icpi

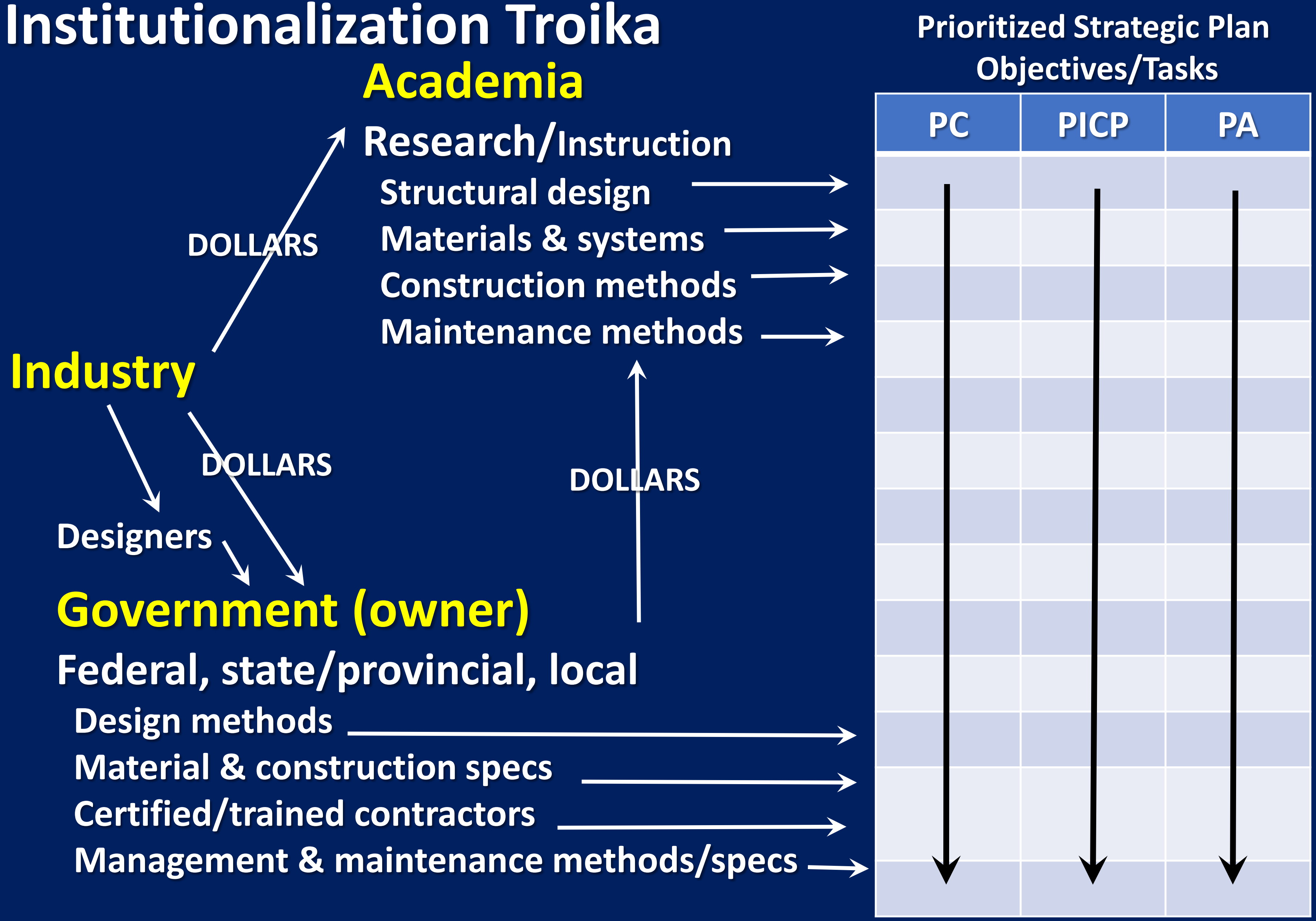
Interlocking Concrete Pavement Institute®

Permeable Pavement Road Map Conference
Industry Perspectives

November 14-15, 2018 UC Davis

David R. Smith, ICPI Technical Director

The Pavement Institutionalization Troika



Institutional:

Unlike impervious pavements….

Not enough ownership to justify research investment

How much ownership is required?

