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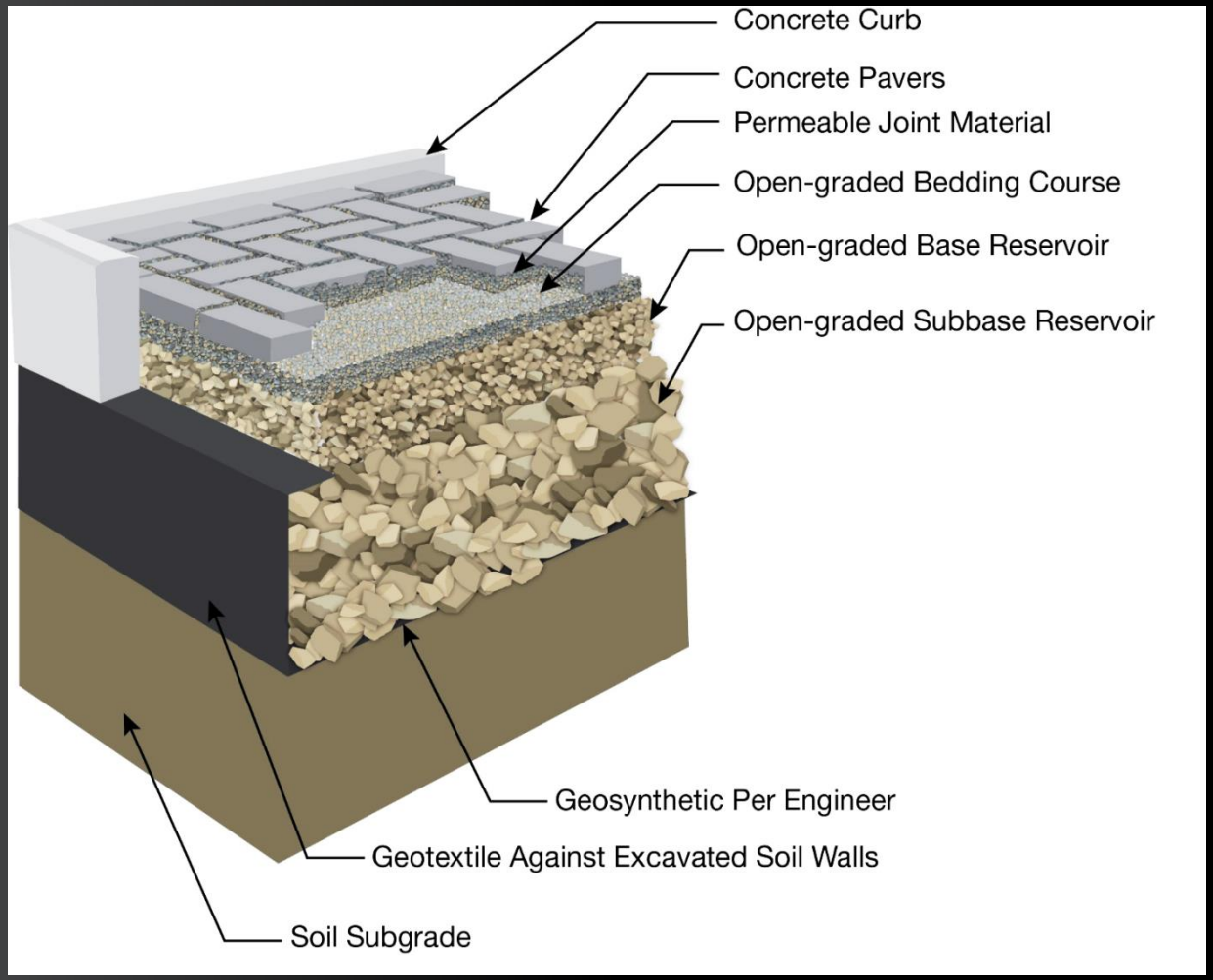
WATER CANADA THE COMPLETE WATER MAGAZINE

icpi
Interlocking Concrete Pavement Institute

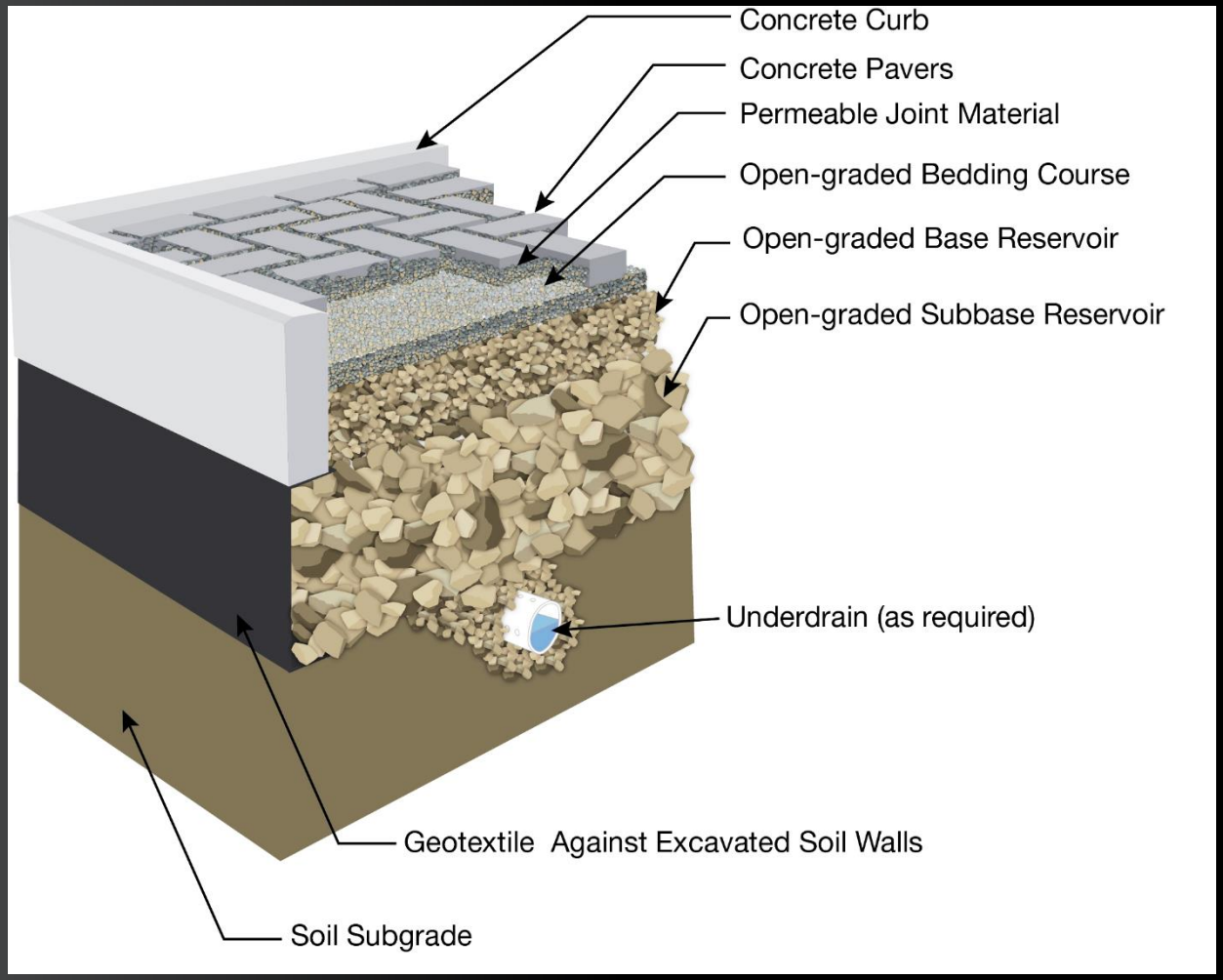
Full-scale Structural Testing and Development of Design Guidelines for PICP

