How Should You Be Designing Your Permeable Pavements? New ASCE Standard for Permeable Interlocking Concrete Pavement

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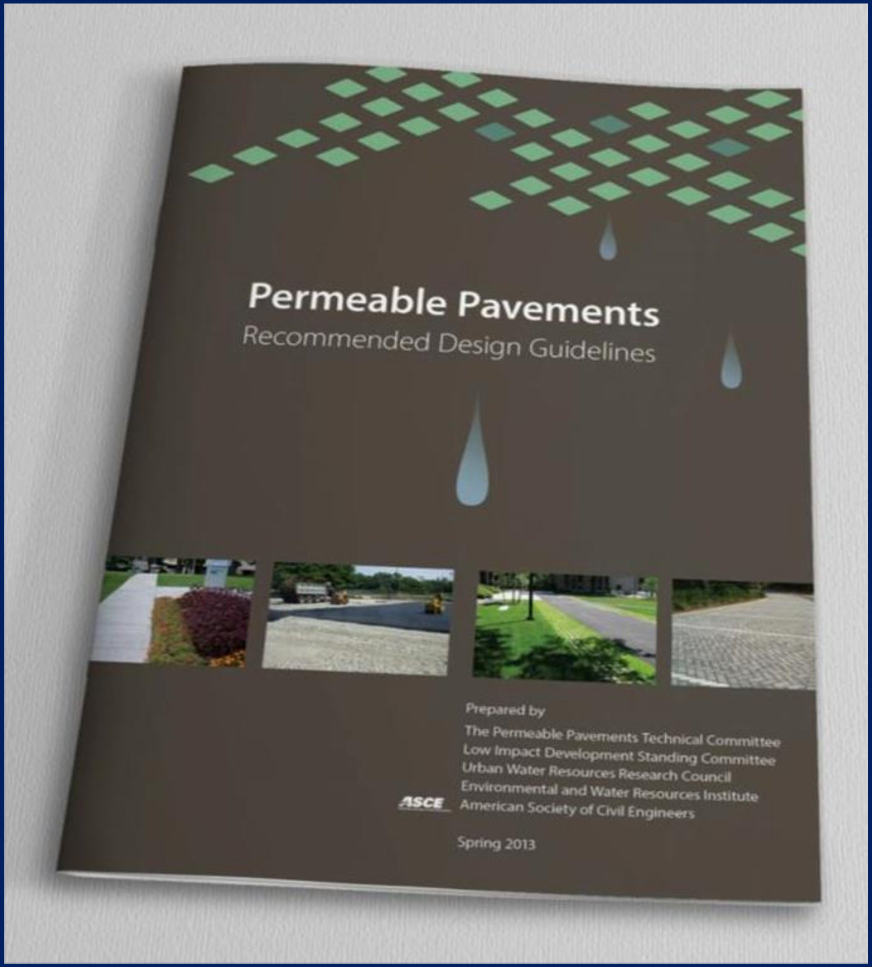
Spring 2014: Permeable Pavements Recommended Design Guidelines

ASCE EWRI Committee Report – online only

- Fact sheets
- Checklists
- Design information
- Maintenance
- Standards, guide specs & modeling methods
- Research needs



Establishes common terms for all permeable pavements

ASCE PICP Standard Guidelines

Content:

Section 1 – General Scope

Section 2 – Preliminary Assessment

Section 3 – Design (structural & hydraulic design, additional considerations)

Section 4 – Construction

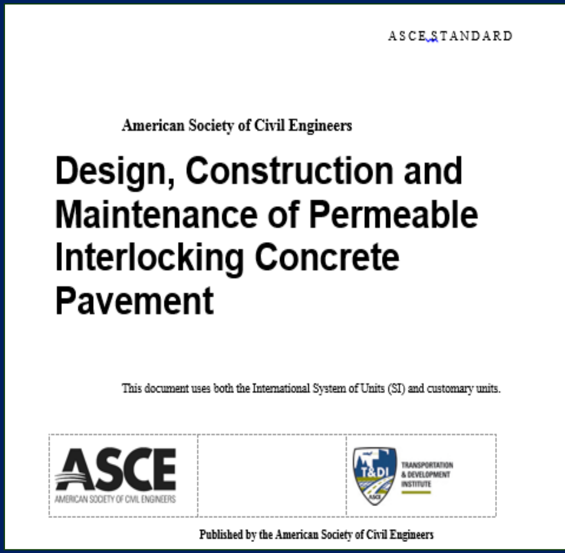
Section 5 – Maintenance

Goal: Early 2017 completion

Uses:

Adoption by State, Provincial & Local agencies

Design professional & contractor guidance



ASCE STANDARD

American Society of Civil Engineers

Design, Construction and Maintenance of Permeable Interlocking Concrete Pavement

This document uses both the International System of Units (SI) and customary units.