Research plan needed

Webinars, NHI courses on permeable pavements

How to transform existing state DOT specs

Road Agency Ownership

PICP in *many* state & local stormwater guides

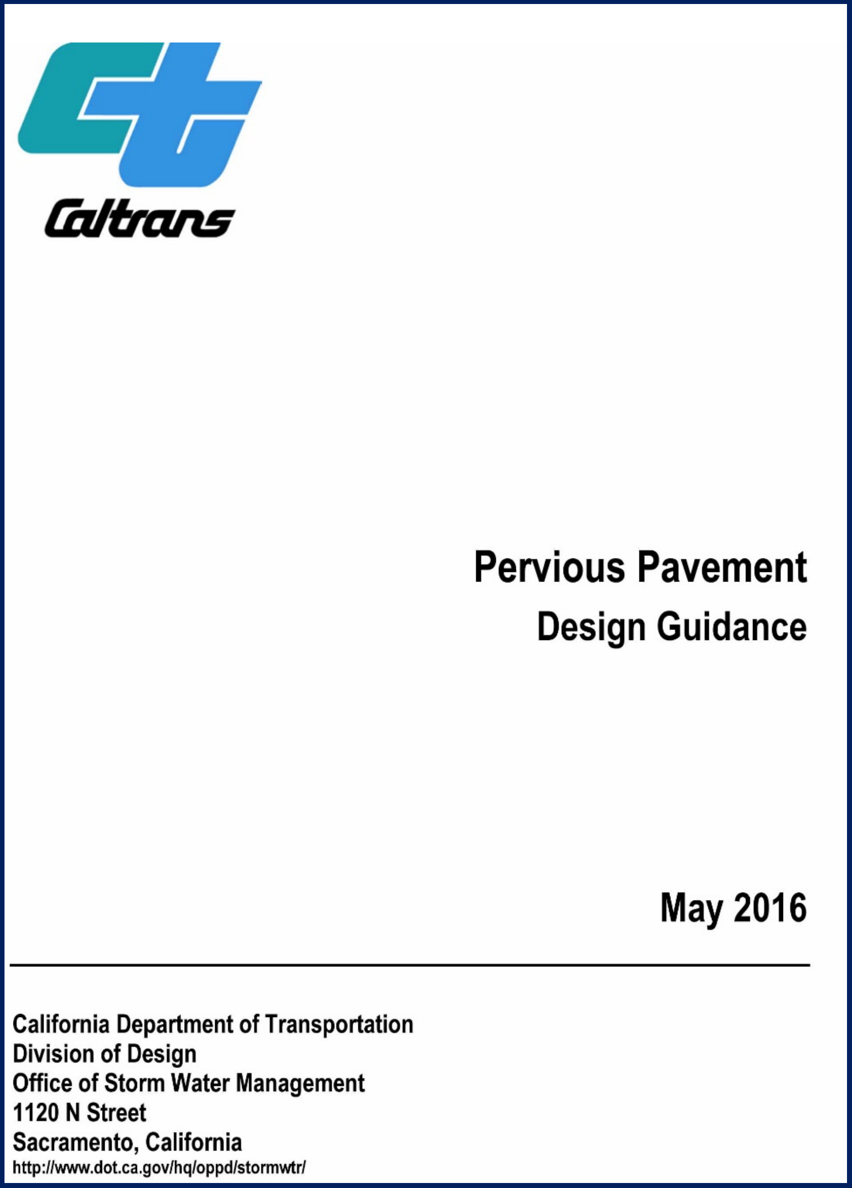
Only a few DOT specs so far

DOTs

- Safety is priority, drainage is not

Stormwater Agencies

- NPDES permit is priority
- Safety & resilience



Caltrans

Pervious Pavement

Design Guidance

May 2016

California Department of Transportation
Division of Design
Office of Storm Water Management
1120 N Street
Sacramento, California
http://www.dot.ca.gov/hq/oppd/stormwtr/

Technical Barriers

Design methods for saturated soils

Load testing & design for hybrid structures – *exceed* 1 million ESALs design life

