FOUNDATION PERFORMANCE ASSOCIATION

Industrial Concrete Paver Presentation

KEYSTONE® HARDSCAPES

Objectives

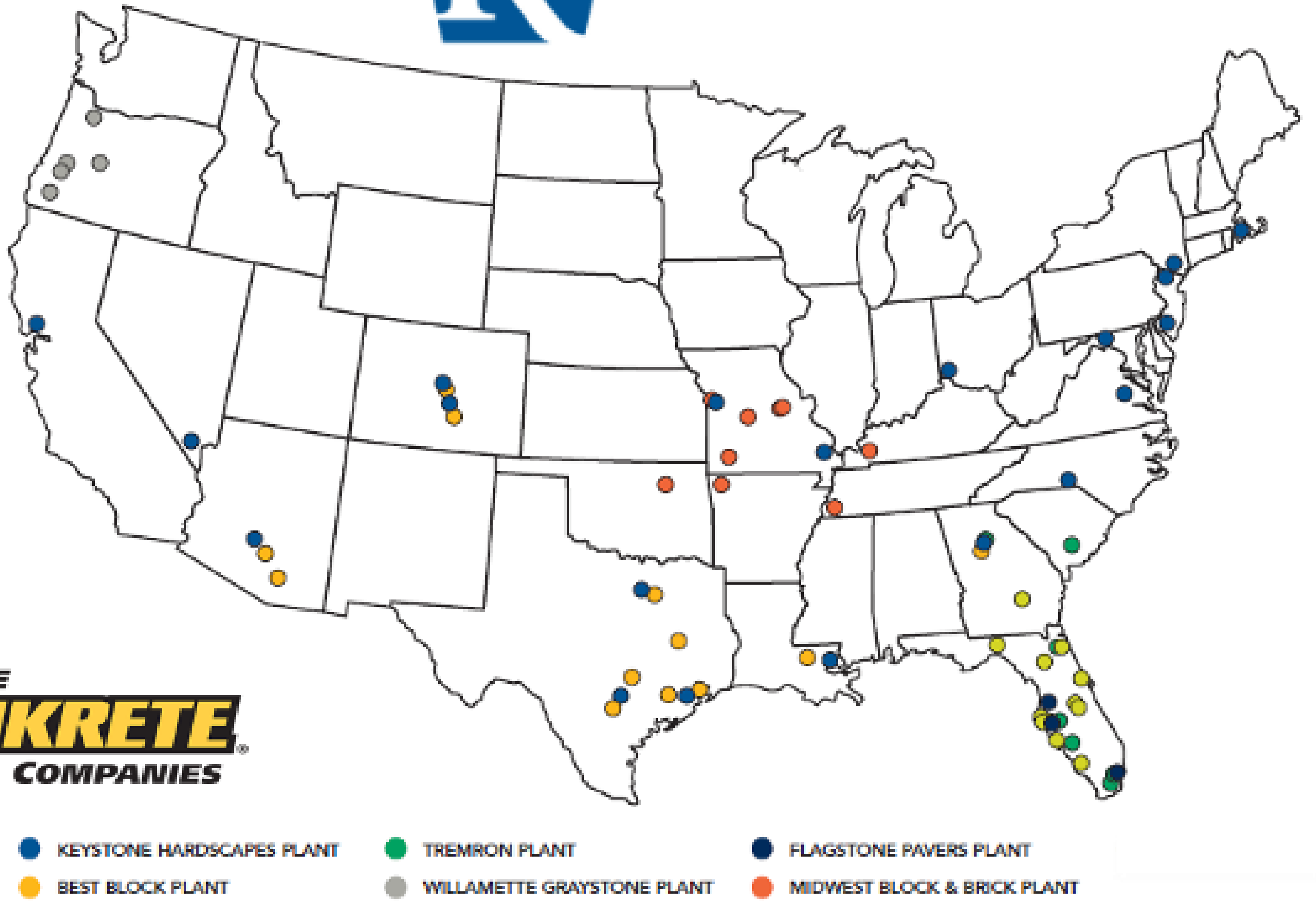
Overview Industrial and Port Paver Applications (Impervious and Permeable)

Design Methodology

Current Construction Best Practices

Project Case Studies

KEYSTONE® HARDSCAPES



THE QUIKRETE® COMPANIES

www.keystonehardscapes.com

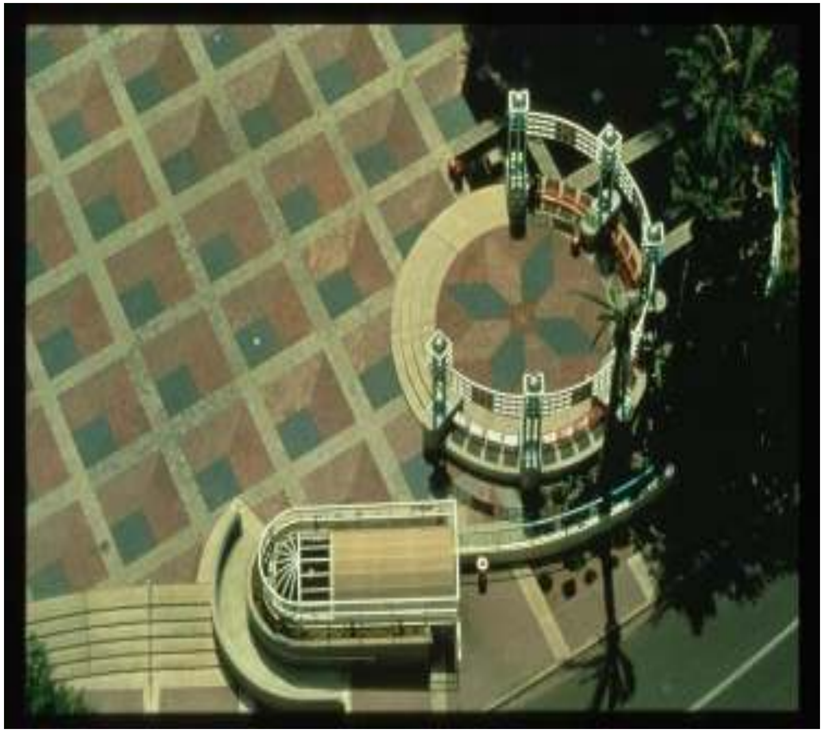
Manufacturing

Paver Specification Data

ASTM C 936

Compressive Strength	**8000 psi**
Absorption	**< 5%**
Freeze Thaw	**ASTM C 1645**

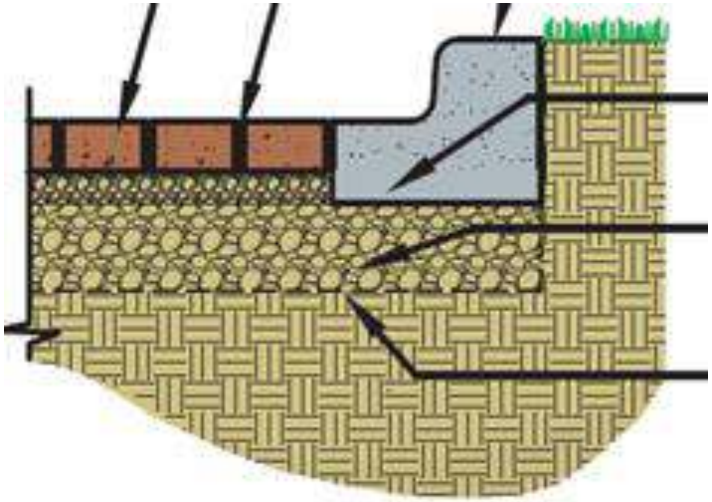
Segmental Paving Product Group



Articulating Concrete Blocks

Roman Road Construction

Industrial Paver System Design



Structural Base Courses

Bedding Materials

Jointing Sands

Paving Unit Thickness, Shape & Pattern

Permanent Edge Restraint

ASCE Paver Design Method

ASCE Standard - ASCE / T&DI / ICPI 58-16
Structural Design of Interlocking Concrete Pavement Municipal Streets and Roadways, 2016

Function of a Structural Number

Formal pavement design relies on engineering calculations based on established design equations, such as the empirical equations found in the 1993 AASHTO *Guide for Design of Pavement Structures*. A critical element of the flexible pavement equation is the Structural Number, which represents the overall structural requirement needed to sustain the traffic loads anticipated in the design. The required Structural Number depends on a combination of existing soil support, total traffic loads, pavement serviceability, and environmental conditions.

$$\log_{10}(W_{18}) = Z_R \times S_o + 9.36 \times \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left(\frac{\Delta PSI}{4.2-1.5}\right)}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \times \log_{10}(M_R) - 8.07$$

AASHTO design equation for flexible pavements. The Structural Number is indicated as SN.