ASCE AMERICAN SOCIETY OF CIVIL ENGINEERS

T&DI TRANSPORTATION & DEVELOPMENT INSTITUTE

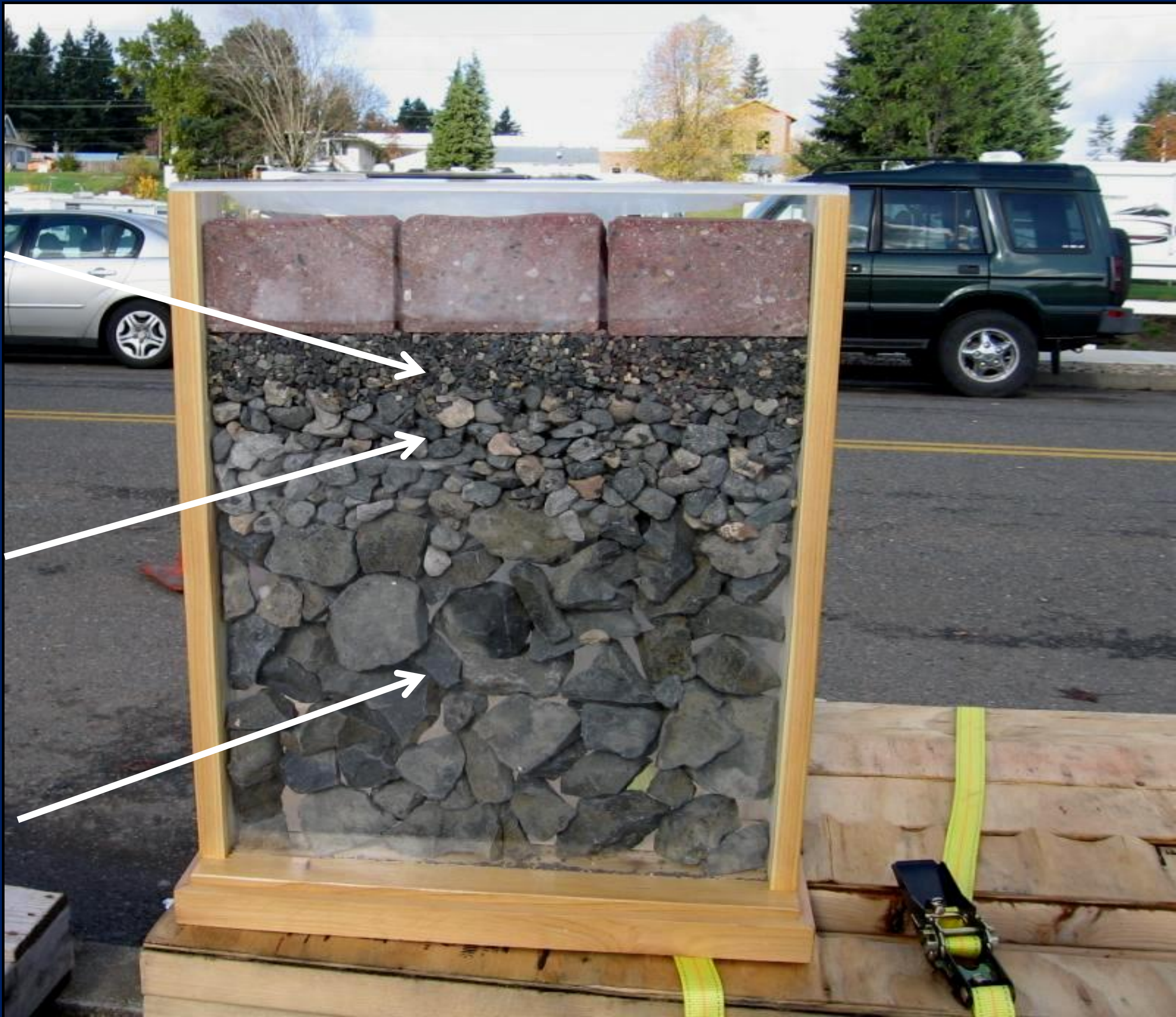
Published by the American Society of Civil Engineers

Permeable Interlocking Concrete Pavement (PICP)