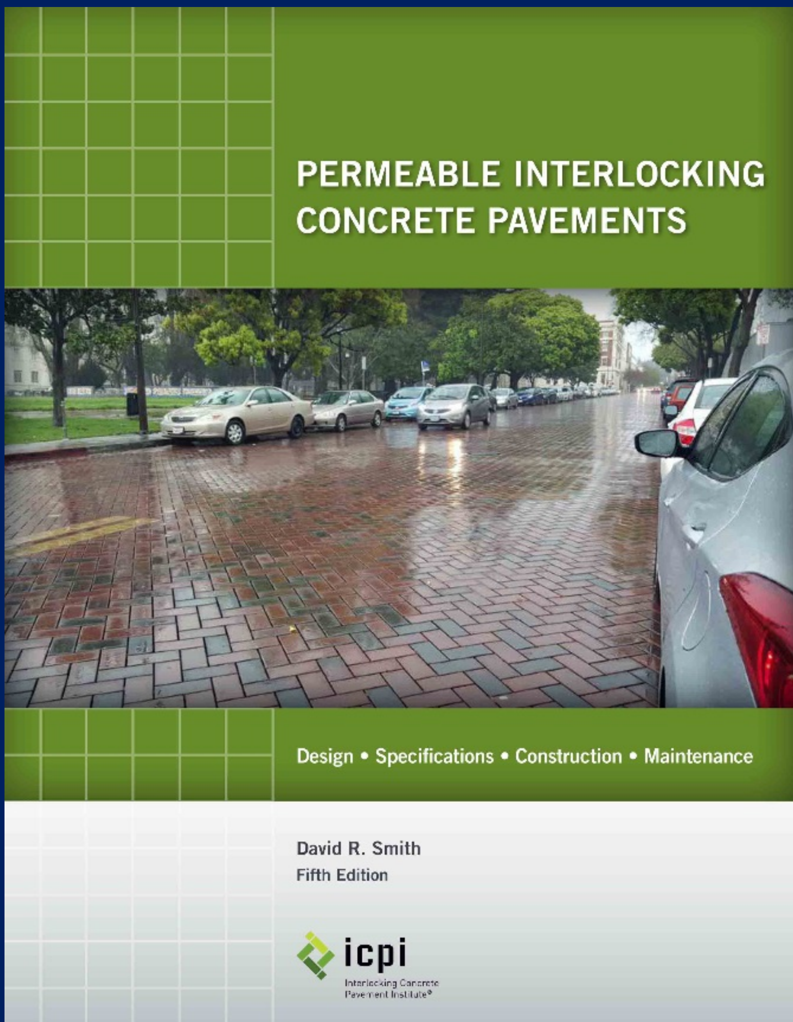
Lightweight deflectometers for OGB QC/QA compaction

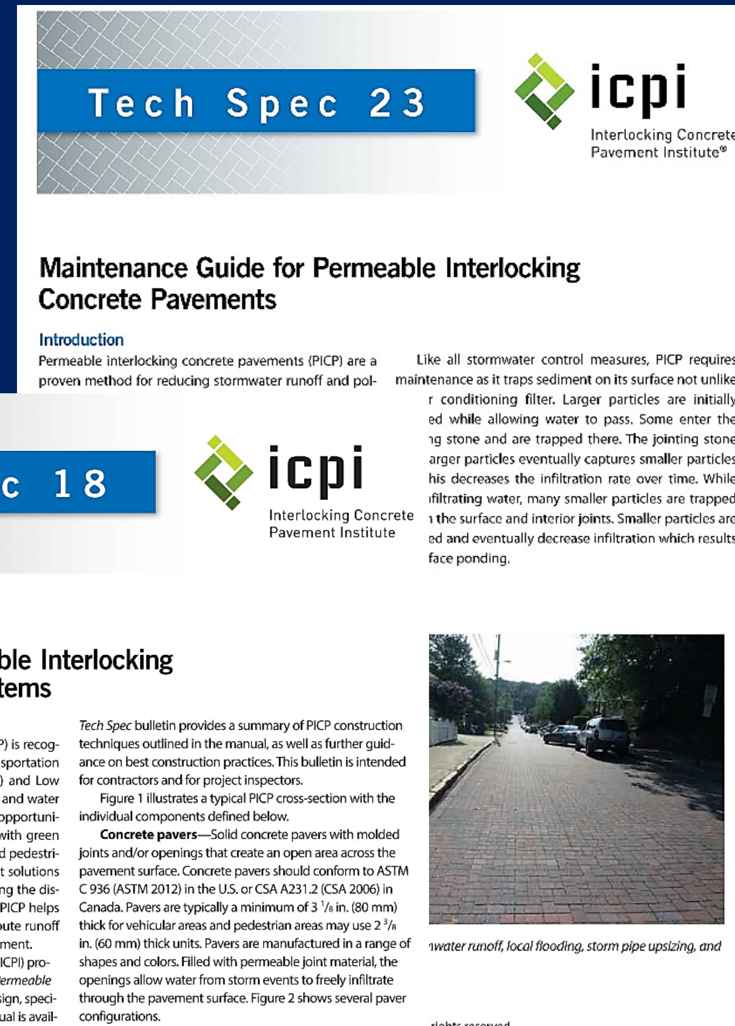
Surface cleaning & maintenance *costs* for LCCA models & GI/stormwater/road asset management