Geotechnical Report

Pavement Design Recommendations

No pavement loading design guidance has been provided to GTS, Inc. by the design team. Therefore, the pavement sections provided in this report are based on an assumed Equivalent Single Axle Loading (ESAL) of about 43,000 for light-duty pavement sections (car and passenger truck), about 200,000 for medium-duty pavement sections (drive lanes for passenger cars and light trucks and fire lanes), and about 500,000 for heavy-duty pavement sections (light semi-truck traffic and dumpster areas). A factor of 1.5 was used to convert flexible ESALs to rigid pavement ESALs. These values should be evaluated by the design team for appropriateness for this project site and intended pavement use.

A design modulus of subgrade reaction (k) of 125 pounds per square inch, per inch, was used for the design of the rigid pavements. A design California Bearing Ratio (CBR) of 5 was used for the design of flexible pavements. The pavement sections assume adequate drainage will be provided to allow removal of water from the pavement structure in 24 hours or less.

The flexible and rigid pavement sections shown in Tables 5 and 6 on the following page are recommended.

Geotechnical Report

GTS, Inc.
Geotechnical & Testing Services

Table 5: Flexible Pavement Section Recommendations

Flexible Pavement Section:	Asphalt Surface Course	Base Course (Class 7)	Design Traffic
Light-Duty	2"	8"	car and passenger truck
Medium-Duty	3"	9"	drive lanes for passenger cars and light trucks and fire lanes
Specification[1]	*Section 407-1 PG 64-22 75 Gyrations*	*Section 303*	

[1] Standard Specification for Highway Construction, Arkansas State Highway and Transportation Department, Edition of 2014.