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

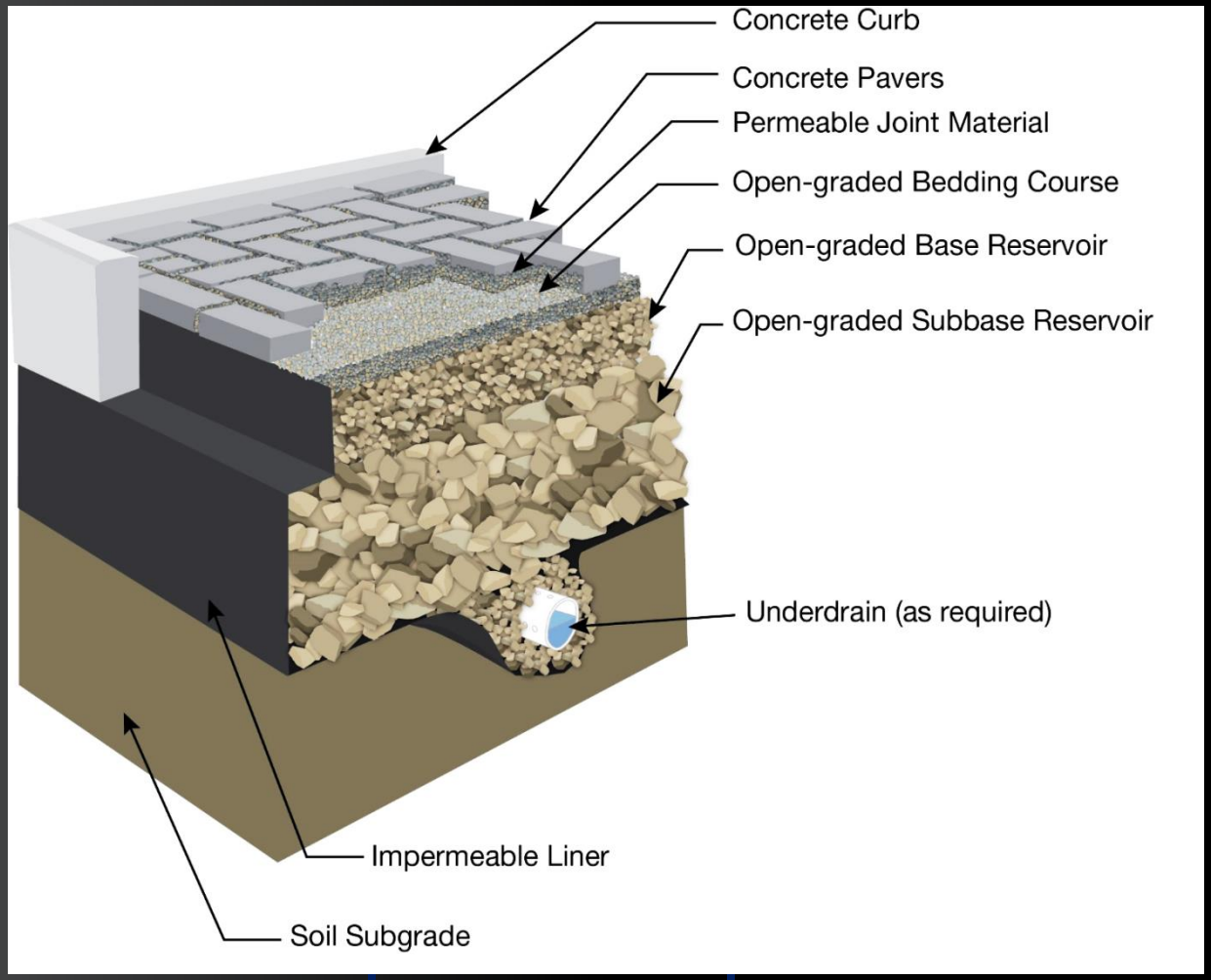
PICP Full-Infiltration



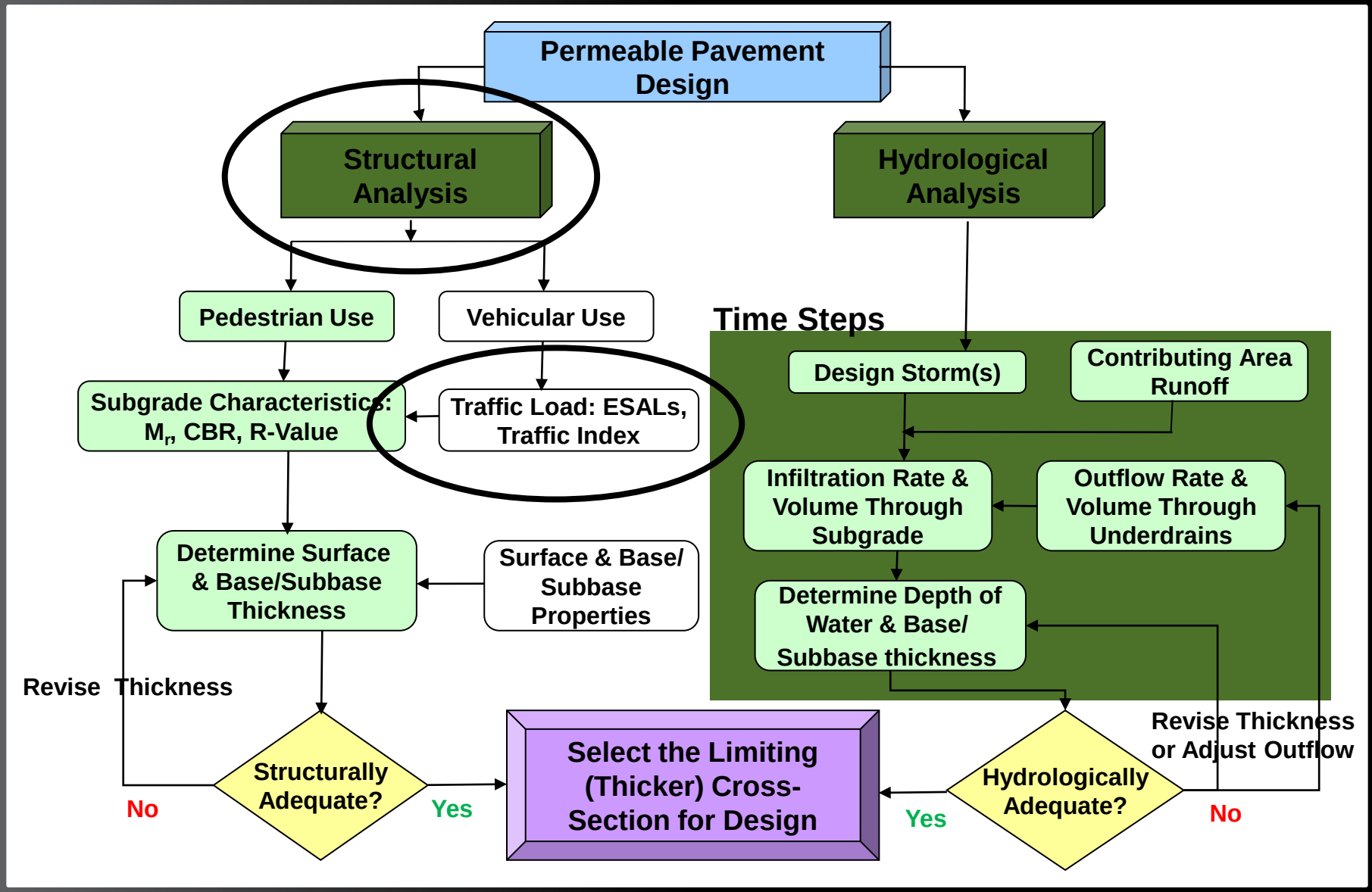
PICP Partial-Infiltration



PICP No-Infiltration

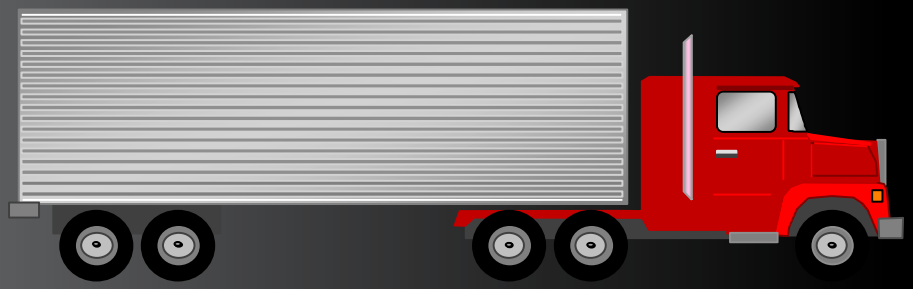


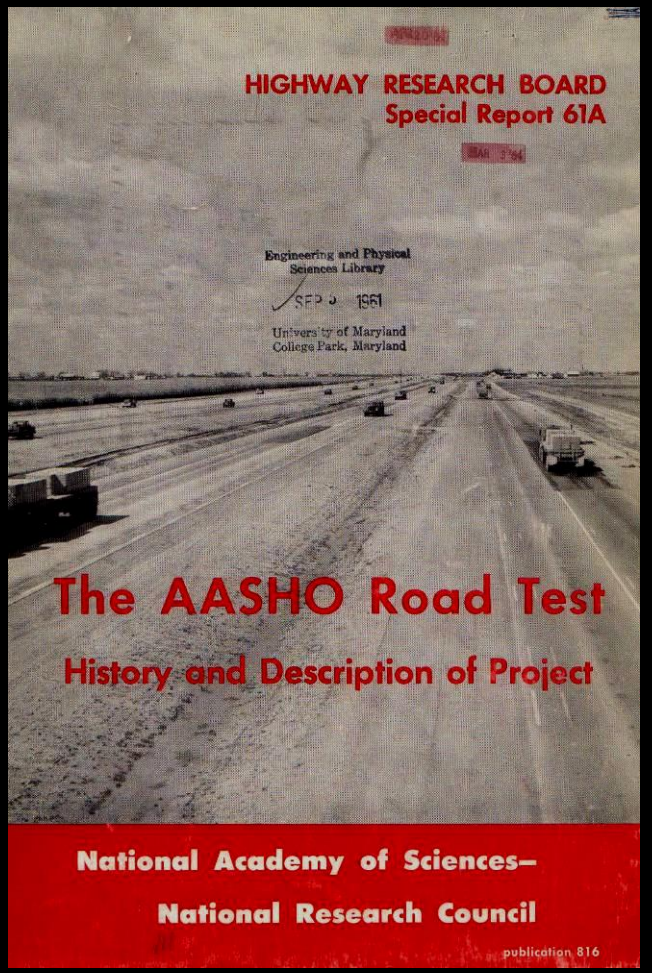
PICP Design


Permeable Pavement Design
Structural Analysis
Hydrological Analysis
Pedestrian Use
Vehicular Use
Time Steps
Subgrade Characteristics: M_r, CBR, R-Value
Traffic Load: ESALs, Traffic Index