Life cycle assessment…including use phase

The Past: What We've Done

Manuals & Technical Bulletins
Guide specs & detail drawings





Tech Spec 23

icpi Interlocking Concrete Pavement Institute®

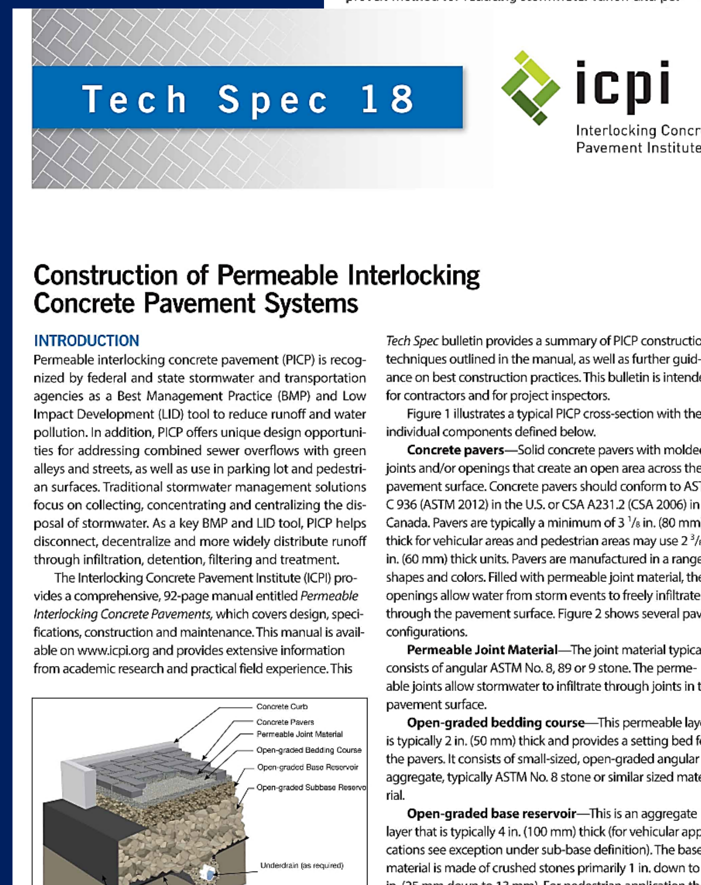
Maintenance Guide for Permeable Interlocking Concrete Pavements

Introduction

Permeable interlocking concrete pavements (PICP) are a proven method for reducing stormwater runoff and pol-

Like all stormwater control measures, PICP requires maintenance as it traps sediment on its surface not unlike r conditioning filter. Larger particles are initially ed while allowing water to pass. Some enter the ng stone and are trapped there. The jointing stone arger particles eventually captures smaller particles his decreases the infiltration rate over time. While ıfiltrating water, many smaller particles are trapped ı the surface and interior joints. Smaller particles are ed and eventually decrease infiltration which results face ponding.

ıwater runoff, local flooding, storm pipe upsizing, and



Tech Spec 18

icpi Interlocking Concrete Pavement Institute

Construction of Permeable Interlocking Concrete Pavement Systems

INTRODUCTION

Permeable interlocking concrete pavement (PICP) is recognized by federal and state stormwater and transportation agencies as a Best Management Practice (BMP) and Low Impact Development (LID) tool to reduce runoff and water pollution. In addition, PICP offers unique design opportunities for addressing combined sewer overflows with green alleys and streets, as well as use in parking lot and pedestrian surfaces. Traditional stormwater management solutions focus on collecting, concentrating and centralizing the disposal of stormwater. As a key BMP and LID tool, PICP helps disconnect, decentralize and more widely distribute runoff through infiltration, detention, filtering and treatment.

The Interlocking Concrete Pavement Institute (ICPI) provides a comprehensive, 92-page manual entitled *Permeable Interlocking Concrete Pavements*, which covers design, specifications, construction and maintenance. This manual is available on www.icpi.org and provides extensive information from academic research and practical field experience. This

Concrete Curb
Concrete Pavers
Permeable Joint Material
Open-graded Bedding Course
Open-graded Base Reservoir
Open-graded Subbase Reservo
Underdrain (as required)

Tech Spec bulletin provides a summary of PICP construction techniques outlined in the manual, as well as further guidance on best construction practices. This bulletin is intended for contractors and for project inspectors.

Figure 1 illustrates a typical PICP cross-section with the individual components defined below.