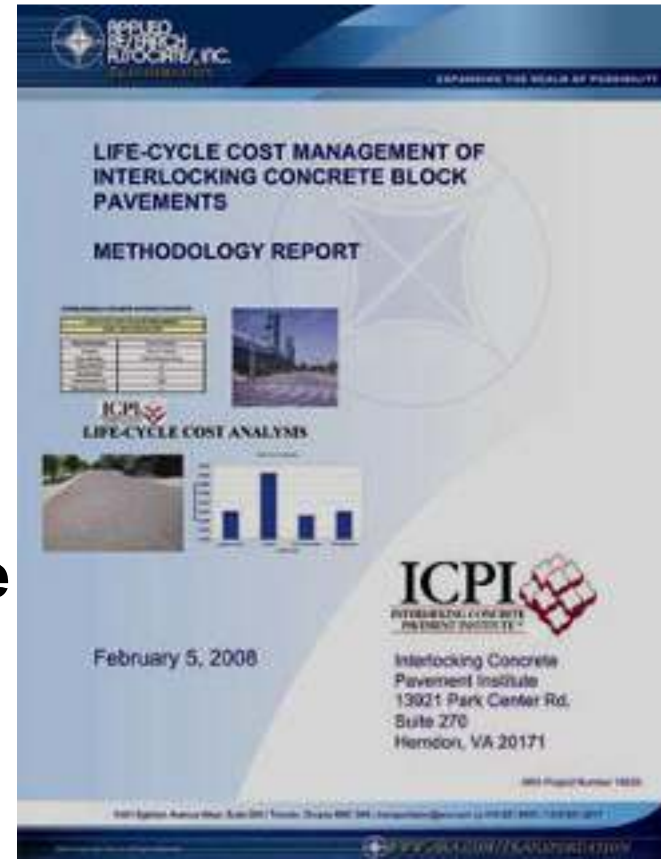
Life Cycle Cost Established

LCCA Methodology Report

Supported By LCC Software

Data From 83 Site Surveys

Pavers Have ~31 Year Initial Design Life



Pavement Condition vs. Age

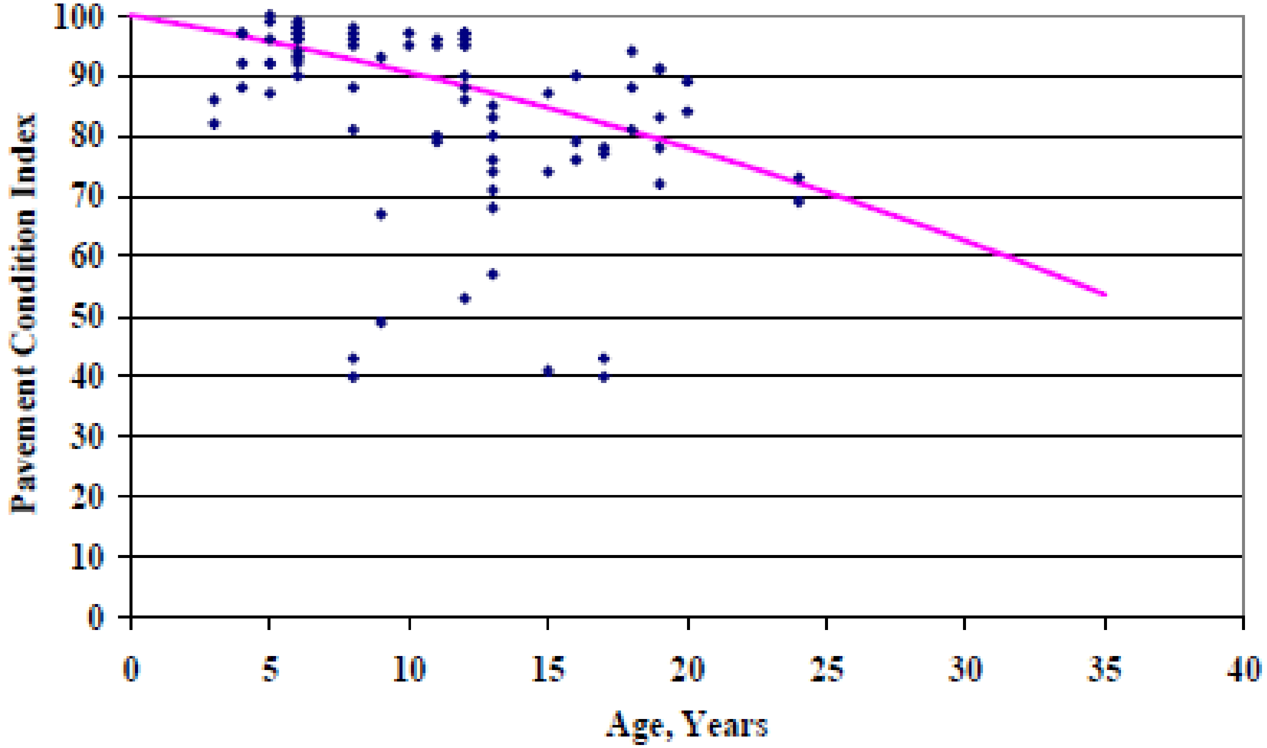
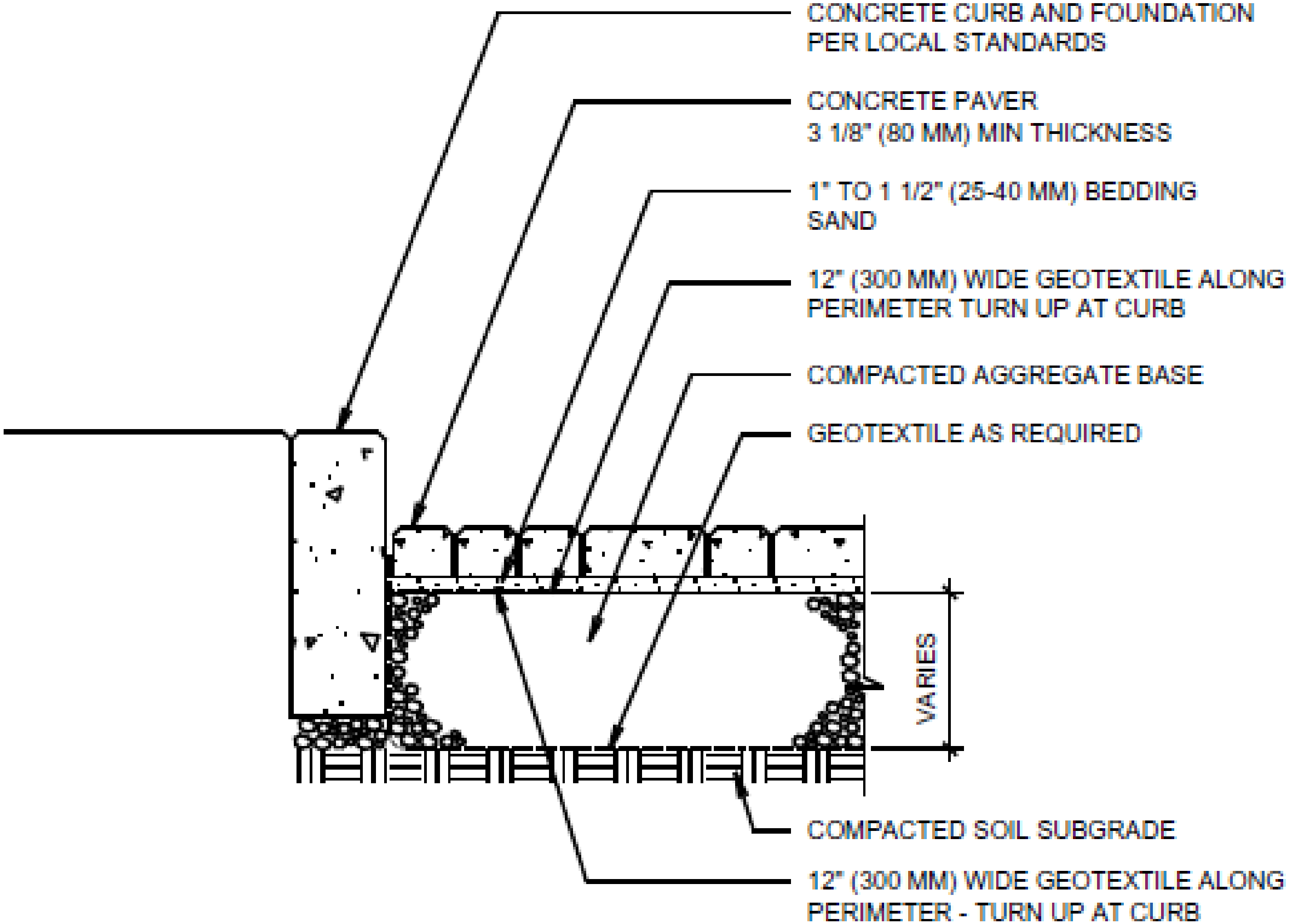
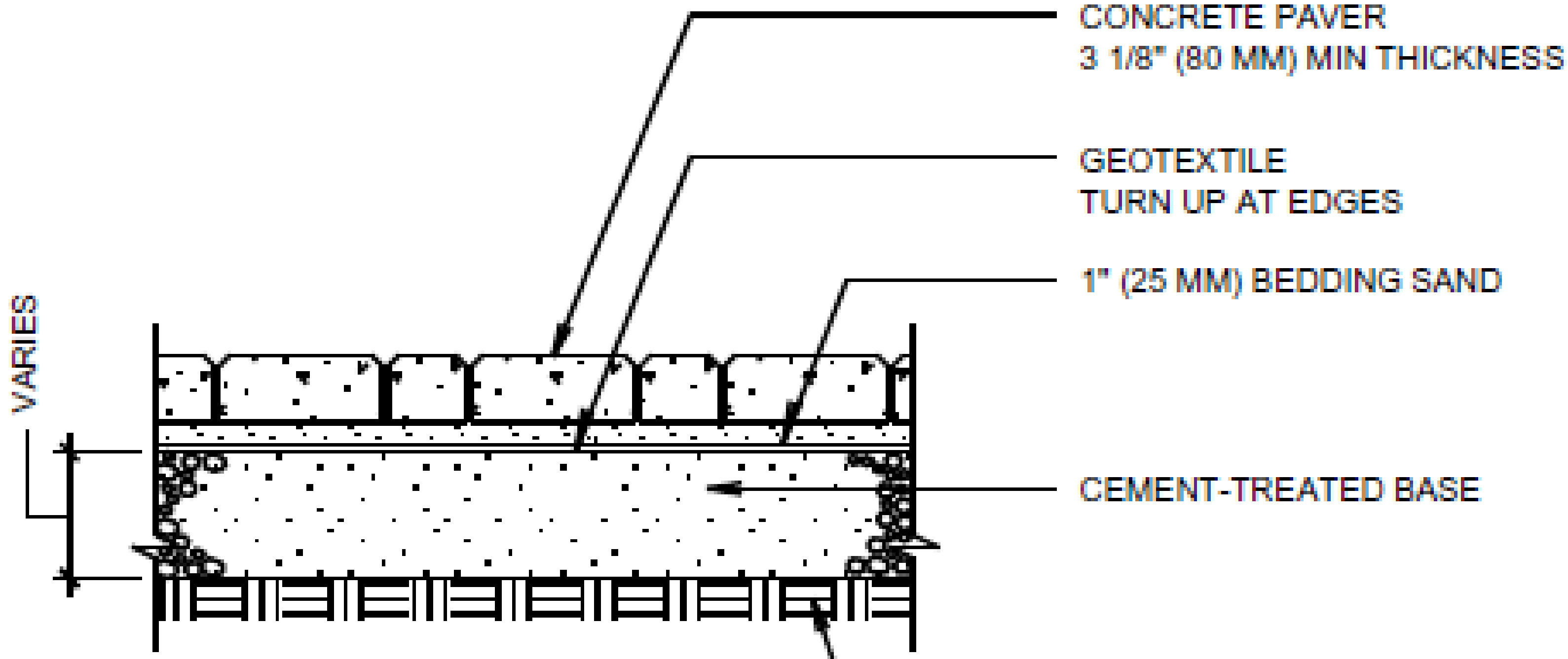


Figure 15. Pavement Condition Index versus Age.

Industrial Pavers – Aggregate Base Detail



Pavers – Cement Bound Agg. Base Detail



Subgrade Preparation

Compacted InSitu

Cement / Lime Treated

Stabilized

Reinforced

DGA Base Installation

Structural Base Placed / Compacted To Specifications

Base Finished Profile = Paver Thickness + 1" Bedding Sand From Finished Elevation