Design Storm(s)
Contributing Area Runoff
Infiltration Rate & Volume Through Subgrade
Outflow Rate & Volume Through Underdrains
Determine Surface & Base/Subbase Thickness
Surface & Base/ Subbase Properties
Determine Depth of Water & Base/ Subbase thickness
Revise Thickness
Structurally Adequate?
No
Yes
Select the Limiting (Thicker) Cross-Section for Design
Hydrologically Adequate?
Yes
No
Revise Thickness or Adjust Outflow

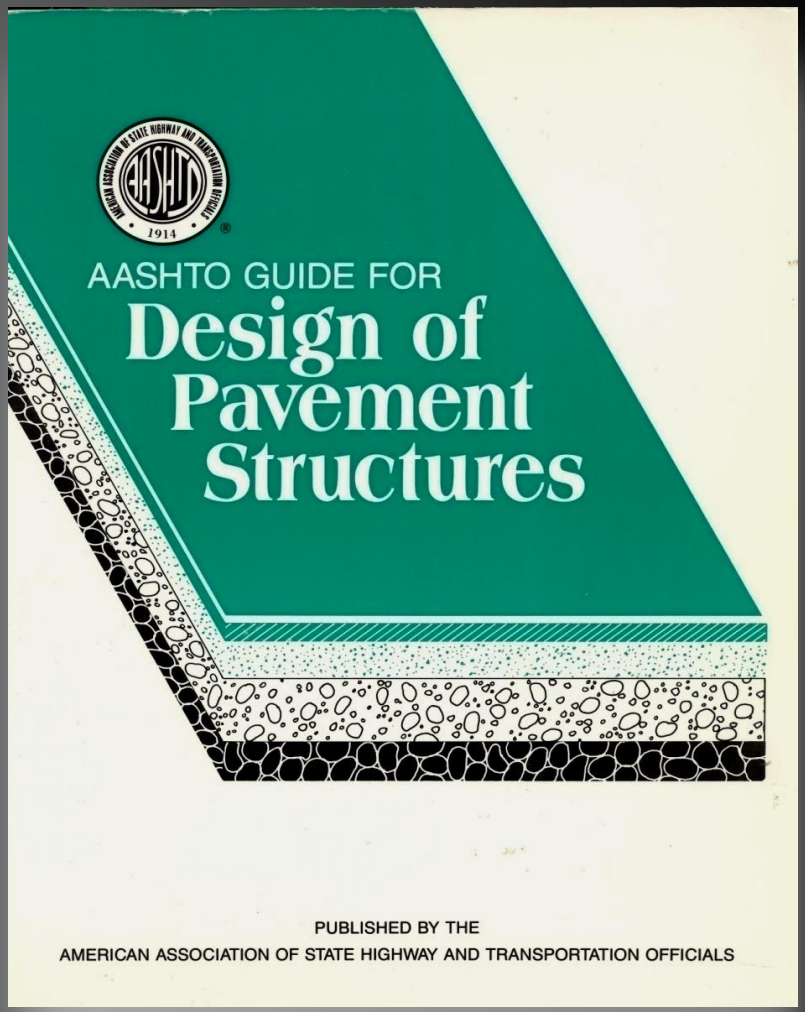
What is an ESAL?