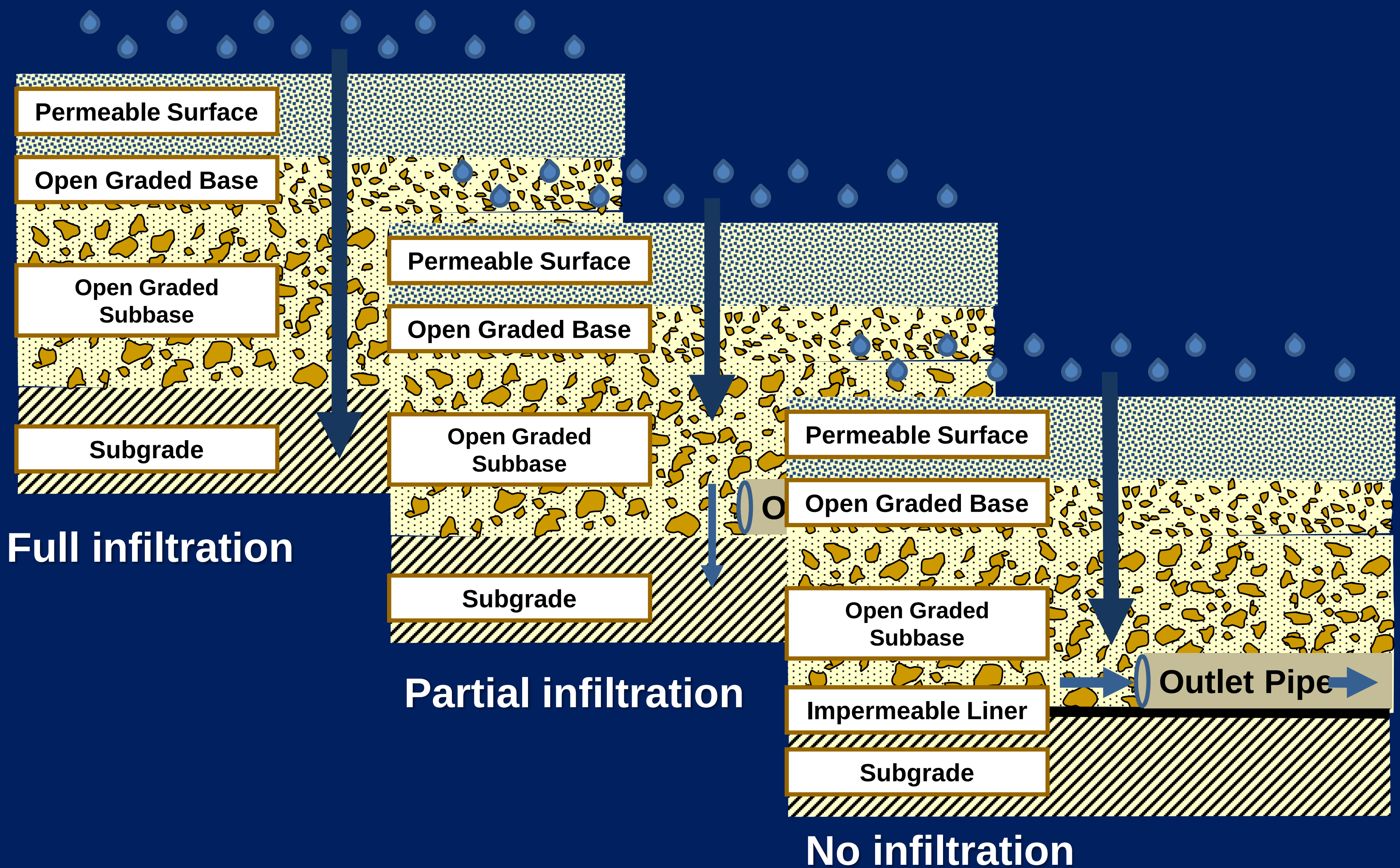
Pavers, bedding & jointing stones

Base reservoir Stone – 100 mm) thick

Subbase stone - thickness varies with water storage & traffic



Permeable Pavement Functions



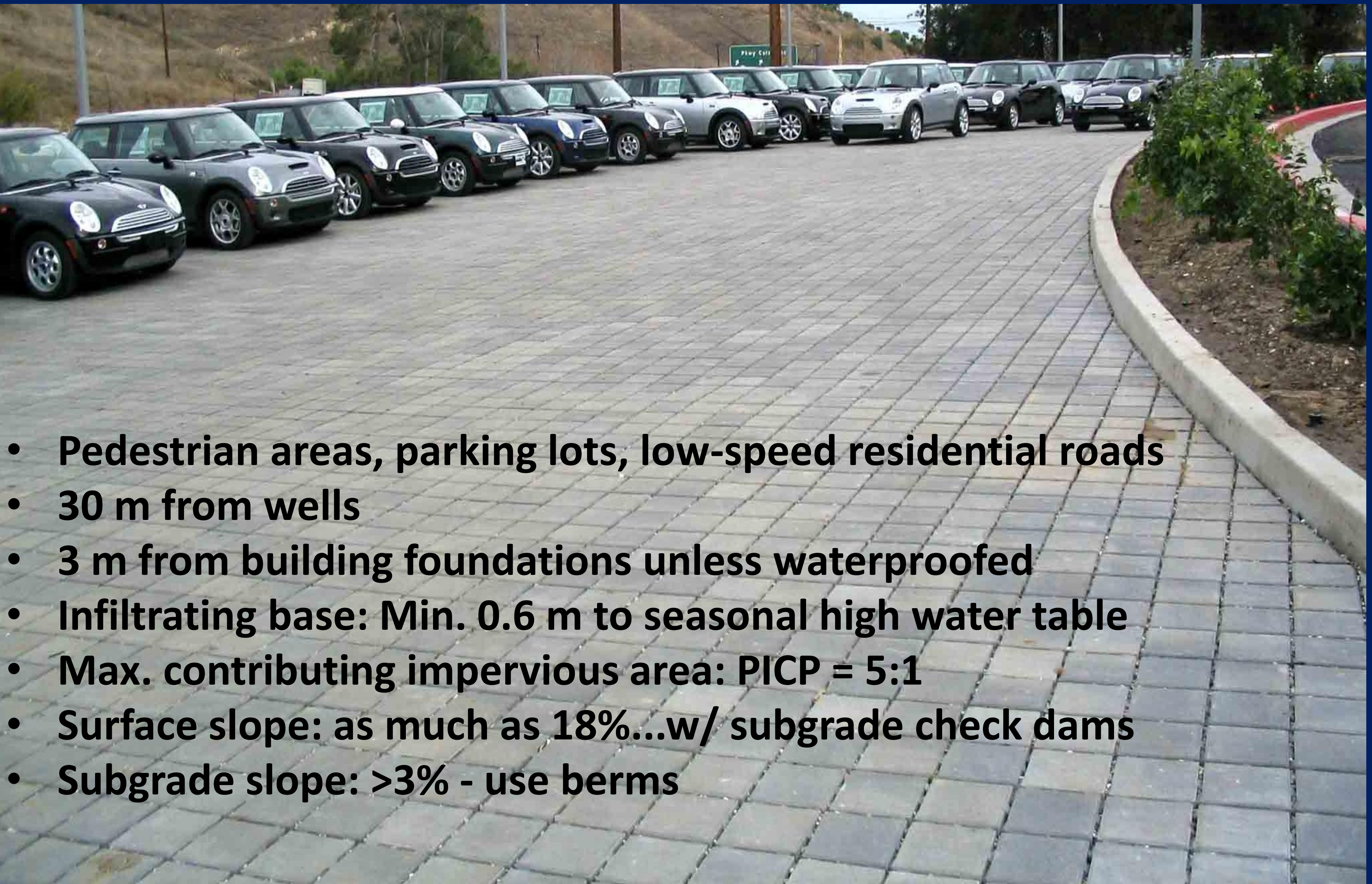
Assessing Suitability (S 2.1)

Considerations	Description
Cost efficiency (including life cycle costs)	Capital cost assessment needs to consider cost of pavement, drainage infrastructure, stormwater quality management, and land use. Overall long-term life-cycle costs can be very competitive if stormwater quality and quantity benefits are taken into account.
Environmental approval process	Verify permeable pavements are permitted, or if additional environmental approvals are required.
Stringent receiving water quality standards	The presence of protected watersheds, cold water streams, marshland, etc. may preclude the use of permeable pavement systems, or require more extensive water quality treatment.
Safety	Pavements are able to accommodate safety features such as traffic calming (rumble strips), and colored units for identification. Reduced ice formation and slip hazards.
Site grades	For grades of more than 5 percent, system will be less effective at promoting infiltration and have reduced water storage capabilities.
Depth of water table	Permeable pavements that include an infiltration component should not be used in areas where the water table is within 0.6 m (2ft) of the top of the soil subgrade.
Winter maintenance, winter sanding	Procedures for snow and ice removal are similar to those for conventional pavements. De-icing salt usage can be reduced, use of courser sand for traction control recommended. PICP are proven to perform even during below freezing conditions.
Risk of accidental chemical spill	PICP may assist in containment of accidental spills (requires the use of a geomembrane liner).