Bedding & Jointing Sands Materials

Gradation - ASTM C 33 – 0-1% Passing #200

Hardness – Silica Mineralogy Preferred

Particle Shape – Sub Rounded to Sub Angular or Cubicle

Durability Testing – ASTM D 7428

Resistance of Fine Aggregate to Degradation in the Micro-Deval Apparatus

Screeding Bedding Sand

Power Screed Machine

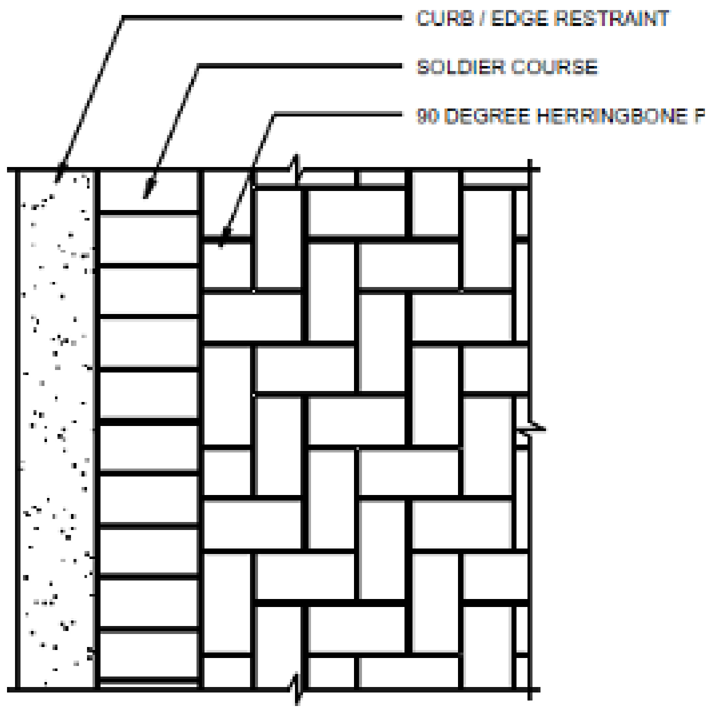
Asphalt Paving Machine

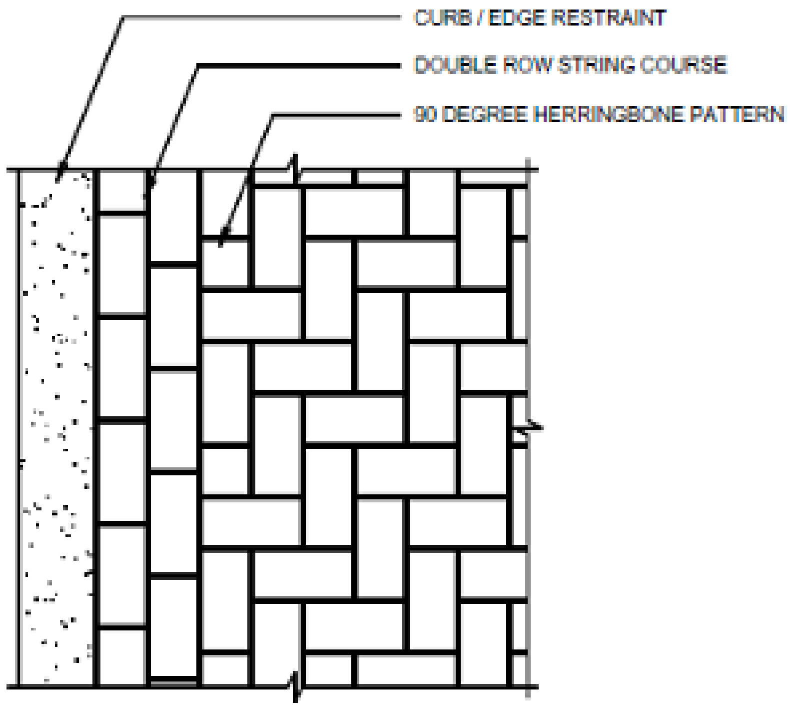
Paver Installation

Hand Installation

Mechanical Installation

Edging Treatment Detail





Vibrating Sand into Joints

First Pass To Seat Pavers In Bedding Sand

Second Pass To Fill Joints

Final Broom Sweep

No Cure Time Required

Surface Proof Rolling

10 Ton Rubber Wheel / Tire Roller

Static Mode

Accelerates Paver Interlock

Paver Thickness

60mm 2 3/8” **80mm 3 1/8”** **80-120mm 3 1/8”- 4 13/16”**

Light Duty

Medium Duty

Heavy Duty

Paver Shapes

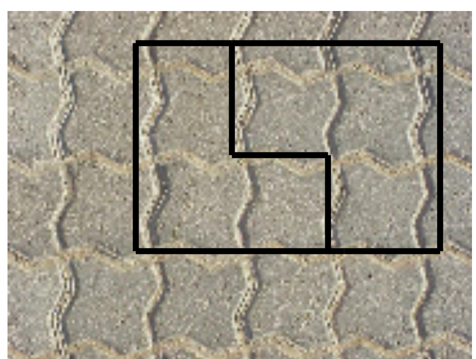
Category A

Shapes with No Interlocking Geometry

Category B

Shapes with Interlocking Indentation Geometry

Category C



Shapes with Interlocking Geometry In Two Axes

Flora Street - Dallas, TX

40,000 sf

1989

80mm Paver

6” CIP Concrete

City Streetscape – Osseo, MN

45,000 sf

2010

80mm Paver

¾" Bitumen Set

CIP Concrete

Port of Tampa - Tampa, Florida

Berth 208 Yard

495,000 sf

1995

80mm Paver

18” Limestone Base

Geogrid Reinforced Base

12” Sand Subgrade

Hong Kong International Airport

5,000,000 sf

1998

80mm Paver

Geotextile/Asphaltic Tack Coat

7" Cement Treated Base

18" Crushed Aggregate Base

10" Crushed Aggregate Base

Howland Hook Marine Terminal
Staten Island, NY

660,000 sf
Standard
1988

13,000 sf
Permeable
2000

80mm Paver
8" Asphaltic Concrete Base
18" Aggregate Base
6" Reinforced Subgrade

Port of Oakland – Oakland, CA

4,700,000 sf
As of 2022

100mm Paver

9" Asphalt Base

Engineered Fill @ 50% CBR

Dock Replacement Dutch Harbor, Unalaska, AK

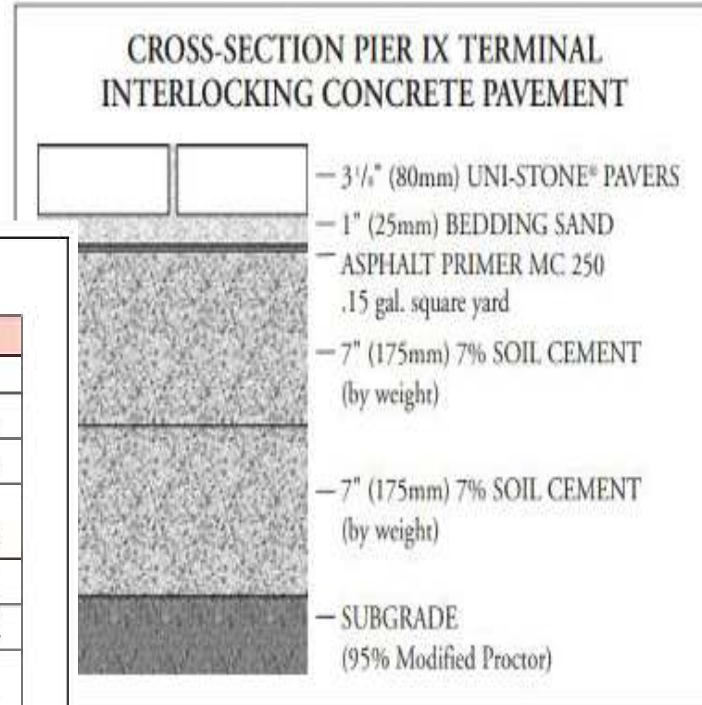
Pier IX Massey Coal Terminal- Newport News, Virginia