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

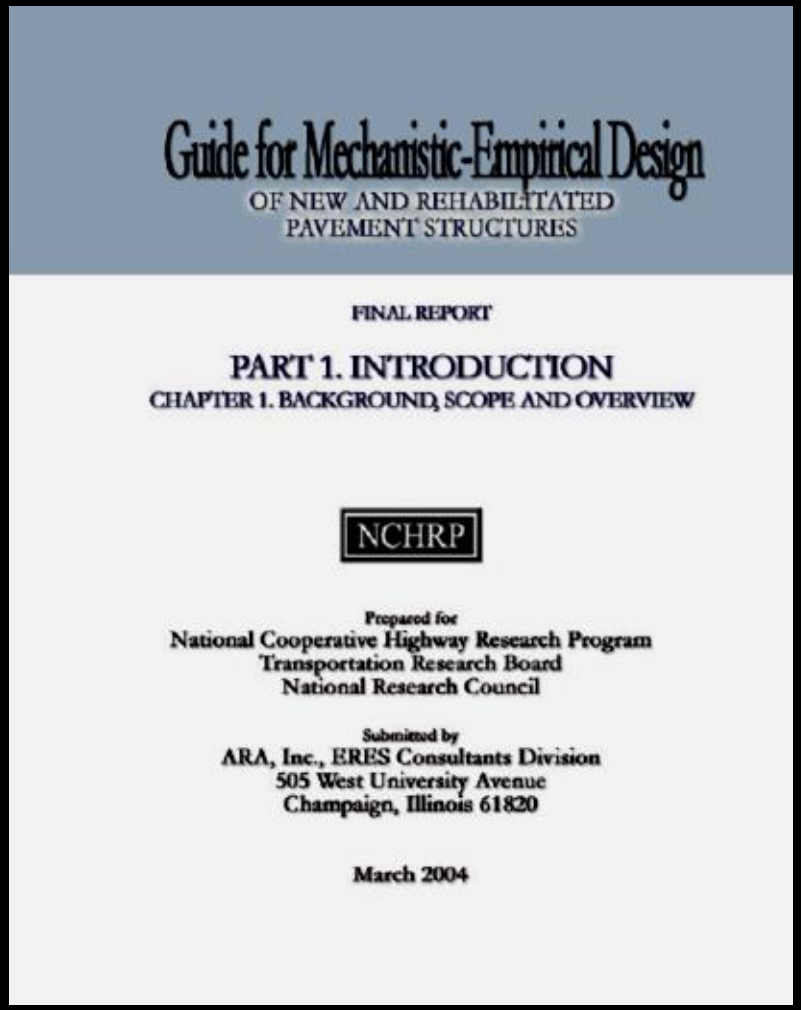




Structural Design - AASHTO



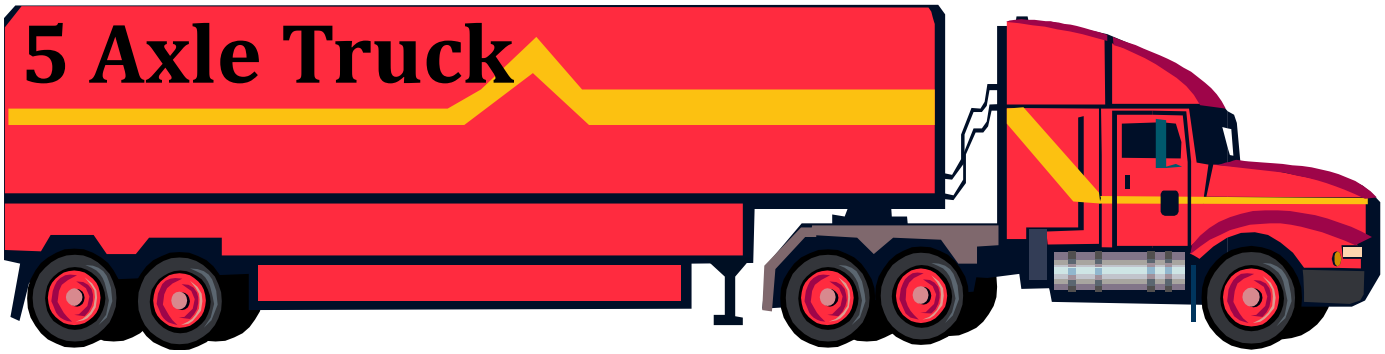
1993



ME PDG 2004

Truck Factor = ESAL per Truck

Gross Weight = 350 kN



2 x 80kN

$$\text{LEF} = \left(\frac{80}{80}\right)^4 = 1$$

2 x 70 kN

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

50 kN

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

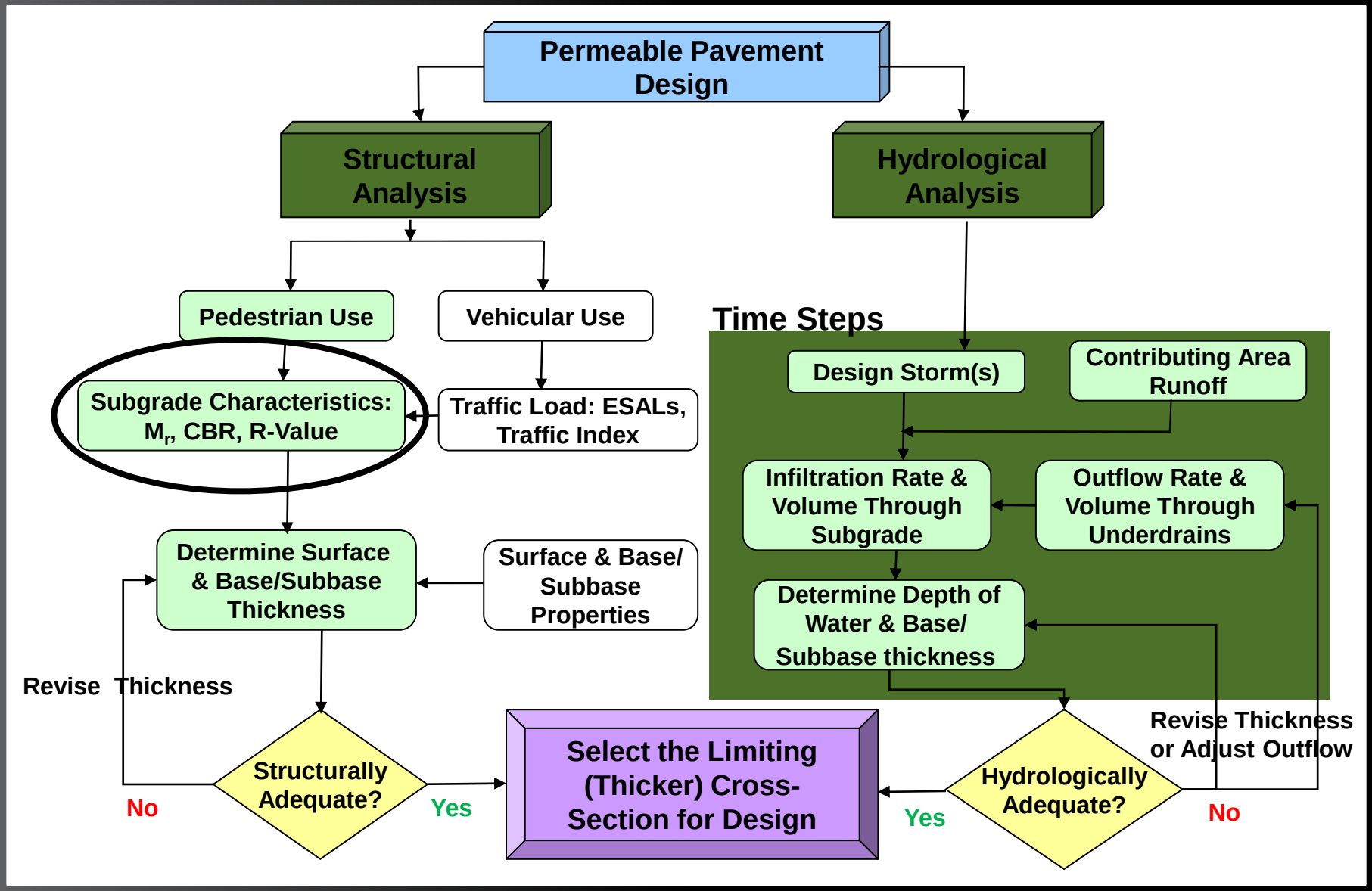
TF = 2 x 1 + 2 x 0.6 + 0.15 = 3.35 ESALs

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	

PICP Design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Revise Thickness
Structurally Adequate?
No
Yes
Select the Limiting (Thicker) Cross-Section for Design
Hydrologically Adequate?
Yes
No
Revise Thickness or Adjust Outflow