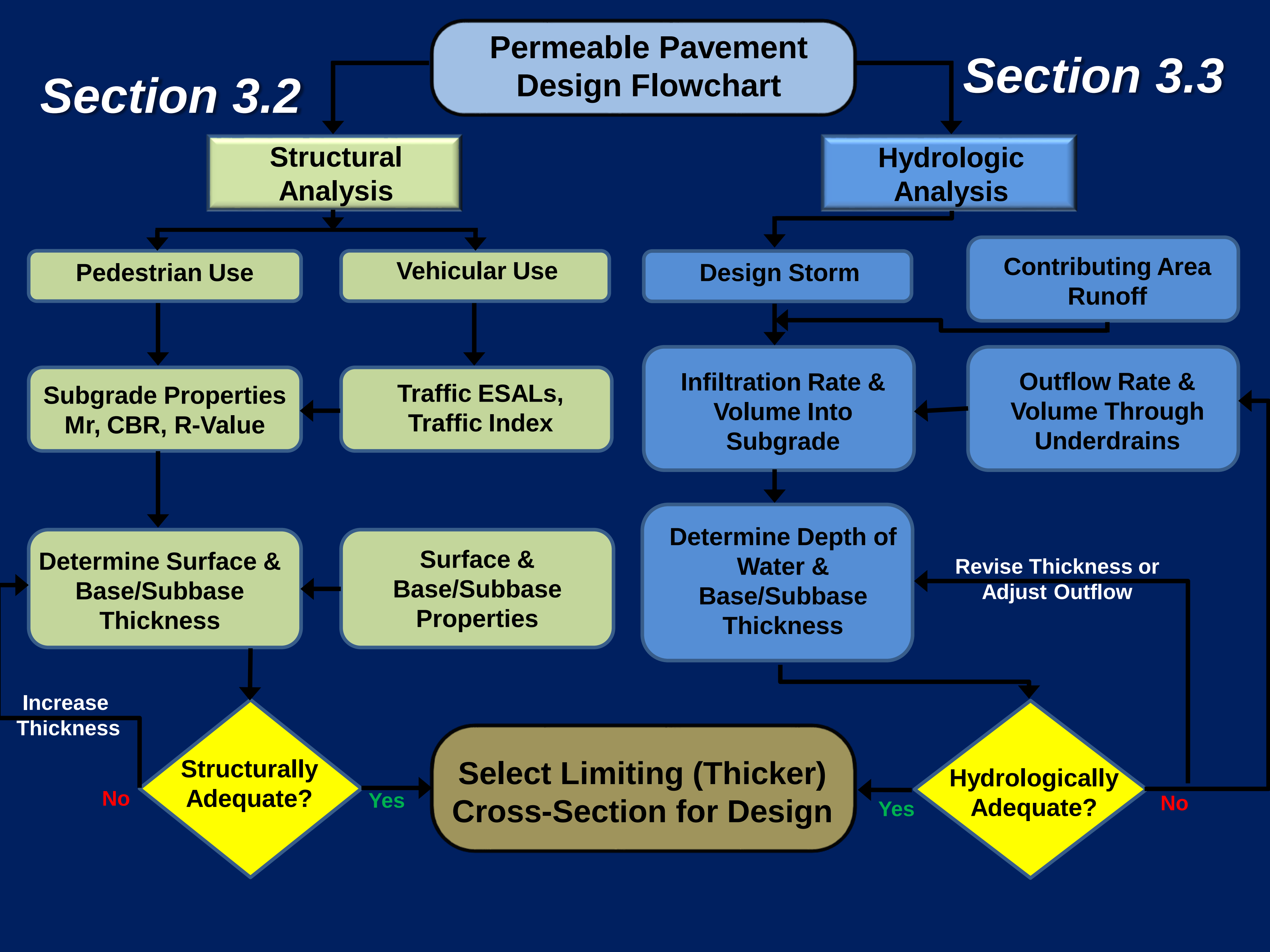
Assessing Suitability (cont.)

Considerations	Description
Amount and intensity of precipitation	Supplemental quantity control may be required in areas of frequent, high intensity storms.
Complexity of site conditions	The design and construction of permeable shoulders may be problematic in areas where retaining walls, utilities, septic systems, municipal or private wells are present.
Geotechnical Aspects	Presence of organics, fill soils, swelling clay soils, karst geology, or shallow bedrock may pose geotechnical risks that introduce added design complexity.
Mandates for water quality control	Permeable pavements may contribute substantially to water quality improvement.
Mandates for water quantity control	Permeable pavements provide stormwater management alternatives to more costly or complicated practices.
Maintenance protocols	Permeable pavement systems require mandatory non-traditional maintenance practices such as vacuum sweeping.
Structural design	Design of PICP for moderate to heavy axle loads or high traffic counts may require additional analysis and details.
Interest in innovation	Designs that include PICP can provide opportunity for innovation and sustainable benefits.
Owner experience and resources	Permeable pavements should be designed to address owners expectations for performance, aesthetics, inspections, maintenance, benefits, costs, etc.

Key Criteria



- Pedestrian areas, parking lots, low-speed residential roads
- 30 m from wells
- 3 m from building foundations unless waterproofed
- Infiltrating base: Min. 0.6 m to seasonal high water table
- Max. contributing impervious area: PICP = 5:1
- Surface slope: as much as 18%...w/ subgrade check dams
- Subgrade slope: >3% - use berms


Permeable Pavement Design Flowchart
Section 3.2
Section 3.3
Structural Analysis
Hydrologic Analysis
Pedestrian Use
Vehicular Use
Design Storm
Contributing Area Runoff
Subgrade Properties Mr, CBR, R-Value
Traffic ESALs, Traffic Index
Infiltration Rate & Volume Into Subgrade
Outflow Rate & Volume Through Underdrains
Determine Surface & Base/Subbase Thickness
Surface & Base/Subbase Properties
Determine Depth of Water & Base/Subbase Thickness
Revise Thickness or Adjust Outflow
Increase Thickness
No
Structurally Adequate?
Yes
Select Limiting (Thicker) Cross-Section for Design
Yes
Hydrologically Adequate?
No