660,000 sf

1983

80mm Paver
Asphalt Primer Coat
7” Soil Cement @ 7% Base
7” Soil Cement @ 5%

Pier IX Massey Coal Terminal- Newport News, Virginia



SUMMARY ANAYSIS OF PAVEMENT ALTERNATIVES

FACTORS CONSIDERED	TYPE OF PAVEMENT								
	1	2	3	4	5	6	7	8	9
Prevent Contamination	Excel	Excel	Excel	Excel*	Excel	Fair	Poor	Poor	Poor
Allows Cleanup of Coal	Excel	Excel	V. Good	Excel*	Excel	Fair	Poor	Poor	Poor
Ability to Adjust to Differential Settlement	Excel	Excel	Fair	Poor	Fair	Good	Good	Good	Good
Ability to Carry Heavy Wheel Loads	Excel	V. Good	Good	Excel	Good	Good	Good	Fair	Fair
Resistance to Tracks & Dozers	V. Good	Good	Poor	Good	Poor	Good	Good	Good	Good
Resistance to Breaking Up & Coal Contamination	Excel	V. Good	Good	Fair	Fair	Good	Poor	Poor	Poor
Impermeability	Excel	Excel	Good	Excel*	Excel	Poor	Poor	Poor	Poor
Ease of Repair	Excel	Excel	Fair	Poor	Good	Excel	Excel	Excel	Excel
Resistance to Acid Water	V. Good	V. Good	Good	Good	Good	Good	Good	Good	Good
Surface Drainage & Runoff	Excel	V. Good	Excel	Excel	Excel	Fair	Poor	Poor	Poor
Weather Durability	Excel	Excel	V. Good	V. Good	V. Good	Fair	Fair	Fair	Fair
Expected Life (years)	20-25	15-20	10-15	20-25*	10-15	10-15	10-15	10-15	10-15

**If significant differential settlement does not occur. If it does, rating is poor.*

PAVEMENT TYPES

1. Interlocking Concrete Block Pavers over Soil Cement
2. Interlocking Concrete Block Pavers over Crushed Stone
3. Soil Cement Only
4. Reinforced Concrete
5. Bituminous Concrete over Crushed Stone
6. Crushed Limestone
7. Crusher Run Stone
8. Middling Coal
9. Marketable Coal

Mammoet Materials – Roshea, TX

150,000 sf
2009

80mm Paver
18” Aggregate
6” Sand Layer

Port Fourchon – Fourchon, LA

2,000,000 sf
2008-2012

80mm Paver
18-24” Pre-existing Yard
Crushed Aggregate Base

Design Tools LCCA

LIFE CYCLE COST ANALYSIS

ASPHALT CONCRETE PAVEMENT DESIGN (FLEXIBLE PAVEMENT)

ICPI
INTERLOCKING CONCRETE PAVEMENT INSTITUTE®

Denver Example-2, 3M ESALS, Denver, Colorado

Project Definitions:

Length of Section:	1000	m	Analysis Period:	40.0
Lane Width:	3.75	m	Discount Rate:	4.0
Number of Lanes:	2		Initial Year of Construction:	2008

Total Pavement Area: 7,500 Sq. m

YEAR	CONSTRUCTION ITEM	AMOUNT	QTY.	UNIT	UNIT PRICE	ST DEV	COST	PRESENT WORTH
INITIAL CONSTRUCTION								
0	Asphalt Concrete Surface	50	918.75	Tonne	$95.00	$8.00	$87,281	$87,281
0	Asphalt Concrete Base	125	2062.5	Tonne	$85.00	$7.00	$175,313	$175,313
0	Granular Base	150	2475	Tonne	$13.00	$2.00	$32,175	$32,175
0	Granualr Subbase	525	8662.5	Tonne	$8.50	$1.00	$73,631	$73,631

Design Tools Structural

Design Information

		Layer Coefficient	Thickness (in)
Design Life (years)		20	
Initial Serviceability		4.2	
Terminal Serviceability		2.5	
Reliability		75%	
Z_R		-0.674	
Standard Deviation		0.45	
Pavers and Bedding		0.44	4.125
	Unbound Dense Graded Base	0.14	6
	Asphalt Treated Base	0.28	4
	Cement Treated Base	0.20	4
Base	Asphalt Concrete Base	0.42	2
Unbound Dense Graded Subbase		0.09	

Design Assistant

ESALs	5,000,000
Subgrade Classification	GM, SM
Subgrade Conditions	Fair
Base Type	Unbound Dense Graded Base

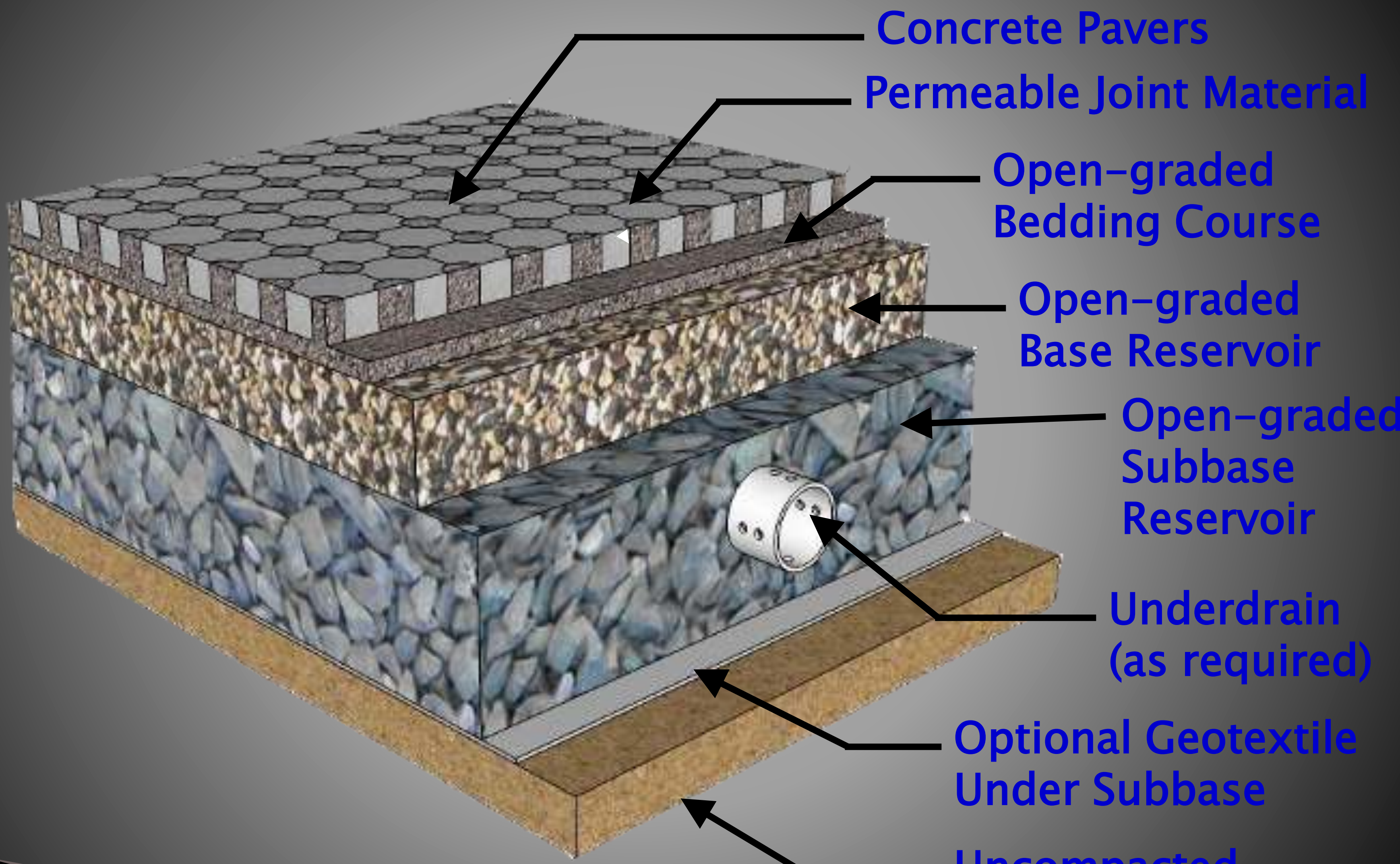
Recommended Design

Pavers and Bedding	4.125
Unbound Dense Graded Base	#NAME?
Unbound Dense Graded Subbase	#NAME?