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

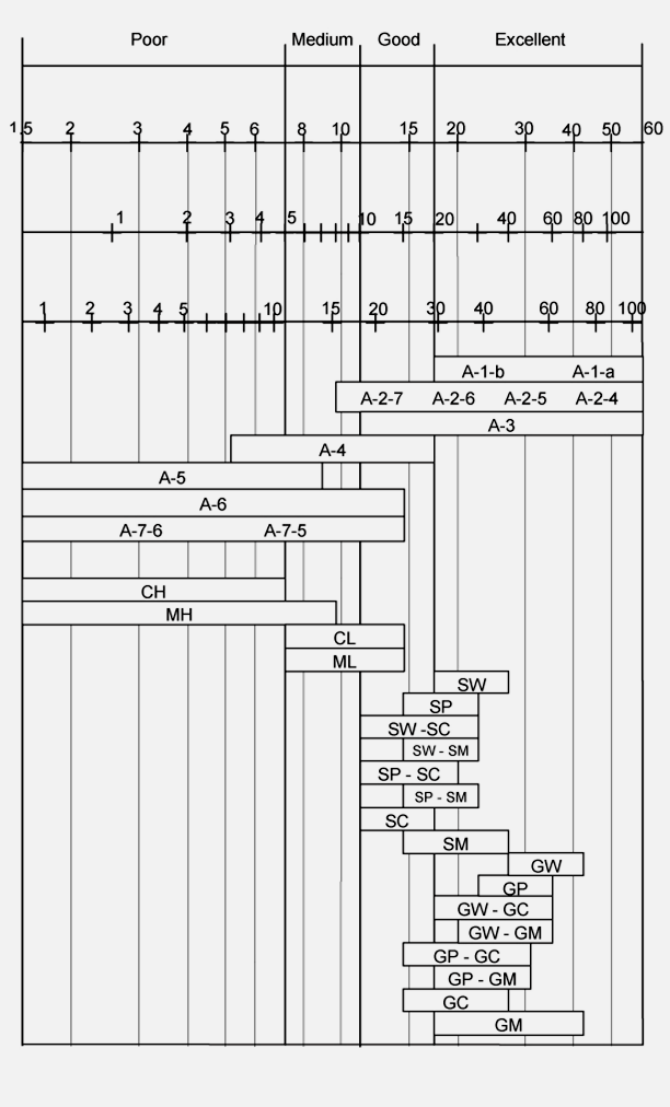
Resilient Modulus, M_r
AASHTO T-307

CBR ASTM D1883

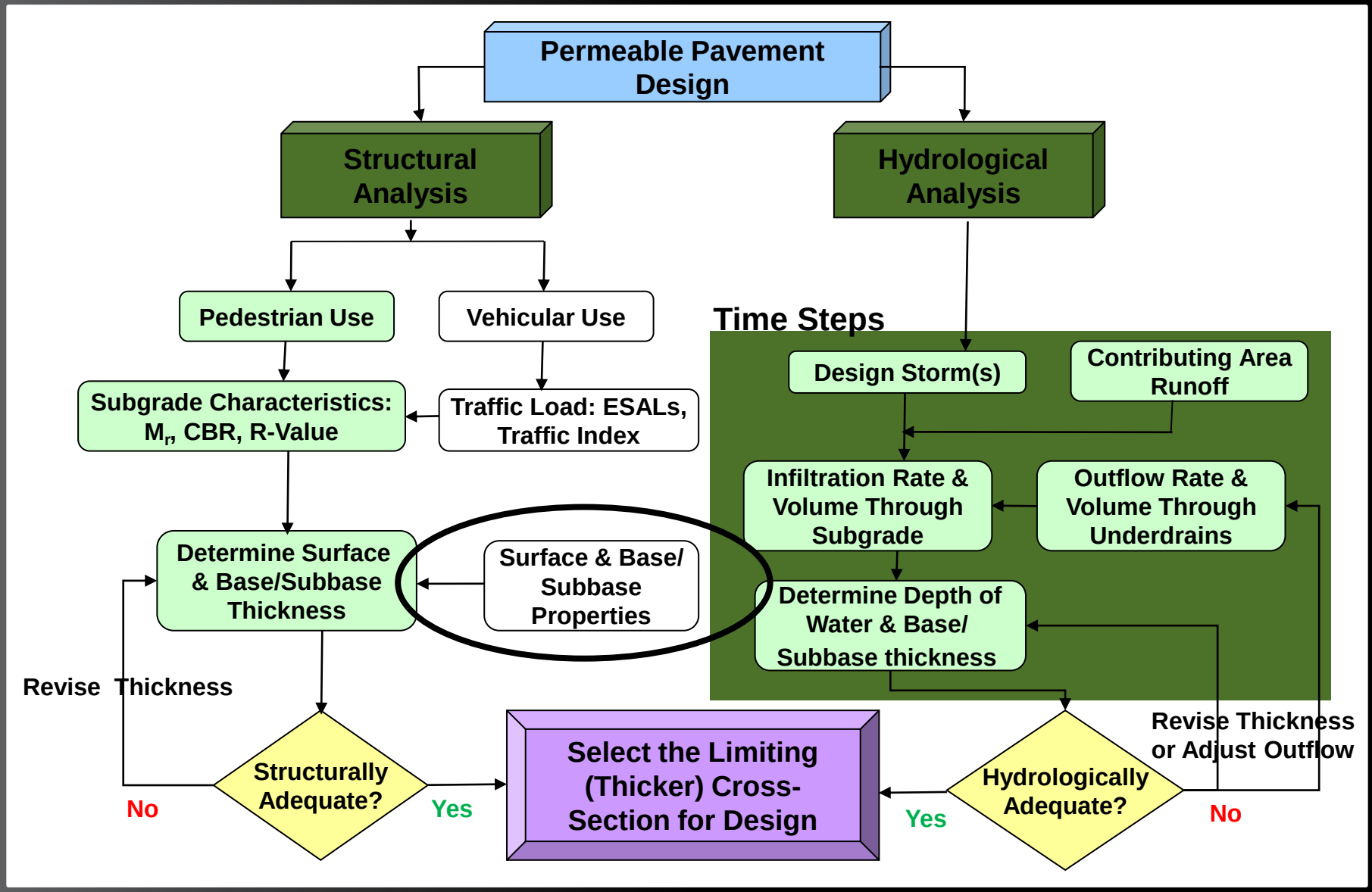
R-value ASTM D2844

AASHTO Soil Classification AASHTO M-45

Unified Soil Classification ASTM D2487



PICP Design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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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Lifetime ESALs (Traffic Index)								
50,000 (6.3) and Residential Driveways	Base thickness, in. (mm) ASTM No. 57	4 (100)						
	Subbase thickness in. (mm) ASTM No. 2	6 (150)						
100,000 (6.8)	Base thickness, in. (mm) ASTM No. 57	4 (100)						
	Subbase thickness in. (mm) ASTM No. 2	8 (200)	6 (150)					
200,000 (7.4)	Base thickness, in. (mm) ASTM No. 57	4 (100)	4 (100)					
	Subbase thickness in. (mm) ASTM No. 2	13 (325)	11 (275)	9 (225)	7 (175)	6 (150)		
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)
400,000 (8.1)	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	19 (475)	16 (400)	14 (350)	12 (300)	11 (275)	10 (250)	9 (225)
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	Subbase thickness in. (mm) ASTM No. 2	21 (525)	18 (450)	16 (400)	14 (350)	12 (300)	11 (275)	10 (250)
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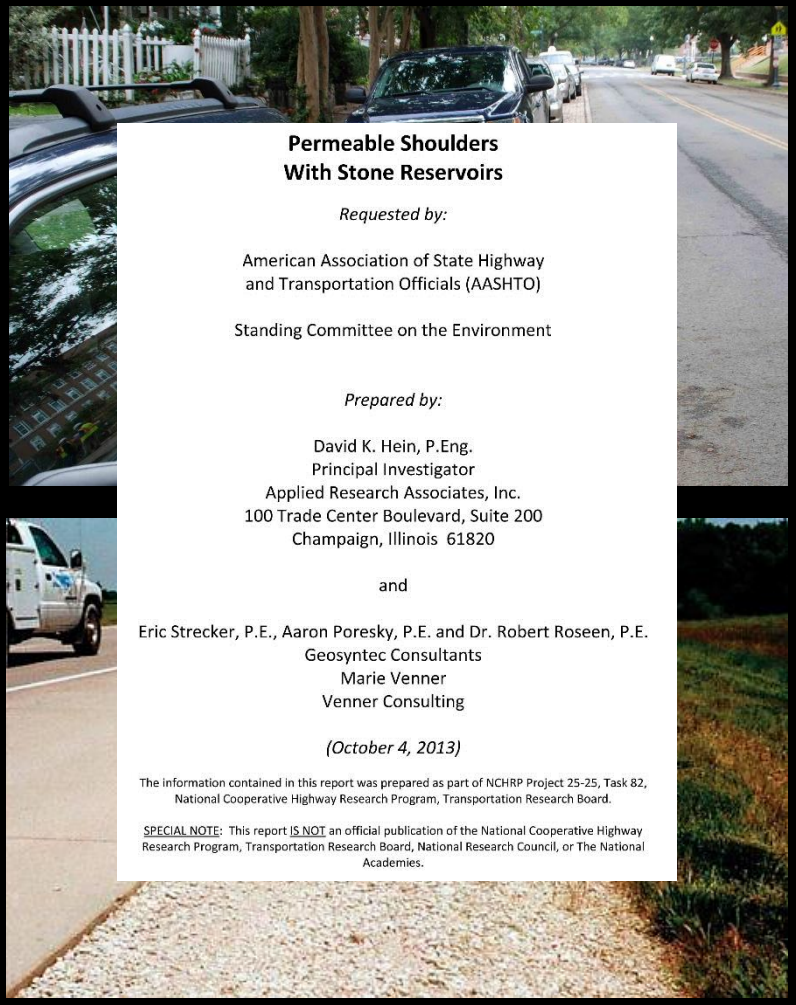
	Subbase thickness in. (mm) ASTM No. 2	22 (550)	19 (475)	17 (425)	15 (375)	14 (350)	12 (300)	11 (275)
700,000 (8.6)	Base thickness, in. (mm) ASTM No. 57	4 (100)	4 (100)	4 (100)	4 (100)	4 (100)	4 (100)	4 (100)
	Subbase thickness in. (mm) ASTM No. 2	24 (600)	21 (525)	18 (450)	17 (425)	15 (375)	14 (350)	12 (300)
800,000 (8.8)	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	25 (625)	22 (550)	20 (500)	18 (450)	16 (400)	15 (375)	13 (325)
900,000 (8.9)	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	26 (650)	23 (575)	21 (525)	19 (475)	17 (425)	16 (400)	14 (350)
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



Permeable Shoulders With Stone Reservoirs

Requested by:

American Association of State Highway and Transportation Officials (AASHTO)

Standing Committee on the Environment

Prepared by:

David K. Hein, P.Eng.
Principal Investigator
Applied Research Associates, Inc.
100 Trade Center Boulevard, Suite 200
Champaign, Illinois 61820

and

Eric Strecker, P.E., Aaron Poresky, P.E. and Dr. Robert Roseen, P.E.
Geosyntec Consultants
Marie Venner
Venner Consulting

(October 4, 2013)

The information contained in this report was prepared as part of NCHRP Project 25-25, Task 82, National Cooperative Highway Research Program, Transportation Research Board.