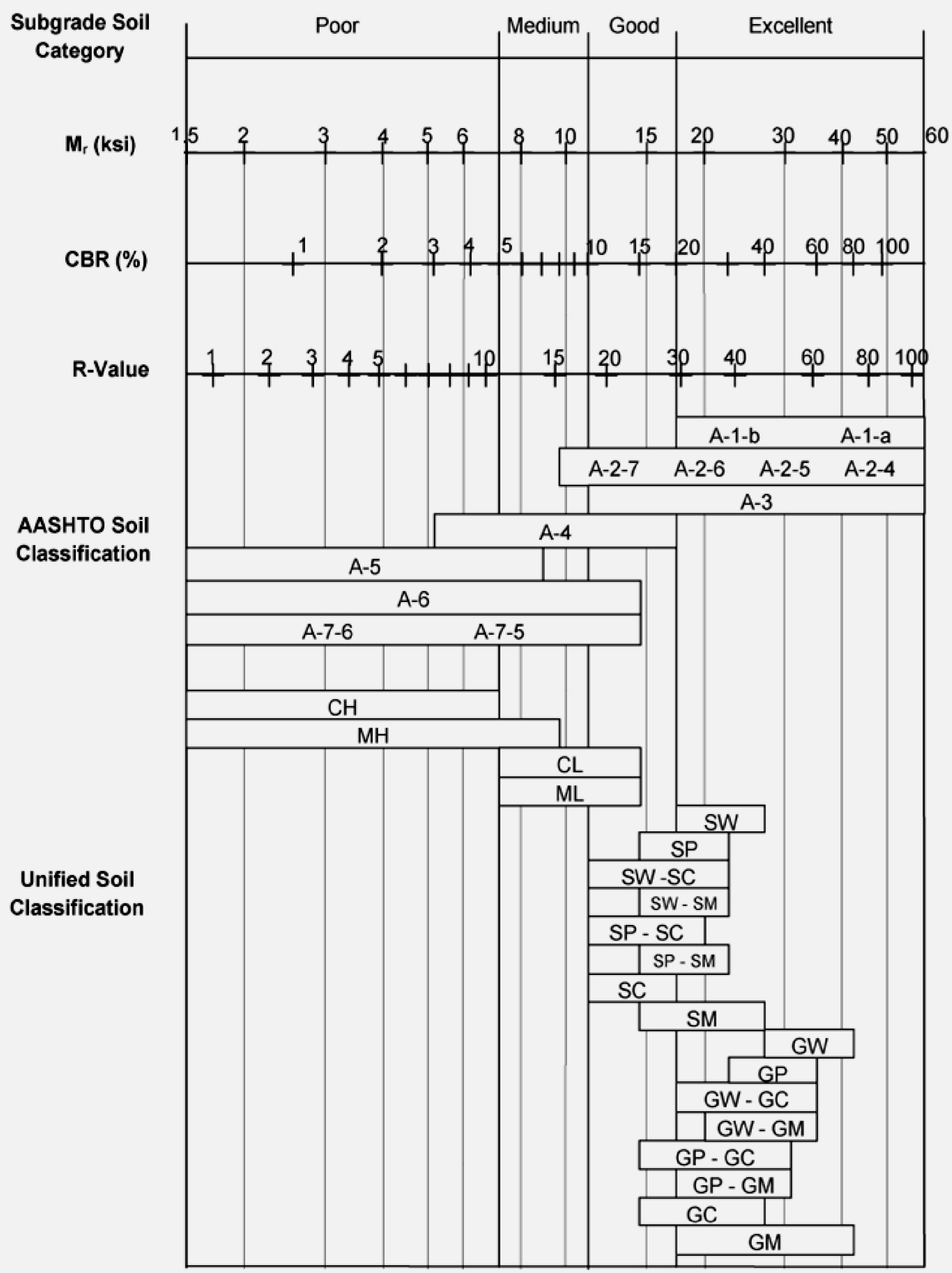
Resilient Modulus, M_r AASHTO T-307

CBR ASTM D1883

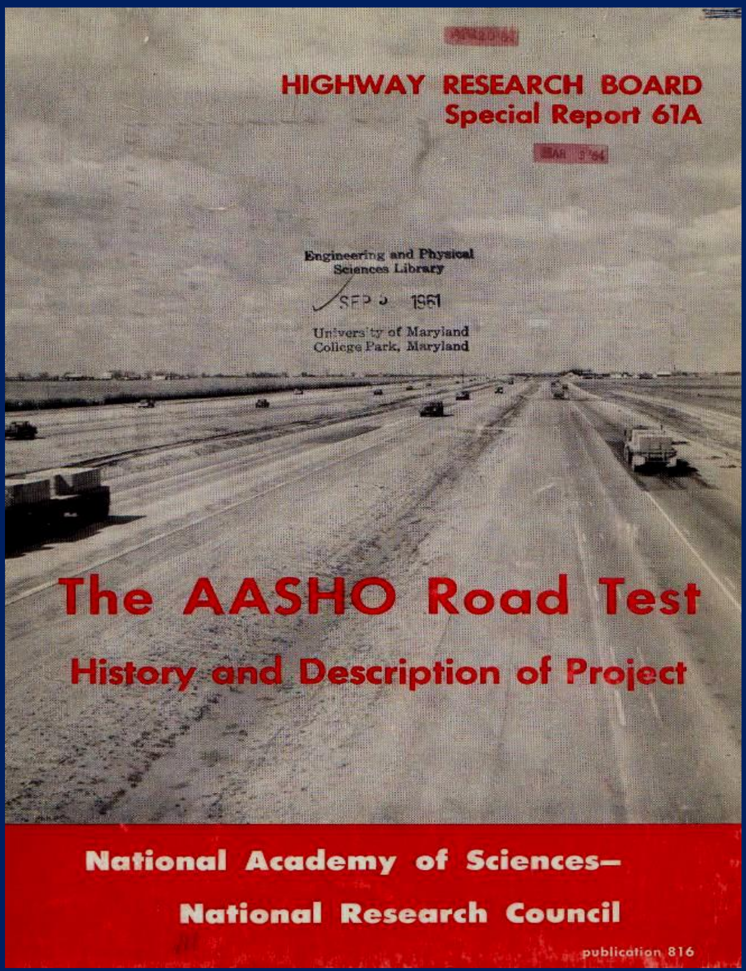
R-value ASTM D2844

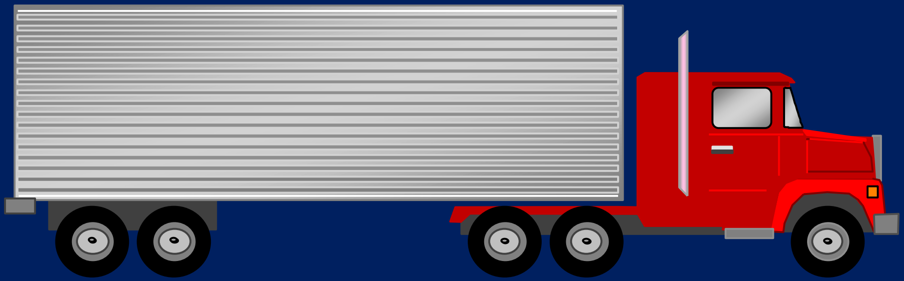
AASHTO Soil Classification AASHTO M-45

Unified Soil Classification ASTM D2487



Equivalent Single Axle Loads
or 80 kN ESALs
Characterizes performance (rutting)

