construction and maintenance. This manual is available on www.icpi.org and provides extensive information from academic research and practical field experience. This figure illustrates a typical cross-section with the individual components labeled below.

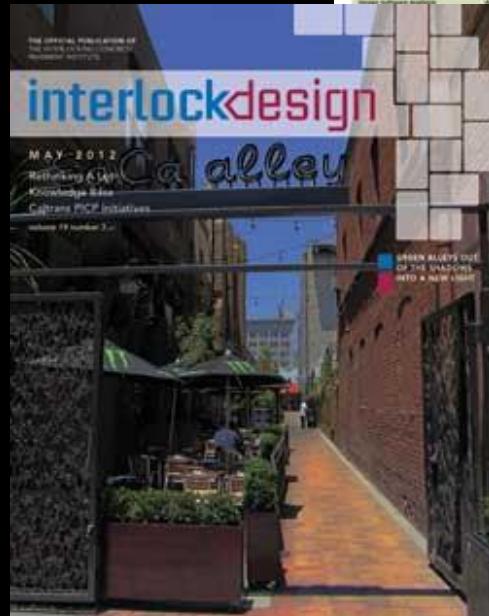
Concrete pavers—Solid concrete pavers with mortared joints and/or openings that create an open area across the pavement surface. The pavers should conform to ASTM C 396 AST C 136 or the U.S. CSA A23.2-06 2006 m standard. Pavers are typically a minimum of 3 1/8 in. (80 mm) thick for vehicular areas and pedestrian areas may use 2 3/8 in. (60 mm) thick units. Pavers are manufactured in a range of shapes and colors. Filled with permeable joint material, they allow water from storm events to freely infiltrate through the pavement surface. Figure 2 shows several paver configurations.

Permeable joint material—The joint material typically conforms to ASTM No. 8, 89 or 9 stone. The permeable stones allow stormwater to infiltrate through joints in the pavement surface.

Open-graded bedding course—This permeable layer is typically 2 in. (50 mm) thick and provides a setting bed for pavers. It consists of small-sized, open-graded angular aggregate, typically ASTM No. 8 or similar sized material.

Open-graded base reservoir—This is an aggregate layer that is typically 4 in. (100 mm) thick that overlies the bedding course and underlies the sub-base material. The base material is made of crushed stones primarily 1 in. to 1/2 in. (25 mm down to 13 mm). For pedestrian application the base layer is a minimum of 6 in. (150 mm) and the subbase may be required. bedding course and base reservoir porosity in the spaces among the stones, this highly permeable material also serves as a chocking layer between the bedding and subbase layers. The stone size is typically ASTM No. 57 or similar sand-sized material.

Figure 1: PCP typical cross section.



www.PermeableDesignPro.com

The screenshot shows the homepage of the Permeable Design Pro website. At the top left is the ICPI logo. The navigation bar includes links for PDP Home, Features, Purchase, Support, and Contact. A shopping cart icon is also present. Below the navigation is a social sharing section with Like, Tweet, and Google+ buttons. A main banner features a car driving on a permeable pavement system. A call-to-action button says "Construction of Permeable Pavement Systems Learn More". The main content area has a heading: "Permeable Interlocking Concrete Pavement (PICP) Design with with ICPI's Permeable Design Pro Software" followed by a subtext: "that integrates hydrologic and structural solutions." Below this is a paragraph about base thickness solutions and stormwater management. A green button says "Download Now! — FREE 30-day Trial". A sidebar on the left lists benefits: "✓ Design solutions with CAD output", "✓ 30 day FREE trial", "✓ Instant download", "✓ Automatic software updates for version 2.0", "✓ Buy three or more licenses and save", and "✓ Now easier to share with multiple license purchases". A green callout box on the right provides a brief description of PICP and its benefits.

icpi
Interlocking Concrete
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Construction of Permeable Pavement Systems

Learn More

Permeable Interlocking Concrete Pavement (PICP) Design with with ICPI's Permeable Design Pro Software

that integrates hydrologic and structural solutions.

Provides base thickness solutions from calculating PICP inflow/outflow and traffic loads.
Design sustainable stormwater management with PICP for pedestrian areas, parking lots, alleys and streets.

Download Now! — FREE 30-day Trial

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● Introduced from Germany in the mid-1990s, PICP is one of the most effective, low-impact development and green infrastructure tools for managing stormwater and for reducing impacts from runoff pollution. PICP offers a cost-effective, attractive and durable permeable surface compared to other permeable pavements.

Permeable Design Pro develops open-graded aggregate base/subbase thickness solutions at the

- 30-day free trial
- Hydrologic & structural design
- Retail:
 - \$190/license
- ICPI members & Design Professionals:
 - \$95/license
 - \$75/license for 3 or more licenses