Traffic Estimates

AADT	Functional Category	Percent Commercial	# Lanes	Estimated ESALs	Total ESALs
500	Local	0.5%	2	719	14,387
1000	Local	1%	2	2825	56,498
5000	Local	1%	2	13516	270,313
10000	Minor Arterial/Collector	3%	2	79521	1,590,414
15000	Major Arterial/Collector	5%	2	196501	3,930,025
20000	Principal Arterial	5%	2	259825	5,196,505
40000	Principal Arterial	5%	2	509163	10,183,257

System Components

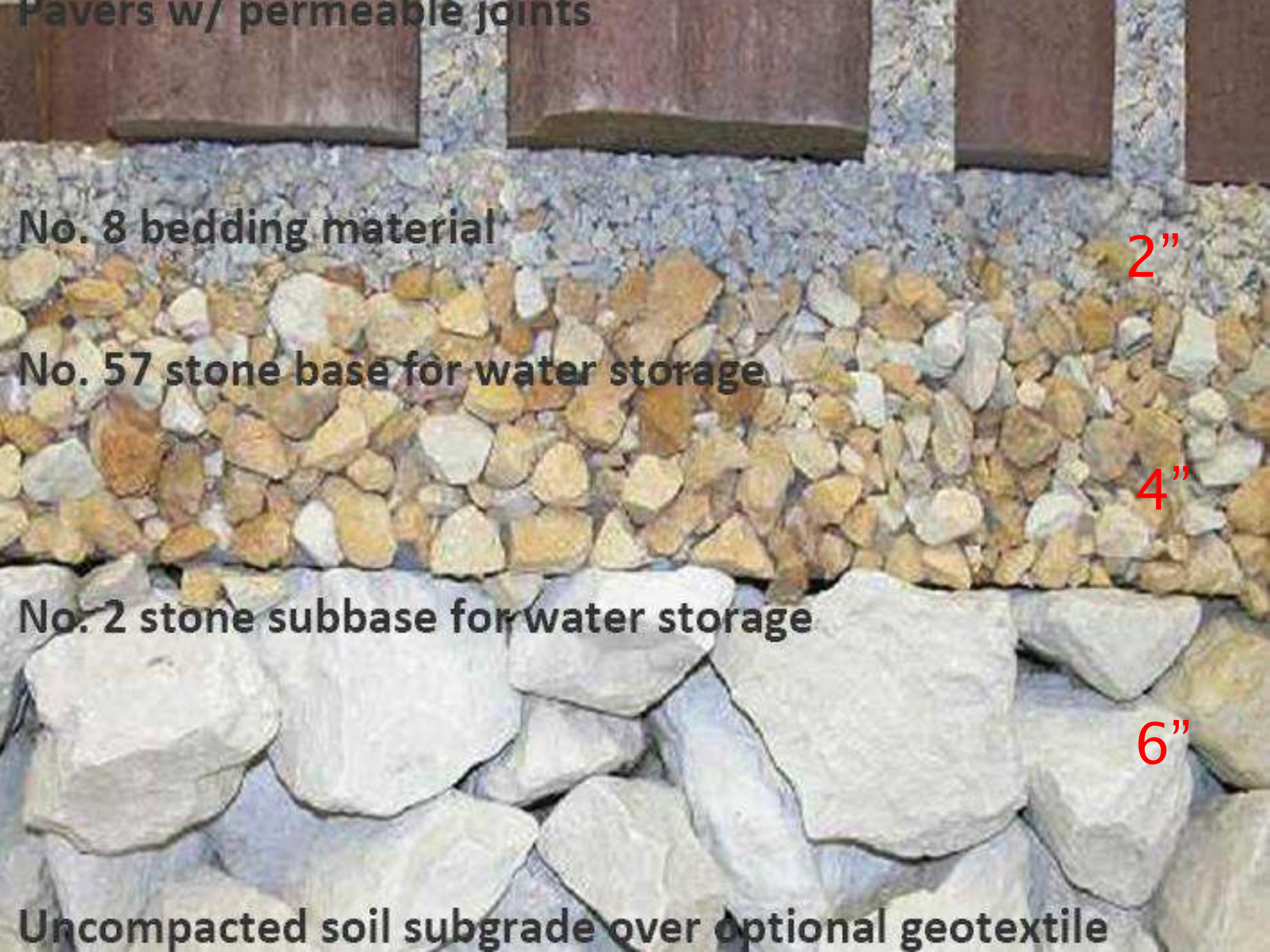


Aggregate Gradations

Sub-Base
No. 2, 3, or 4

Base
No. 57

Bedding/Joints
No. 8, 9 or 89


Pavers w/ permeable joints
No. 8 bedding material
2”
No. 57 stone base for water storage
4”
No. 2 stone subbase for water storage
6”
Uncompacted soil subgrade over optional geotextile

Paver Types:
Interlocking Shapes / Patterns

ICPI

The Low Impact Development Center, Inc.

Test Results

Testing was conducted maintaining a 0.5" head of water above the top surface of the pavers. The level of head water was established, maintained for approximately 30 seconds, and the rate of flow was determined. This procedure was performed a total of five times. The average flow rate was determined and is reported below.

Head Water (Inches)	Rate of Flow (Inches per Hour)
0.5	311

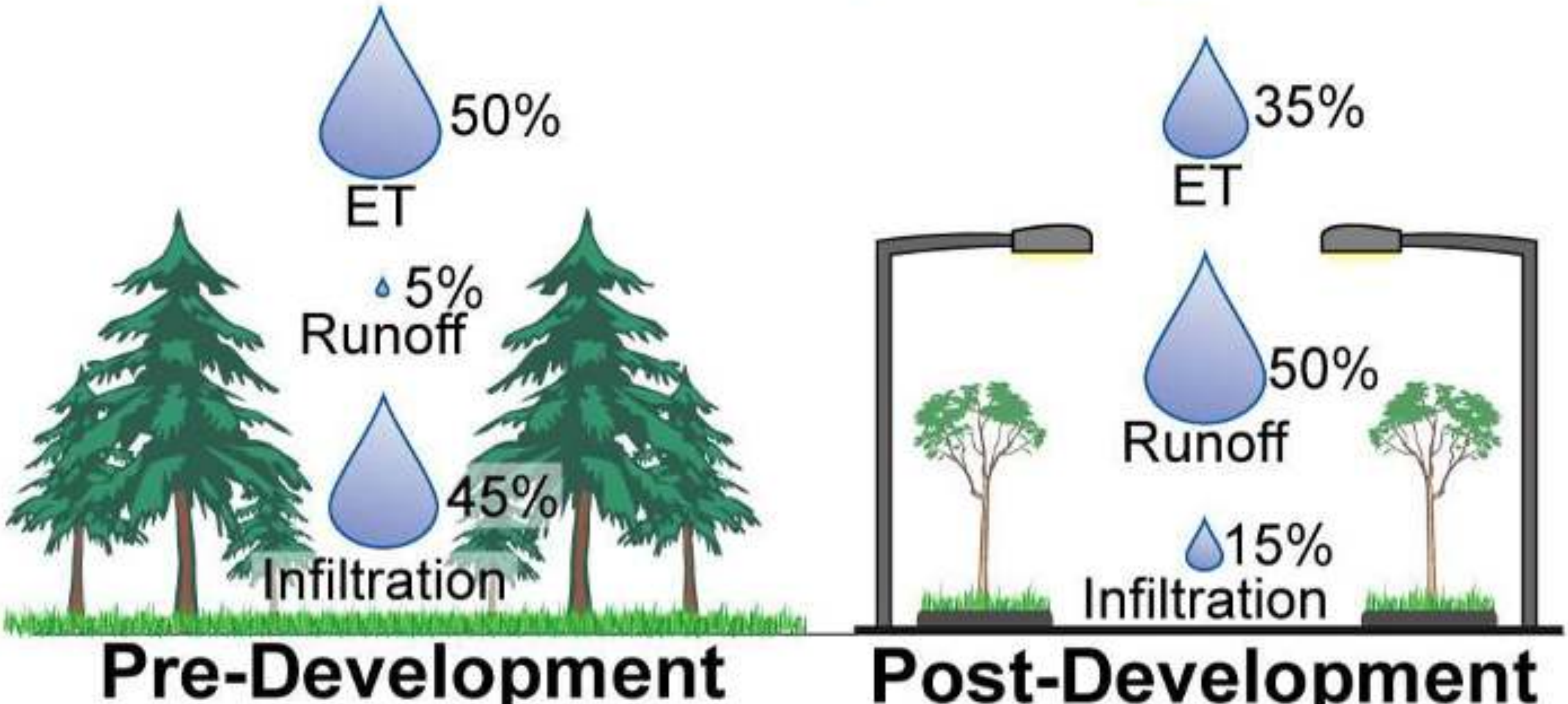
STATE OF TEXAS
KENNETH L. BOWNDS
76345
LICENSED
PROFESSIONAL ENGINEER

Kenneth L. Bownds, P.E.