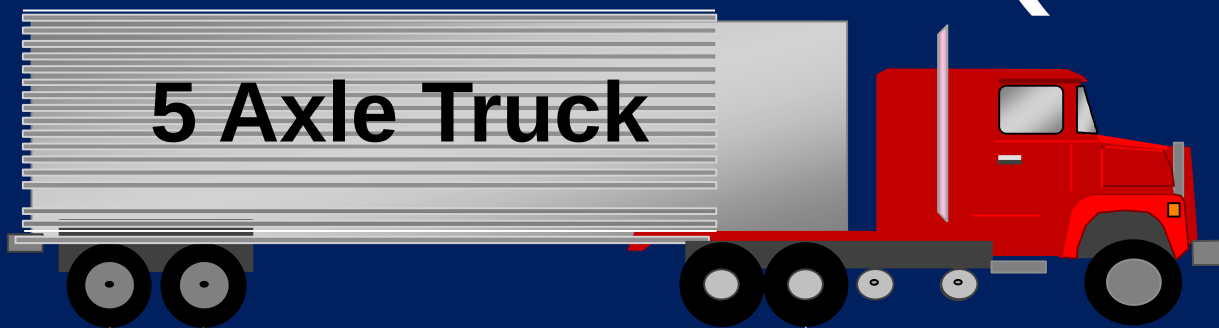




What is an ESAL?

ESALs per Truck

LEF: Load Equivalency Factor = $\left(\dfrac{\text{axle load}}{80\text{ kN}}\right)^4$



2 x 80 kN   2 x 70 kN   50 kN

LEF = $\left(\dfrac{80}{80}\right)^4 = 1 \times 2$ LEF = $\left(\dfrac{70}{80}\right)^4 = 0.6 \times 2 = 1.2$ LEF = $\left(\dfrac{50}{80}\right)^4 = 0.14$

One pass = 2 + 1.2 + 0.14 = 3.34 ESALs

How many ESALs does one pass of a car equal?