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

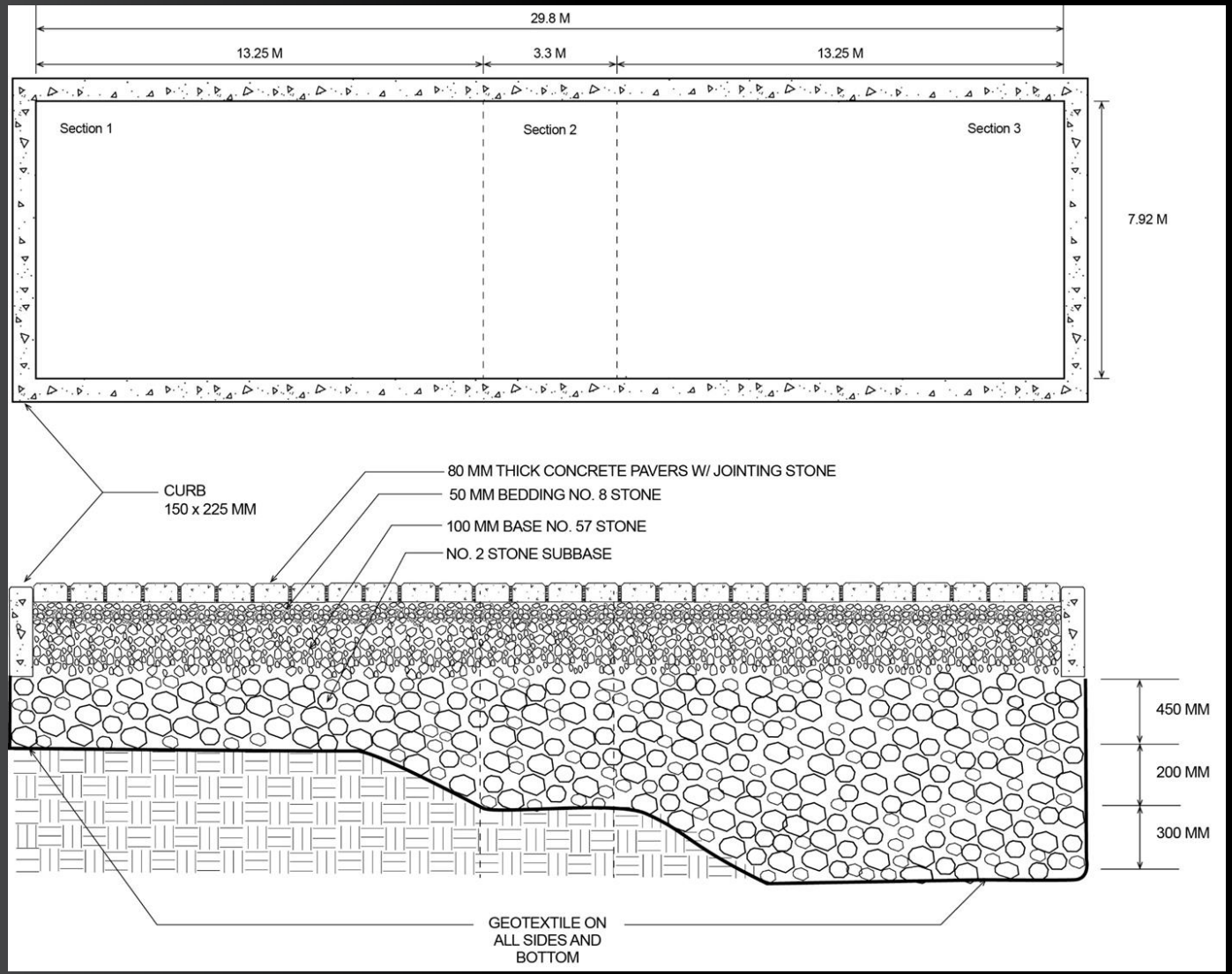
UC Davis Pavement Research Center Tasks

- 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

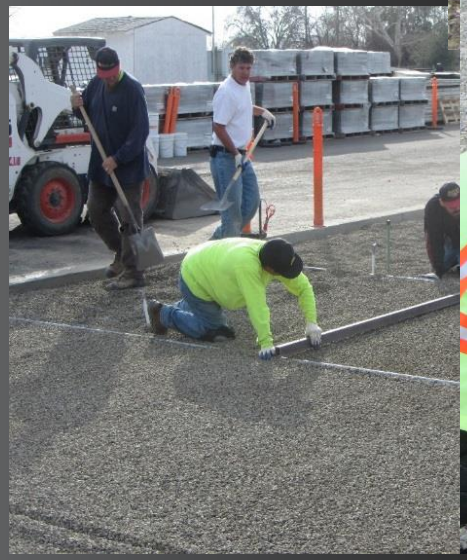
UC Davis Pavement Research Center Tasks

- 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 Repetitions	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 Repetitions	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 Repetitions	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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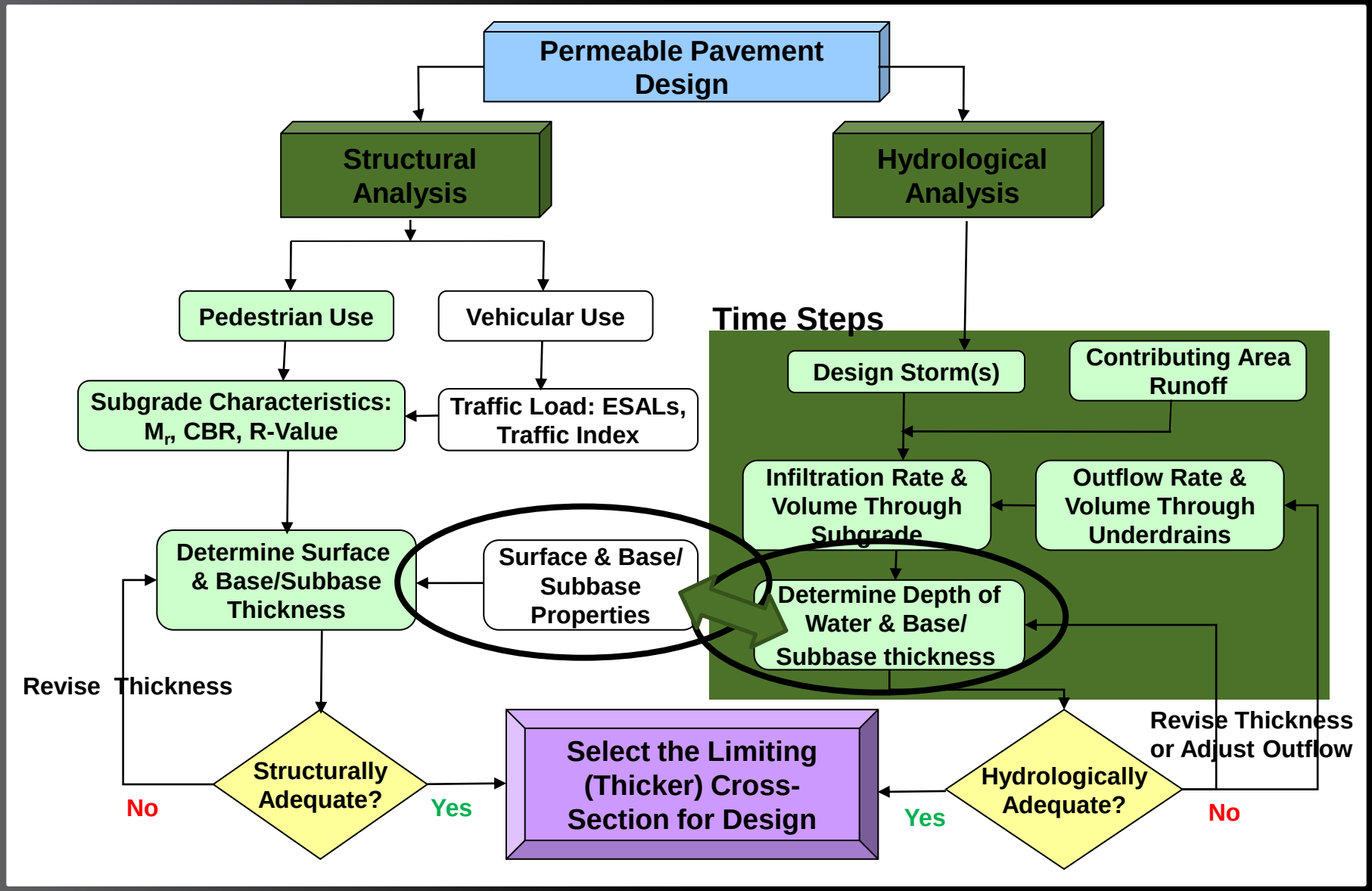
	Subbase thickness in. (mm) ASTM No. 2	26 (650)	23 (575)	21 (525)	19 (475)	17 (425)	16 (400)	14 (350)
1,000,000 (9)	Base thickness, in. (mm) ASTM No. 57	4 (100)	4 (100)	4 (100)	4 (100)	4 (100)	4 (100)	4 (100)
	Subbase thickness in. (mm) ASTM No. 2	27 (675)	24 (600)	21 (525)	19 (475)	18 (425)	16 (400)	15 (375)