6/8/11

LIMITATIONS: The test results presented herein were prepared based upon the specific samples provided for testing. We assume no responsibility for variation in quality (composition, appearance, performance, etc.) or any other feature of similar subject matter provided by persons or conditions over which we have no control. Our letters and reports are for the exclusive use of the clients to whom they are addressed and shall not be reproduced except in full without the written approval of Construction Testing Sciences, LLC.

Annual Hydrology



Swank, W.T., and Crossley, D.A. 1988. *Forest Hydrology and Ecology at Coweeta*. New York, NY: Springer-Verlag.

Treatment Train Site Design

1. Source controls = Infiltrate
2. Conveyance controls = Filter & detain
3. End of Pipe Controls = Retain in ponds, streams or storm sewer

Stormwater Management Objectives

…Varies with locality…

Water Quantity

Retain/infiltrate runoff volumes & peak flows
Imitate pre-development conditions
Control amount of impervious cover
Stormwater utility fees

Water Quality

Capture percentage of storms
Control specific nutrients, metals

PICP addresses all objectives

How PICP Manages Stormwater

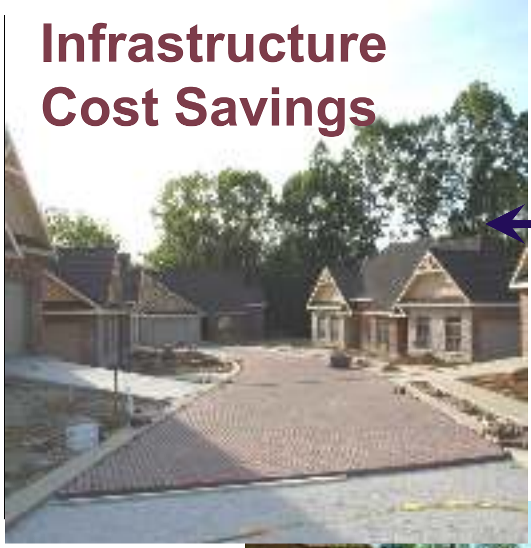
Water Quantity

- Reduces volumes & peak flows via infiltration
- Imitates predevelopment conditions: no runoff from common storms
- Reduces or eliminates retention/detention facilities & conserves land
- Reduces stormwater utility fees

Water Quality

- Reduced downstream erosion, preserves drainage system
- Filters & reduces nutrients, metals
- Recharges groundwater
- Helps maintain dry-weather stream flows
- Filters oil drippings
- Reduces runoff temperatures

Local Regulations



ICPI

The Low Impact Development Center, Inc.

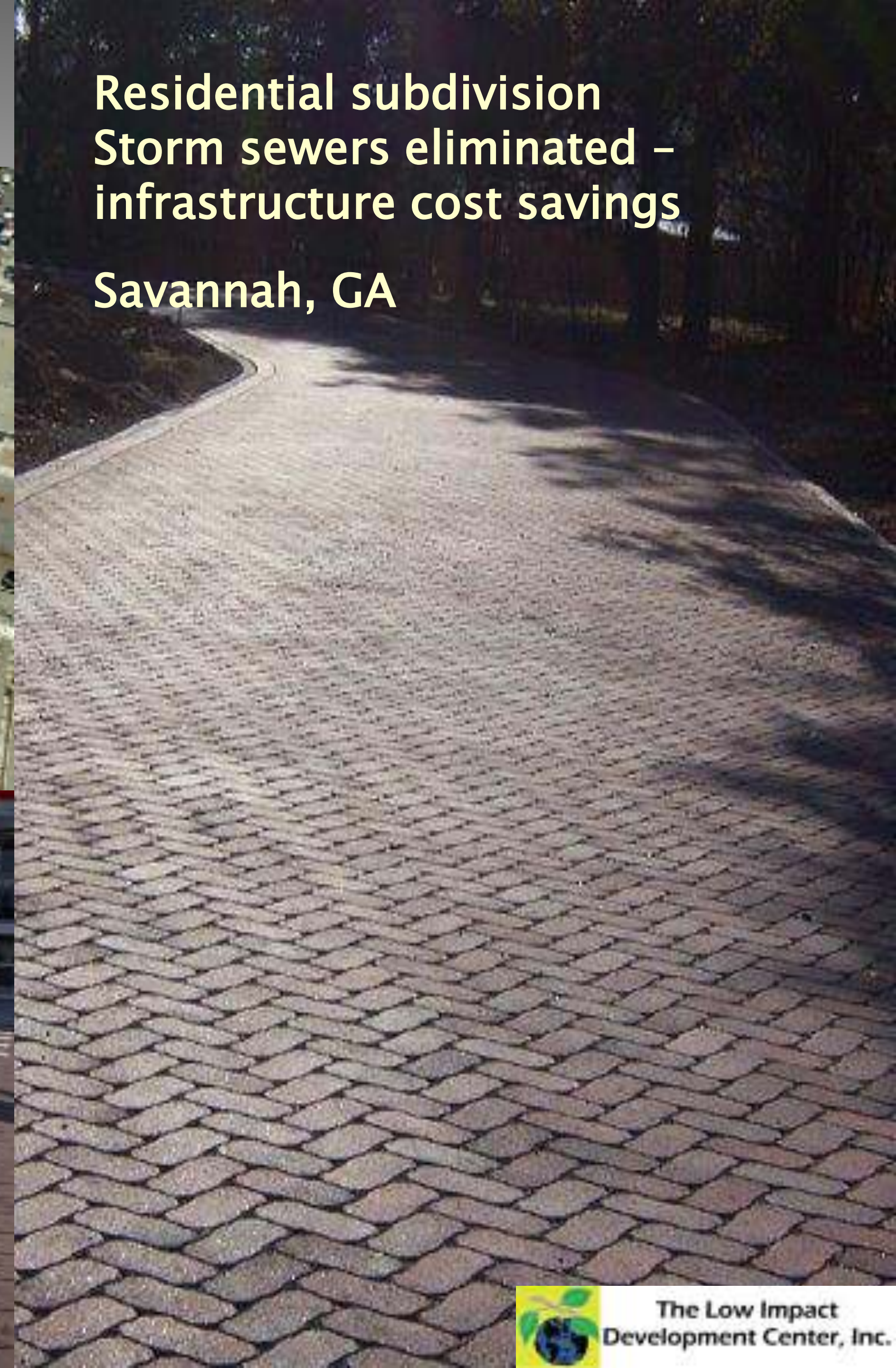
Design Solutions

PICP detains runoff under parking for peak flow reduction, oil treatment

Burnaby, BC

PICP handicapped parking over stormwater detention system

Burnaby, BC



Residential subdivision
Storm sewers eliminated – infrastructure cost savings

Savannah, GA

ICPI

The Low Impact Development Center, Inc.

Detention pond
N
© 2008 Tele Atlas


N
© 2008 Tele Atlas
Google


© 2008 Tele Atlas
N

Beach Community Goals:

Reduce erosion & salt water incursion, protect water quality

GULF SHORES, AL

Installed: 2005
105,000 sf
Base: 8 in. (200 mm) thick
Subgrade: sandy

Widely accepted in coastal regions

Green Infrastructure

Chicago, IL & Portland, OR

- Reduced combined sewer overflows
- Less expensive than separating storm & sanitary sewers
- Supports tree growth
- Improves neighborhood character

Images courtesy of Chicago DOT

PICP Sizing Steps

Inputs:

- 3 1/8 in. thick pavers over 2 in. thick bedding material
- Project location (no-frost or frost region)
- Design storm (in. depth)
- PICP area (sf)
- Contributing area (sf) – if applicable
- Contributing area runoff depth (in.) – if applicable
- Depth to seasonal high water table (ft.)