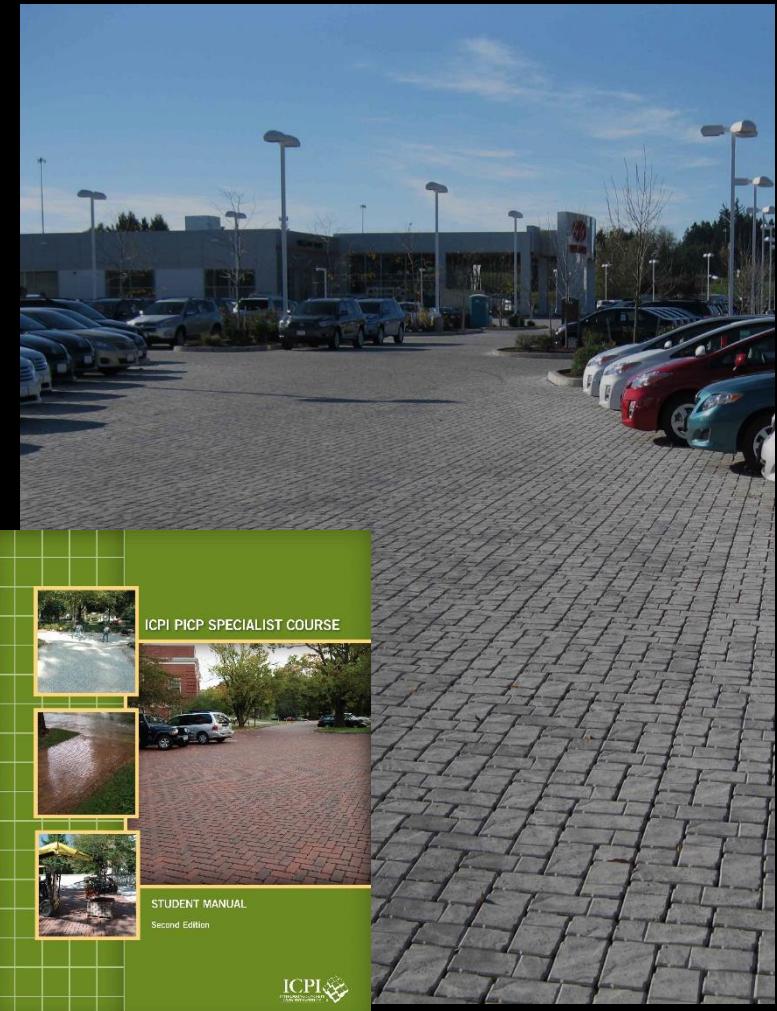
ICPI PICP Installer Designations

Option 1 - PICP Record of Completion

- Complete 1-day PICP Specialist course and pass the exam
- Does not expire

Option 2 - ICPI Certified PICP Specialist

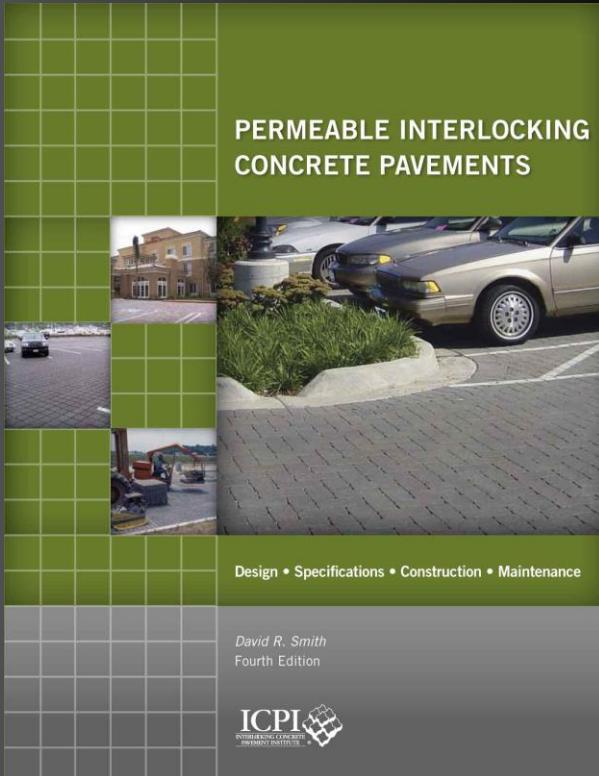
- Hold a PICP Record of Completion
- Be an ICPI Certified Installer
 - ♦ Complete 2-day Concrete Paver Installer course and pass the exam
 - ♦ Document ICP experience of 5 project and 10,000 SF
 - ♦ Earn continuing education credits: minimum of 8 hours over 2 years
 - ♦ Renew certification biennially
- Document PICP experience of 10 projects & 50,000 SF
- Submit application for PICP Specialist Designation



ICPI & ASCE Resources

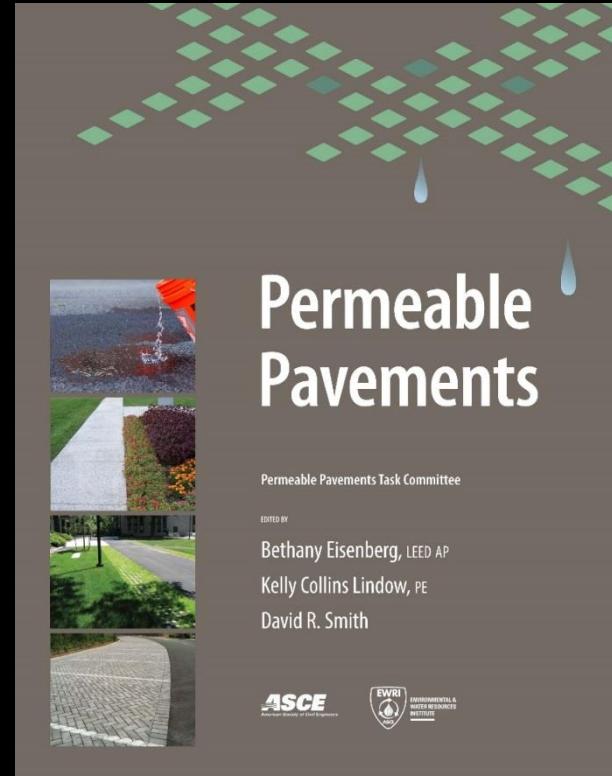
Permeable Interlocking Concrete Pavements

Design, Specifications,
Construction & maintenance
(100 pages)



Permeable Pavements

ASCE e-book
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