Concrete pavers—Solid concrete pavers with molded joints and/or openings that create an open area across the pavement surface. Concrete pavers should conform to ASTM C 936 (ASTM 2012) in the U.S. or CSA A231.2 (CSA 2006) in Canada. 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, the openings allow water from storm events to freely infiltrate through the pavement surface. Figure 2 shows several paver configurations.

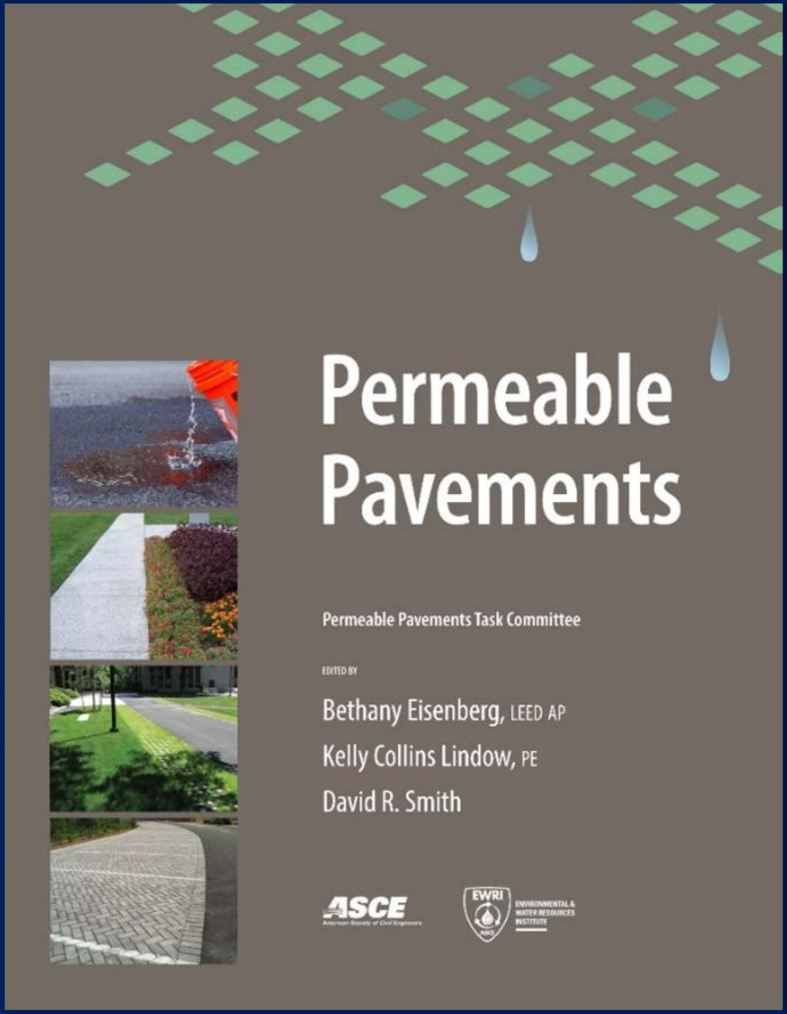
Permeable Joint Material—The joint material typically consists of angular ASTM No. 8, 89 or 9 stone. The permeable joints allow stormwater to infiltrate through joints in the pavement surface.

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

Open-graded base reservoir—This is an aggregate layer that is typically 4 in. (100 mm) thick (for vehicular applications see exception under sub-base definition). The base material is made of crushed stones primarily 1 in. down to $^{1}/_{2}$