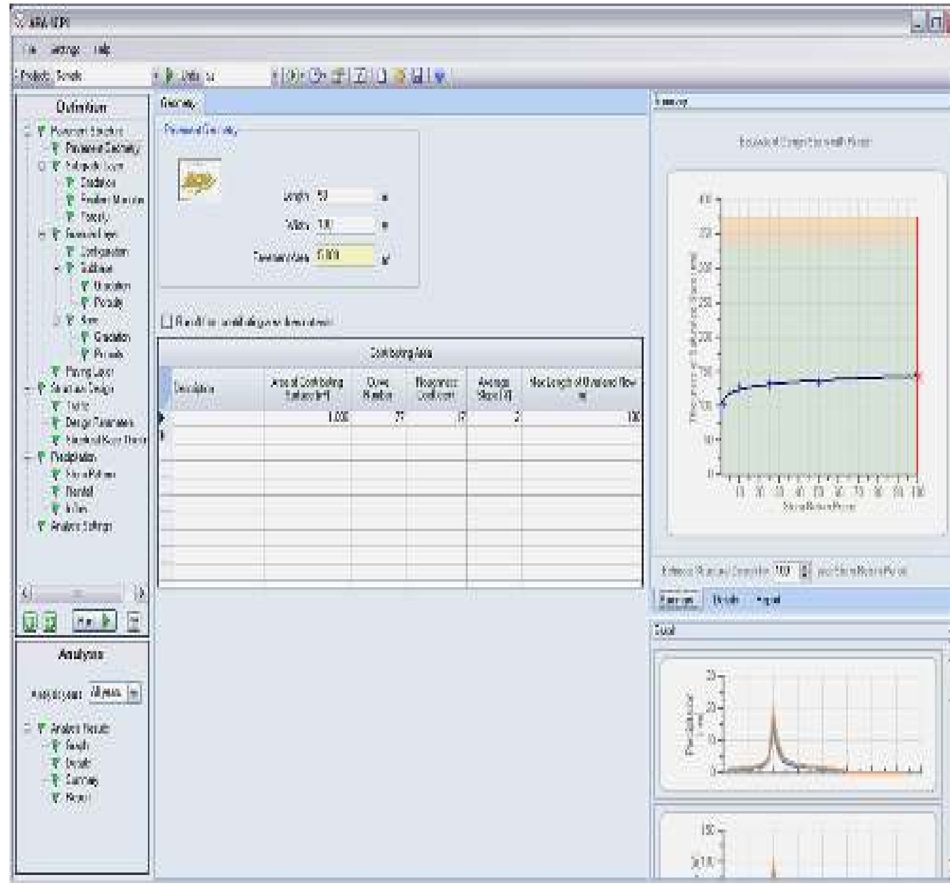
PICP Sizing Steps

Inputs – continued:

- Soil type (classification)
- Soil infiltration rate (in./hr)
- Soil strength (California Bearing Ratio or R-value)
- Base porosity
- Drainage time typically 24 – 48 hrs
- Traffic (18 kip or 80 kN equivalent single axle loads)
- Traffic design life = 20 years

PICP Design

- Permeable Design Pro
- Software integrates:
  - Hydrologic Design
  - Structural Design
- Contact ICPI
  to obtain software
  www.icpi.org



The Low Impact Development Center, Inc.

Test Site Range 109 - Ft. Carson, CO

5000 sf
2011

80mm Paver

14” Crushed Stone

Port Manchac, LA

Structural Concrete Pavers Advantages

Installation Time Equal / Quicker Than CIP

High Surface Durability / Abrasion Resistance

Serviceability in Differential Settlement Areas

Enhanced LCCA

Technical Support

Resource for Specifications / Details

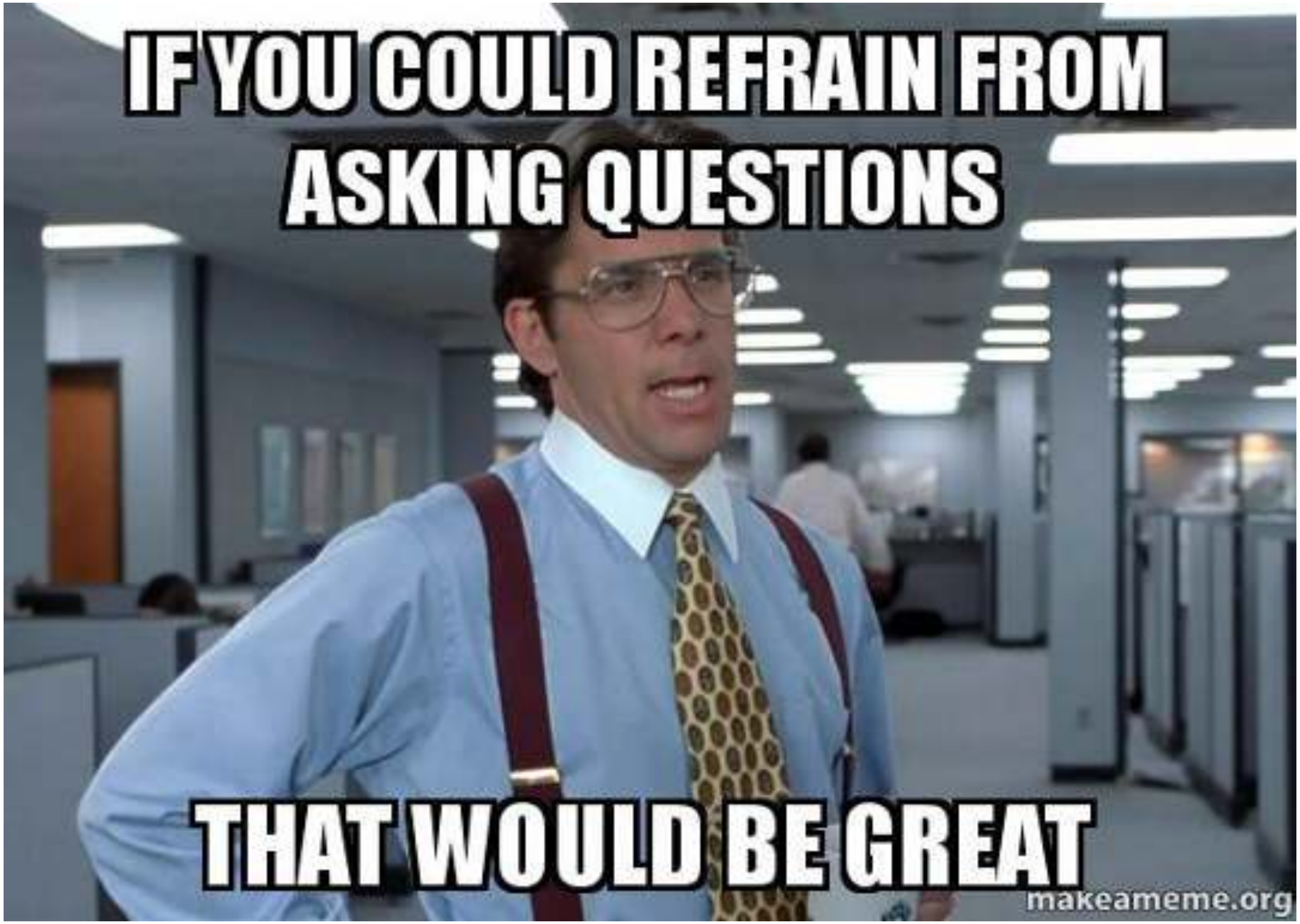
Facilitate Preliminary Design / Cost Estimation

Access To Local ICPI Certified Installers

Provide Inspector Training

Provide Maintenance Guidelines

Thank You!


IF YOU COULD REFRAIN FROM
ASKING QUESTIONS
THAT WOULD BE GREAT
makeameme.org