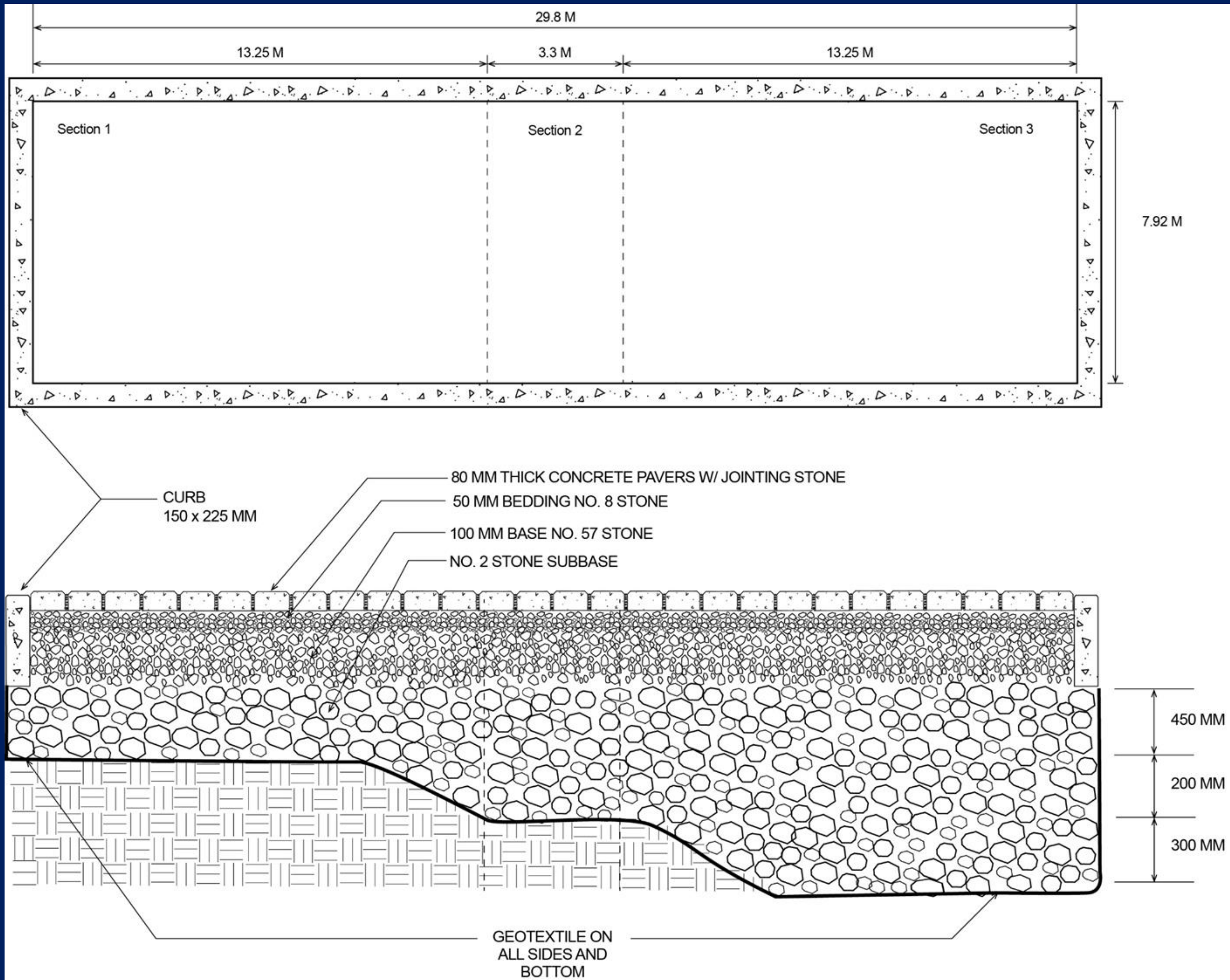
Assume 1 axle = 10 kN   0.00015 ESALs

Traffic Loading and Design

Pavement Class	Description	Design ESALs	Design TI
Arterial	Through traffic with access to high-density, regional, commercial and office developments or downtown streets. General traffic mix.	9,000,000	11.5
Major Collector	Traffic with access to low-density, local, commercial and office development or high density, residential sub-divisions. General traffic mix	3,000,000	10
Minor Collector	Through traffic with access to low-density, neighborhood, commercial development or low-density, residential sub-divisions. General traffic mix.	1,000,000	9
Bus Terminal	Public Transport Centralized facility for buses to pick up passengers from other modes of transport, or for parking of city or school buses.	500,000	8.5
Local Commercial	Commercial and limited through traffic with access to commercial premises and multi-family and single-family residential roads. Used by private automobiles, service vehicles and heavy delivery trucks	330,000	8
Residential	No through traffic with access to multi-family and single-family residential properties. Used by private automobiles, service vehicles and light delivery trucks, including limited construction traffic.	110,000	7
Facility Parking	Open parking areas for private automobiles at large facilities with access for emergency vehicles and occasional use by service vehicles or heavy delivery trucks.	90,000	7
Commercial Parking	Restricted parking and drop-off areas associated with business premises, mostly used by private automobiles and occasional light delivery trucks. No construction traffic over finished surface.	30,000	6
Commercial Plaza	Predominantly pedestrian traffic, but with access for occasional heavy maintenance and emergency vehicles. No construction traffic over finished surface.	10,000	5

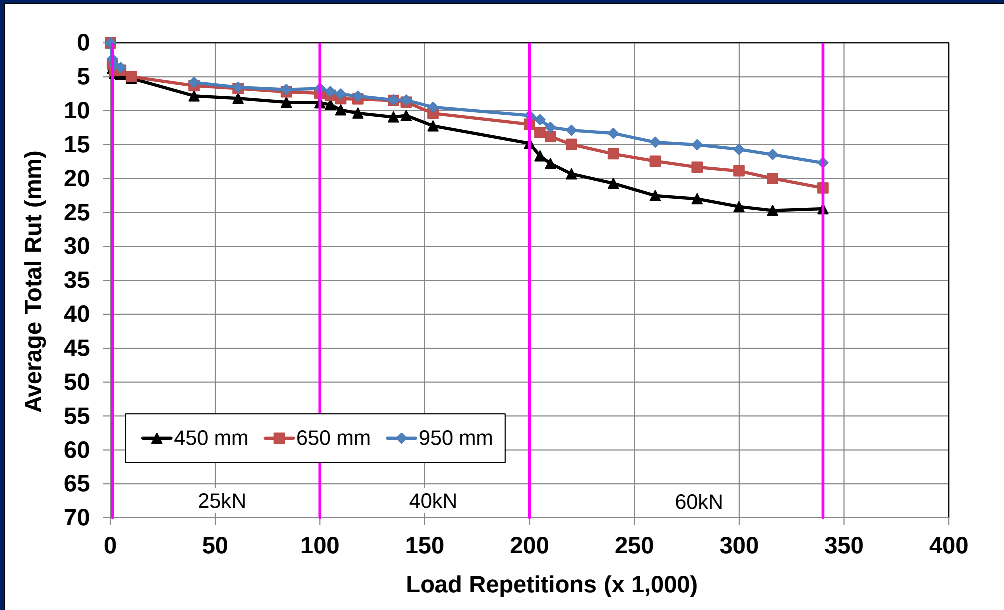
Need: Validated Base Thickness Charts

Design Tables for PICP
Accelerated Pavement Testing
UC Pavement Research Center

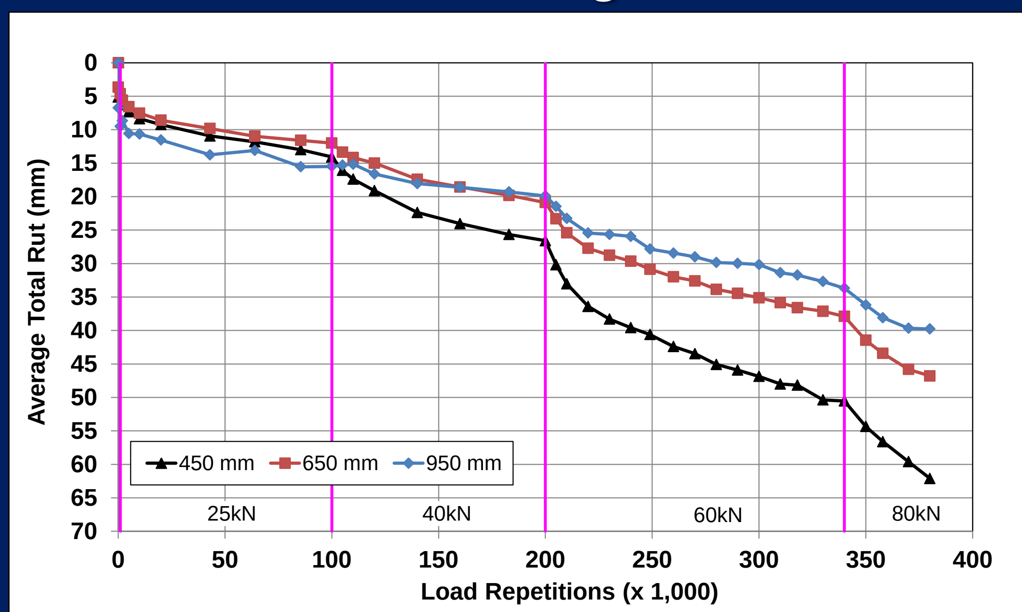

29.8 M
13.25 M
3.3 M
13.25 M
Section 1
Section 2
Section 3
7.92 M
CURB
150 x 225 MM
80 MM THICK CONCRETE PAVERS W/ JOINTING STONE
50 MM BEDDING NO. 8 STONE
100 MM BASE NO. 57 STONE
NO. 2 STONE SUBBASE
450 MM
200 MM
300 MM
GEOTEXTILE ON
ALL SIDES AND
BOTTOM

PICP Test Track Construction

Total Surface Rutting - Dry



Total Surface Rutting - Wet



Summary of Rutting Models

Layer	Rut Model[1]	Moisture Condition	Model Parameters		
			a	b	c
Combined bedding & base	$RD_{BB} = a \times h\_SB + b$	Dry	0	4.0	-
		Wet	-0.012	13.1	-
Subbase	$RD_{SB} = (a \times SSR^{b}) \times N^{c}$	Dry	3.10E-06	2.70	1
		Wet	3.10E-06	2.70	1
Subgrade (Silty clay)	$RD_{SG} = (a \times SSR + b) \times N^{c}$	Dry	0.03	-0.01	0.5
		Wet	0.03	-0.01	0.5

[1] RD_{xx}, rut depth of xx layer (BB=surface (paver, bedding and base); SB=subbase; SG=subgrade), mm;
h_SB, thickness of subbase, mm;
SSR, shear stress/strength ratio at the top of the layer;
N, load repetition;
a, b, c, model constants.