www.PermeableDesignPro.com

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



2015

ASCE/ANSI Standard

Permeable Interlocking Concrete Pavements

Standard Guide for Design, Construction and Maintenance

Early 2018

The Present: What We Know

Hydrologic design via water balance

Volume & pollutant reductions

Source: ICPI PICP manual

Study	Type	Site Location	Sampled Events	Concentration (C) or Mass (M)	% Average Removal Efficiency											
					NH3	NO3,2	TKN	TN	OP	TP	TSS	Cd	Pb	Zn	Cu	TPH-D
Bean 2007	PICP	Goldsboro, NC	6-14	C	84	-47	60	42	42	63	33			88	62	
Boving 2008	PA	Kingston, RI	14	C				27		27				90	90	
Brattebo 2003	PICP	Renton, WA	9	C										69	89	
Collins 2010	PC	Kinston, NC	20	C	85	-152	42	-2								
Collins 2010	PICP	Kinston, NC	19	C	85	-331	50	-40								
Collins 2010	PICP	Kinston, NC	19	C	85	-210	50	-11								
Gilbert 2006	PICP	Waterford, CT	1 year	C	72	50	91			34	67		67	71	65	
Dierks 2010	PICP	Ann Arbor, MI	5	C					31	56	12			6	0	
Fassman 2011	PICP	Auckland, NZ	3-13	C							49			93	57	
Pagatto 2000	PA	Nantes, France	25	C	73	69	43				81	69	78	66	35	
Rankin 2004	PICP	Port Adelaide, Australia	9	C			59			43	40		22	43	8	
Roseen 2009	PA	Durham, NH	24 mos.	C						25	96			80		99
Roseen 2011	PA	Durham, NH	13-16	C		-87				20	89			75		92
Roseen 2013	PICP	Durham, NH	18	C	95	95	95	95	95	95	95			95		95
Rushton 2001	PC	Tampa, FL	12-30	C	0	48		28	55	56	31		58	36	58	
Rushton 2001	PC	Tampa, FL	12-30	C	0	36		26	32	39	62		69	53	67	
Smolek 2016	PICP	Durham, NC	19 - 29	C	37			68		96	98		93	90	79	
Van Seters 2007	PICP	North York, ON	27-40	C		-68	53			53	81			73	13	
Drake 2012	PICP	Vaughan, ON	31-45	C	90	-4	89		82	86	89		27		75	
Drake 2012	PICP	Vaughan, ON	45	C	90	-18	87		82	86	87		-20	78	71	
Drake 2012	PC	Vaughan, ON	30-45	C	90	21	78		38	52	79		-5	87	49	
Fassman 2011	PICP	Auckland, NZ	3-13	M							65			93	79	
Legret 1999	PA	Reze, France	11	M							59	77	84	73		
Pagatto 2000	PA	Nantes, France	25	M							77	62	74	59	21	
Rushton 2001	PC	Tampa, FL	12-30	M							91		85	75	81	
Winston 2015	PICP	Willoughby Hills, OH	18	M		-23	42	23	1	30	#		-55	37	13	
Winston 2015	PICP	Willoughby Hills, OH	12	M		42	56	52	22	40	##		-47	53	30	
Winston 2017	PICP	Huron, OH	16	M			67	63	-56	82	100		15	40	14	
Average Concentration Removal					80.7	-42.7	66.3	25.9	57.0	55.4	68.1	69.0	43.1	70.1	58.4	95.3
Average Mass Removal						9.5	55.0	46.1	-10.9	50.5	78.3	69.5	26.1	61.5	39.7	

Author	Type	Location	Events	CDA Ratio, %	Soil	Underdrains	Mean Volume Reduction, %
Bean 2007	PICP	Goldsboro, NC	14	0	sand	No	100
Bean 2007*	PICP	Swansboro, NC	16	0	sand	No	100
Boving	PA	Kingston, RI	14	0	gravel	No	100
Brattebo 2003*	PICP	Renton, WA	15	0	NR	No	100
Booth 1996*	PICP	Renton, WA	3	0	NR	No	100
Collins 2010	PC	Kinston, NC	51	0	sandy clay	Yes	13
Collins 2010	PICP	Kinston, NC	50	0	loam	Yes	48
Collins 2010	PICP	Kinston, NC	46	0	sandy clay	Yes	3
Gilbert 2006	PICP	Waterford, CT	1 year	Varied	sandy clay	No	72
Dierks 2010*	PICP	Ann Arbor, MI	14	300	NR	Yes	80
Fassman 2010	PICP	Auckland, NZ	44	100	silty clay	Yes	28
Rankin 2002*	PICP	Port Adelaide, Australia	22	45	sandy	No	93
James 1997	PICP	Guelph, ON	9	0	NR	NR	38
James 1997	PICP	Guelph, ON	9	0	NR	NR	61
Legret 1999	PA	Reze, France	40	37	NR	Yes	97
Roseen 2013	PICP	Durham, NH	18	0	sandy clay	Yes	100
Roseen 2012	PA	Durham, NH	17	0	HSG C	No	25
Rushton 2001	PC	Tampa, FL	30	0	sandy	No	29
Rushton 2001	PC	Tampa, FL	30	0	sandy	No	32
Smolek 2016	PICP	Durham, NC	29	300	HSG D	Yes	22
Van Seters 2008	PICP	North York, ON	71	0	clay loam	Yes	90
Drake 2012	PICP	Vaughan, ON	185	0	silty clay	Yes	45
Drake 2012	PICP	Vaughan, ON	185	0	silty clay	Yes	45
Drake 2012	PC	Vaughan, ON	185	0	silty clay	Yes	45
Winston 2015*	PICP	Willoughby Hills, OH	77	220	silt loam HSG D	Yes	32
Winston 2015*	PICP	Willoughby Hills, OH	77	720	silt loam HSG D	Yes	16
Winston 2015*	PICP	Orange Village, OH	77	0	silt loam HSG D	Yes	99