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

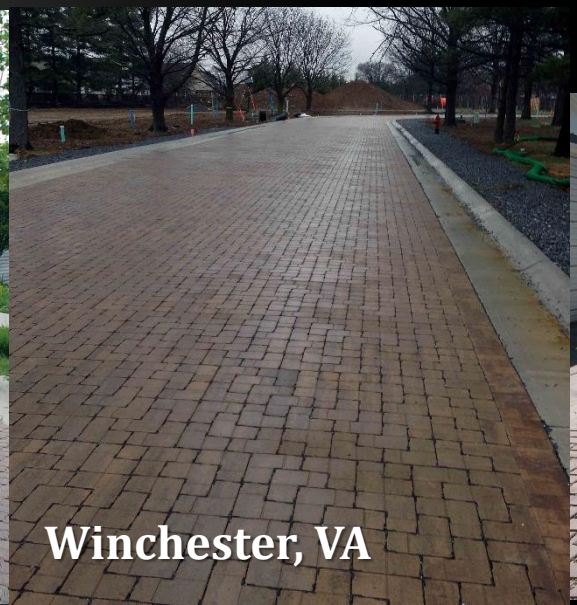
PICP Design


Permeable Pavement Design
Structural Analysis
Hydrological Analysis
Pedestrian Use
Vehicular Use
Subgrade Characteristics: M_r, CBR, R-Value
Traffic Load: ESALs, Traffic Index
Time Steps
Design Storm(s)
Contributing Area Runoff
Infiltration Rate & Volume Through Subgrade
Outflow Rate & Volume Through Underdrains
Determine Surface & Base/Subbase Thickness
Surface & Base/ Subbase Properties
Determine Depth of Water & Base/ Subbase thickness
Revise Thickness
Structurally Adequate?
No
Yes
Select the Limiting (Thicker) Cross-Section for Design
Hydrologically Adequate?
Yes
No
Revise Thickness or Adjust Outflow

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

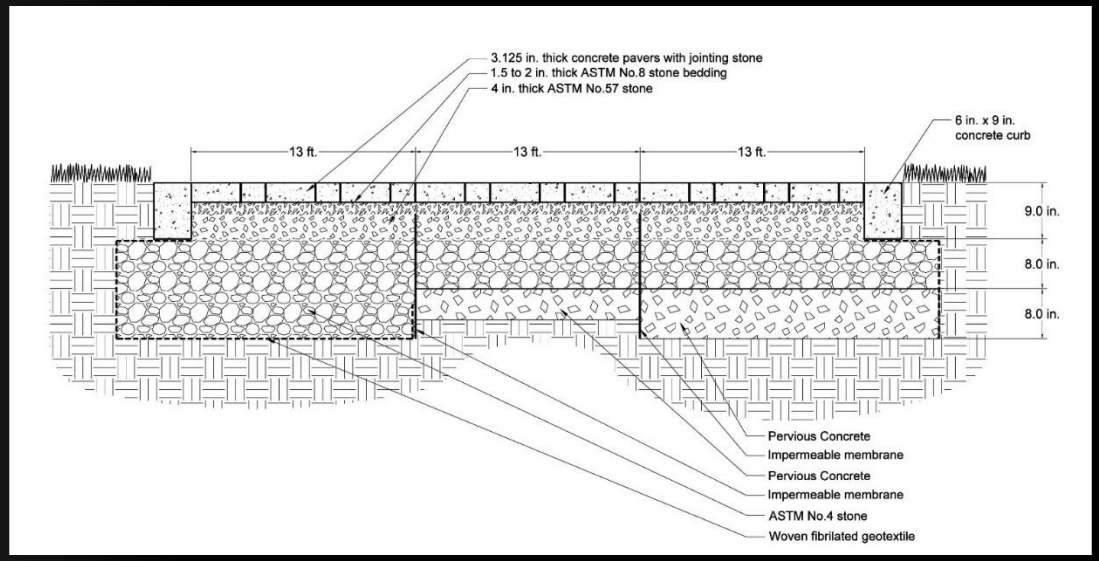

Chicago, IL


Winchester, VA


Dubuque, IA

Next Test Tracks

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



- PICP & bedding
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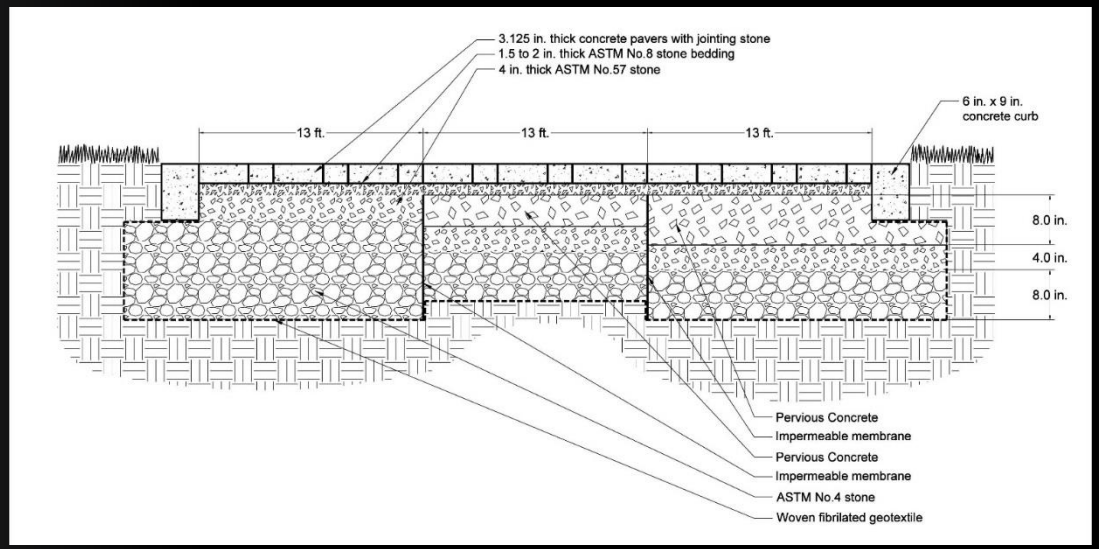
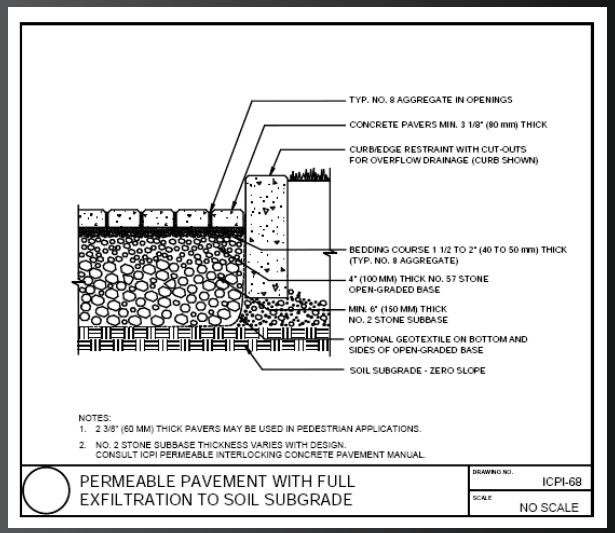
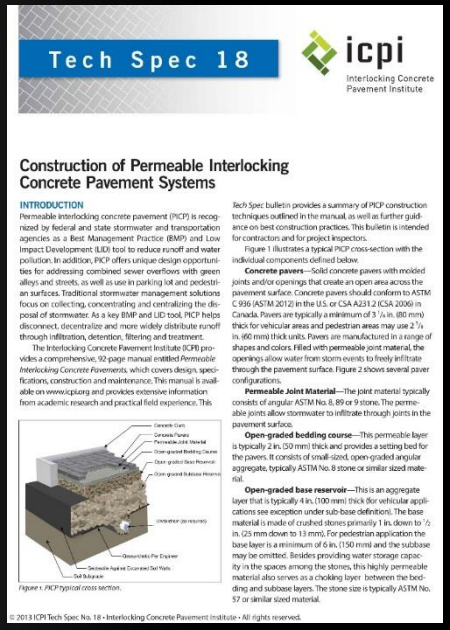
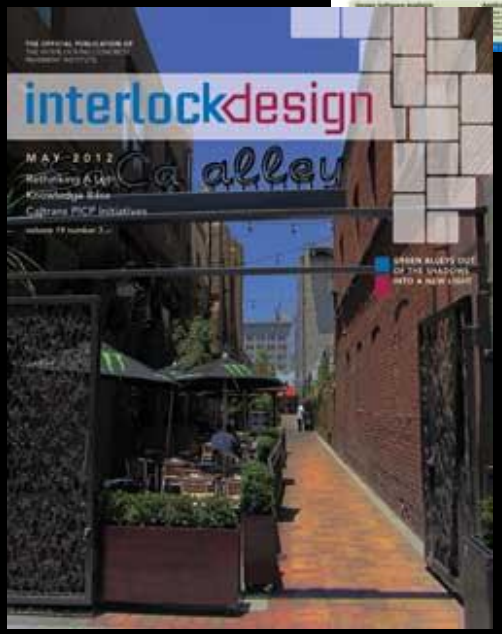