The Present: What We Know

Structural Design to 1 million ESALs

UC Davis full-scale load testing & mechanistic modeling

2014 - Subbase thickness design tables

Tables in ICPI PICP 5th edition manual & ASCE PICP standard

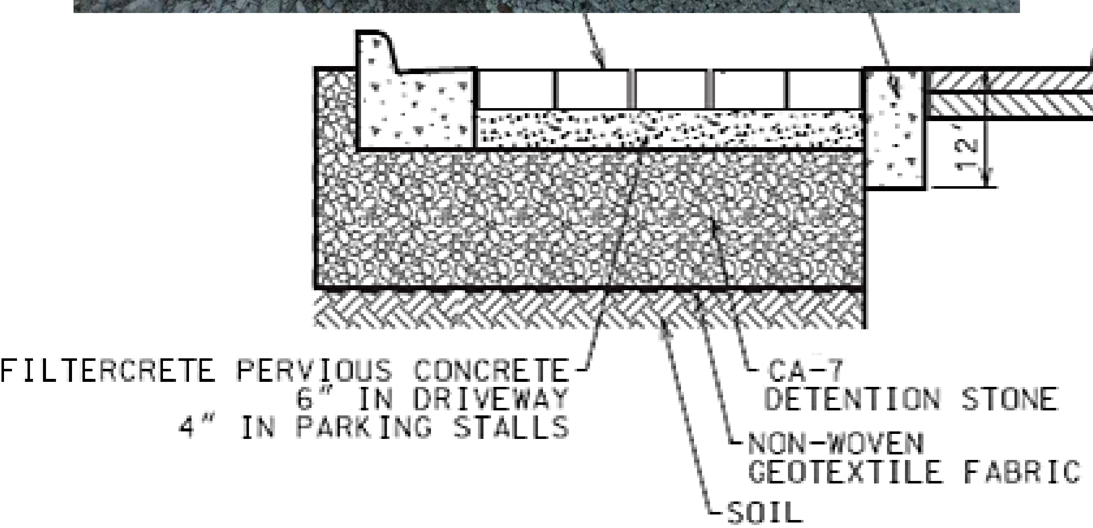
PICP Structural Design
Design Tables

Number of Days in a Year Water Stands in Subbase		0				≤10				11 - 30				31 - 50			
Subgrade Resilient Modulus, ksi (CBR)	Dry	5.8	8.7	11.6	14.5	5.8	8.7	11.6	14.5	5.8	8.7	11.6	14.5	5.8	8.7	11.6	14.5
	Wet	3.5 (1.6)	5.2 (3)	6.7 (4.8)	8.7 (6.8)	3.5 (1.6)	5.2 (3)	6.7 (4.8)	8.7 (6.8)	3.5 (1.6)	5.2 (3)	6.7 (4.8)	8.7 (6.8)	3.5 (1.6)	5.2 (3)	6.7 (4.8)	8.7 (6.8
Lifetime ESALs (Traffic Index)		Minimum Subbase Thickness in mm ASTM No. 2 for 1 in. Allowable Rut Depth (All subbases are under 4 in. thick ASTM No. 57 base, under 2 in. ASTM No. 8 bedding layer under 3 1/8 in. thick concrete pavers.)															
50,000 (6.3)		6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	7.0	6.0	6.0	6.0
100,000 (6.8)		6.0	6.0	6.0	6.0	8.5	6.0	6.0	6.0	10.5	6.0	6.0	6.0	11.5	7.0	6.0	6.0
200,000 (7.4)		9.0	6.0	6.0	6.0	12.5	8.5	6.0	6.0	14.5	10.0	6.5	6.0	16.0	11.5	7.5	6.0
300,000 (7.8)		11.5	7.0	6.0	6.0	15.0	10.5	7.0	6.0	17.0	12.5	8.5	6.0	18.0	13.5	9.5	6.5
400,000 (8.1)		13.0	9.0	6.0	6.0	17.0	12.0	8.5	6.0	19.0	14.0	10.0	7.0	20.0	15.0	11.0	8.0
500,000 (8.3)		14.5	10.0	6.5	6.0	18.0	13.5	9.5	6.5	20.0	15.0	11.0	8.0	21.0	16.5	12.0	9.0
600,000 (8.5)		15.5	11.0	7.5	6.0	19.0	14.5	10.5	7.0	21.0	16.0	12.0	9.0	22.0	17.5	13.0	10.0
700,000 (8.6)		16.5	12.0	8.0	6.0	20.0	15.0	11.0	8.0	22.0	17.0	13.0	10.0	23.0	18.0	14.0	11.0
800,000 (8.8)		17.0	12.5	9.0	6.0	20.5	16.0	12.0	8.5	22.5	17.5	13.5	10.5	24.0	19.0	14.5	11.5
900,000 (8.9)		17.5	13.0	9.5	6.0	21.0	16.5	12.5	9.0	23.5	18.0	14.0	11.0	24.5	19.5	15.0	12.0
1,000,000 (9.0)		18.0	13.5	10.0	6.5	22.0	17.0	13.0	9.5	24.0	19.0	14.5	11.5	25.0	20.0	15.5	12.5

PICP Structural Design
Design Tables (continued)

Number of Days in a Year Water Stands in Subbase	51 - 70				71 - 90				91 - 110				111 - 130			
Subgrade Resilient Modulus, ksi (CBR) Dry	5.8	8.7	11.6	14.5	5.8	8.7	11.6	14.5	5.8	8.7	11.6	14.5	5.8	8.7	11.6	14.5
Wet	3.5 (1.6)	5.2 (3)	6.7 (4.8)	8.7 (6.8)	3.5 (1.6)	5.2 (3)	6.7 (4.8)	8.7 (6.8)	3.5 (1.6)	5.2 (3)	6.7 (4.8)	8.7 (6.8)	3.5 (1.6)	5.2 (3)	6.7 (4.8)	8.7 (6.8)
Lifetime ESALs (Traffic Index)	Minimum Subbase Thickness in mm ASTM No. 2 for 1 in. Allowable Rut Depth (All subbases are under 4 in. thick ASTM No. 57 base, under 2 in. ASTM No. 8 bedding layer under 3 1/8 in. thick concrete pavers.)															
50,000 (6.3)	8.0	6.0	6.0	6.0	8.5	6.0	6.0	6.0	9.0	6.0	6.0	6.0	9.5	6.0	6.0	6.0
100,000 (6.8)	12.0	8.0	6.0	6.0	13.0	8.5	6.0	6.0	13.0	9.0	6.0	6.0	14.0	9.5	6.0	6.0
200,000 (7.4)	16.5	12.0	8.0	6.0	17.0	13.0	8.5	6.0	17.5	13.0	9.0	6.0	18.0	13.5	9.5	6.5
300,000 (7.8)	18.5	14.0	10.0	7.0	20.0	15.0	11.0	8.0	20.0	15.5	11.0	8.5	20.5	15.5	11.5	8.5
400,000 (8.1)	20.5	15.5	11.5	8.5	21.5	16.5	12.5	9.5	21.5	17.0	13.0	9.5	22.0	17.5	13.0	10.0
500,000 (8.3)	21.5	17.0	13.0	9.5	23.0	18.0	13.5	10.5	23.0	18.0	14.0	10.5	23.5	18.5	14.0	11.0
600,000 (8.5)	23.0	18.0	14.0	10.5	24.0	19.0	14.5	11.0	24.0	19.0	15.0	11.5	24.5	19.5	15.0	12.0
700,000 (8.6)	23.5	18.5	14.5	11.0	25.0	19.5	15.0	12.0	25.0	20.0	15.5	12.0	25.5	20.5	16.0	12.5
800,000 (8.8)	24.5	19.5	15.0	12.0	25.5	20.0	16.0	12.5	26.0	20.5	16.0	13.0	26.0	21.0	16.5	13.5
900,000 (8.9)	25.0	20.0	15.5	12.5	26.0	21.0	16.5	13.0	26.5	21.0	16.5	13.5	27.0	21.5	17.0	14.0
1,000,000 (9.0)	25.5	20.5	16.0	13.0	27.0	21.5	17.0	13.5	27.0	21.5	17.0	14.0	27.5	22.0	17.5	14.5

Hybrid: PICP over PC in Chicago, IL



Hybrid designs can *triple* ESAL capacity

icpi

Interlocking Concrete Pavement Institute

icpi

Foundation for Education and Research

dsmith@icpi.org
rbowers@icpi.org

Beyond parking lots & alleys to streets