ICPI Resources

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







www.PermeableDesignPro.com

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

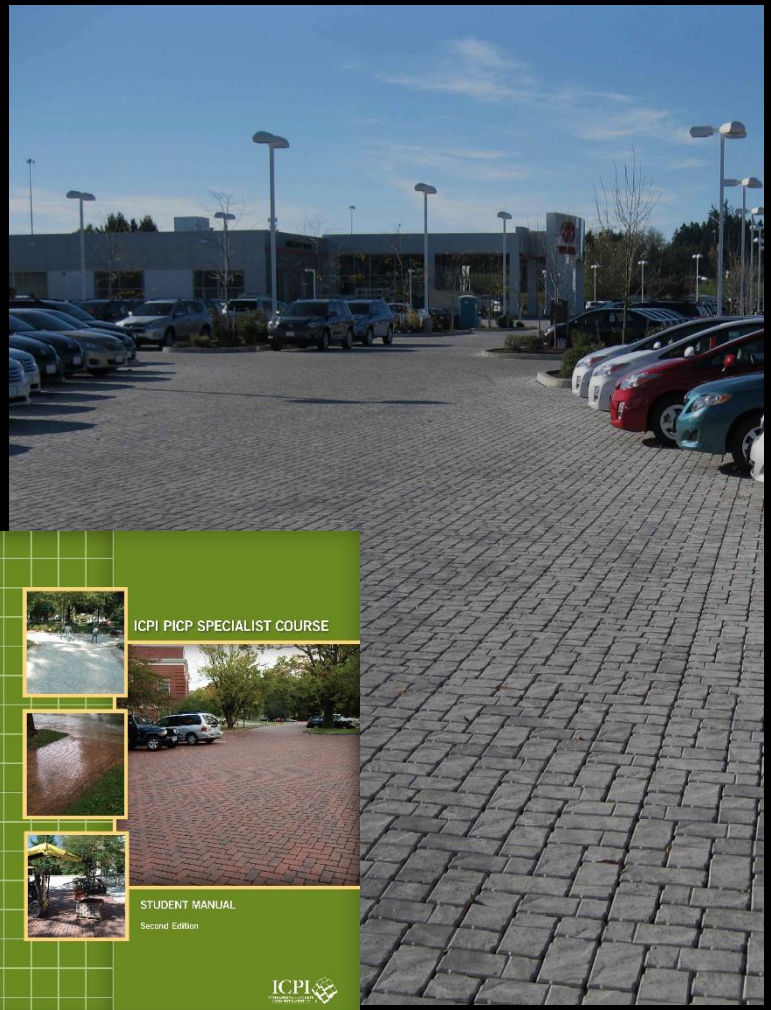
ICPI PICP Installer Designations

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

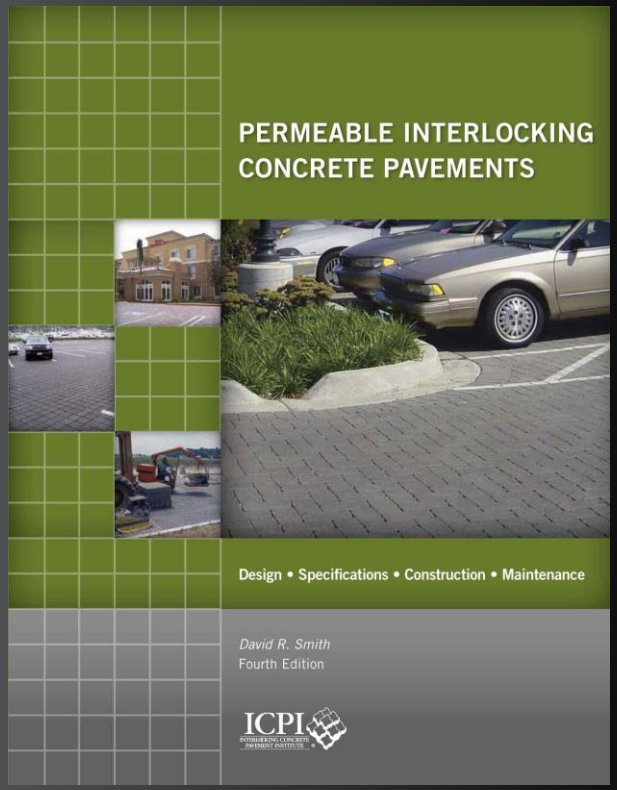
- Hold a PICP Record of Completion
- Be an ICPI Certified Installer
  - Complete 2-day Concrete Paver Installer course and pass the exam
  - Document ICP experience of 5 project and 10,000 SF
  - Earn continuing education credits: minimum of 8 hours over 2 years
  - Renew certification biennially
- Document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



ICPI & ASCE Resources

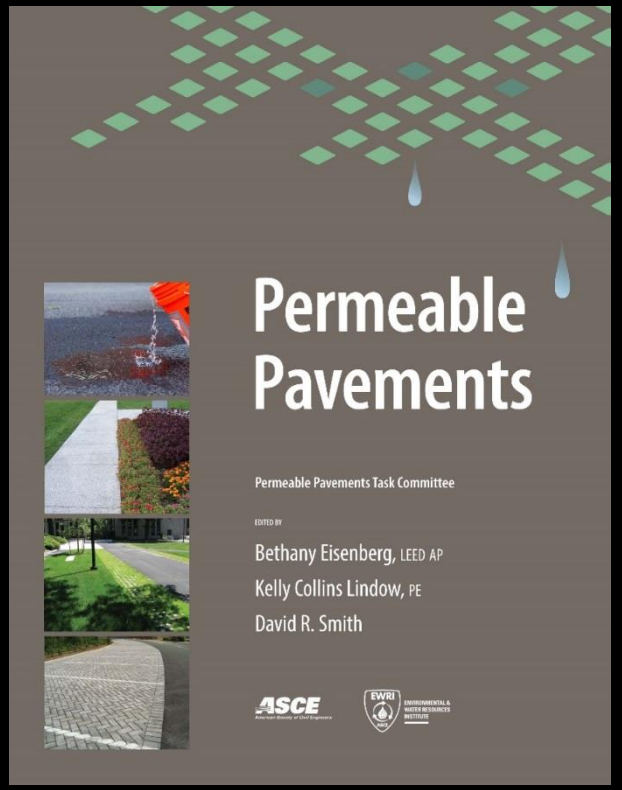
Permeable Interlocking Concrete Pavements

Design, Specifications, Construction & maintenance (100 pages)



Permeable Pavements

ASCE e-book (250 pages)



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Pavement Institute