MS Excel PICP Design Tool

PICP Design Tool

Input

Structure & Materials

Layer	Moisture Condition	Thickness (mm)	Stiffness (MPa) [1]	Poisson's Ratio	c (kPa)	ϕ (°)
Surface (80 mm concrete paver plus 50 mm #8 bedding and 100 mm #57 base)	Wet	230	87	0.35	-	-
	Dry		110	0.35	-	-
Subbase (ASTM #2)	Wet	450	73	0.35	0	30
	Dry		122	0.35	0	45
Subgrade (Clay)	Wet	-	37	0.35	9	15
	Dry		60	0.35	15	25

Climate

Number of Days in a Year When the Subbase has Standing Water (Wet Days) [2]	50

[1] The wet stiffness to dry stiffness ratio can be assumed as 0.8, 0.6 and 0.6 for surface, subbase abd subgrade layers, respectively.

[2] Seasons when the subbase has standing water.

Traffic

Traffic Volume Calculation	
AADT (two-way)	*5,700*
Percent Trucks, T	*10.0%*
Direction Distribution Factor, D	*0.5*
Lane Distribution Factor, L	*0.8*
Annual Growth Rate, r	*3.0%*
Design Life (years), Y	*20*
Traffic Safety Factor, TSF	*1.0*
Truck Traffic Volume, *V*	**2,236,814**

$$V = 365 \times AADT \times T \times D \times L \times (1+r)^{Y/2} \times Y \times TSF$$

Axle Type	Axle Load (kN)	Axle-Load Distribution (%)	Lifetime Repetition: Wet Season [2]	Lifetime Repetition: Dry Season	Lifetime Repetition: Total	Lifetime Repetition: ESALs	Lifetime ESALs (Millions)
Single	10	3.25	9,959	62,740	72,699	18	0.50
	20	5.97	18,286	115,200	133,486	521	
	30	5.83	17,850	112,456	130,307	2,577	
	40	4.43	13,568	85,481	99,050	6,191	
	50	3.23	9,896	62,345	72,241	11,023	
	60	2.80	8,574	54,019	62,593	19,805	
	70	3.13	9,594	60,443	70,037	41,054	
	80	2.40	7,363	46,388	53,751	53,751	
	90	0.85	2,594	16,340	18,933	30,327	
	100	0.15	445	2,804	3,249	7,931	
	120	0.03	94	594	688	3,485	
	160	0.01	31	194	225	3,596	
Tandem	20	1.59	4,887	30,788	35,675	17	
	40	5.79	17,734	111,727	129,461	1,011	
	60	6.76	20,729	130,591	151,319	5,985	
	80	4.48	13,720	86,437	100,158	12,520	
	100	3.42	10,472	65,971	76,443	23,329	
	120	3.86	11,815	74,432	86,247	54,578	
	140	4.12	12,630	79,569	92,199	108,091	
	160	1.94	5,946	37,460	43,406	86,813	
	180	0.29	900	5,670	6,570	21,048	
	200	0.05	154	973	1,128	5,506	

Outcome

Rut Depth

Layer	Moisture Condition	Shift Factor	Rut Depth by Layer (mm)	Expected Total Rut Depth (mm)	Allowable Rut Depth (mm)	Satisfactory ?
Surface (80 mm concrete paver plus 50 mm #8 bedding and 100 mm #57 base)	Wet	1.00	1.1	65.3	25.0	N
	Dry	1.00	3.3			
Subbase (ASTM #2)	Wet	1.23	15.0			
	Dry	1.10	25.0			
Subgrade (Clay)	Wet	1.23	9.0			
	Dry	1.10	12.0			

Calculate Rut Depth

Design Subbase Thickness

Example Design Tables

Number of Days in a Year when the Subbase has Standing Water (Wet Days)		0 to 9				10 to 29				30 to 49			
Resilient Modulus of Subgrade, MPa (CBR)	Dry	40	60	80	100	40	60	80	100	40	60	80	100
	Wet	24 (1.6)	36 (3)	48 (4.8)	60 (6.8)	24 (1.6)	36 (3)	48 (4.8)	60 (6.8)	24 (1.6)	36 (3)	48 (4.8)	60 (6.8)
Lifetime ESALs (Traffic Index)		Minimum Subbase Thickness in mm for ASTM No. 2 Aggregate 25 mm Allowable Rut Depth											
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

Number of Days in a Year when the Subbase has Standing Water (Wet Days)		50 to 89				90 to 119				120 or more			
Resilient Modulus of Subgrade, MPa (CBR)	Dry	40	60	80	100	40	60	80	100	40	60	80	100
	Wet	24 (1.6)	36 (3)	48 (4.8)	60 (6.8)	24 (1.6)	36 (3)	48 (4.8)	60 (6.8)	24 (1.6)	36 (3)	48 (4.8)	60 (6.8)
Lifetime ESALs (Traffic Index)		Minimum Subbase Thickness in mm for ASTM No. 2 Aggregate 25 mm Allowable Rut Depth											
50,000 (6.3)		175	150	150	150	210	150	150	150	230	150	150	150
100,000 (6.8)		285	180	150	150	325	215	150	150	340	235	150	150
200,000 (7.4)		395	285	185	150	430	320	215	150	450	335	235	155
300,000 (7.8)		455	340	240	160	495	375	275	195	515	395	290	215
400,000 (8.1)		500	380	280	200	535	415	310	235	555	435	330	250
500,000 (8.3)		530	410	305	230	570	445	340	260	590	465	355	275
600,000 (8.5)		555	435	330	250	595	470	360	280	615	490	380	300
700,000 (8.6)		580	455	350	270	620	490	380	300	640	510	400	315
800,000 (8.8)		600	470	365	285	640	505	395	315	660	525	415	335
900,000 (8.9)		615	485	380	295	655	525	410	330	675	540	430	345
1,000,000 (9.0)		630	500	390	310	670	535	425	340	690	555	440	360

Final Comment – Structural Design

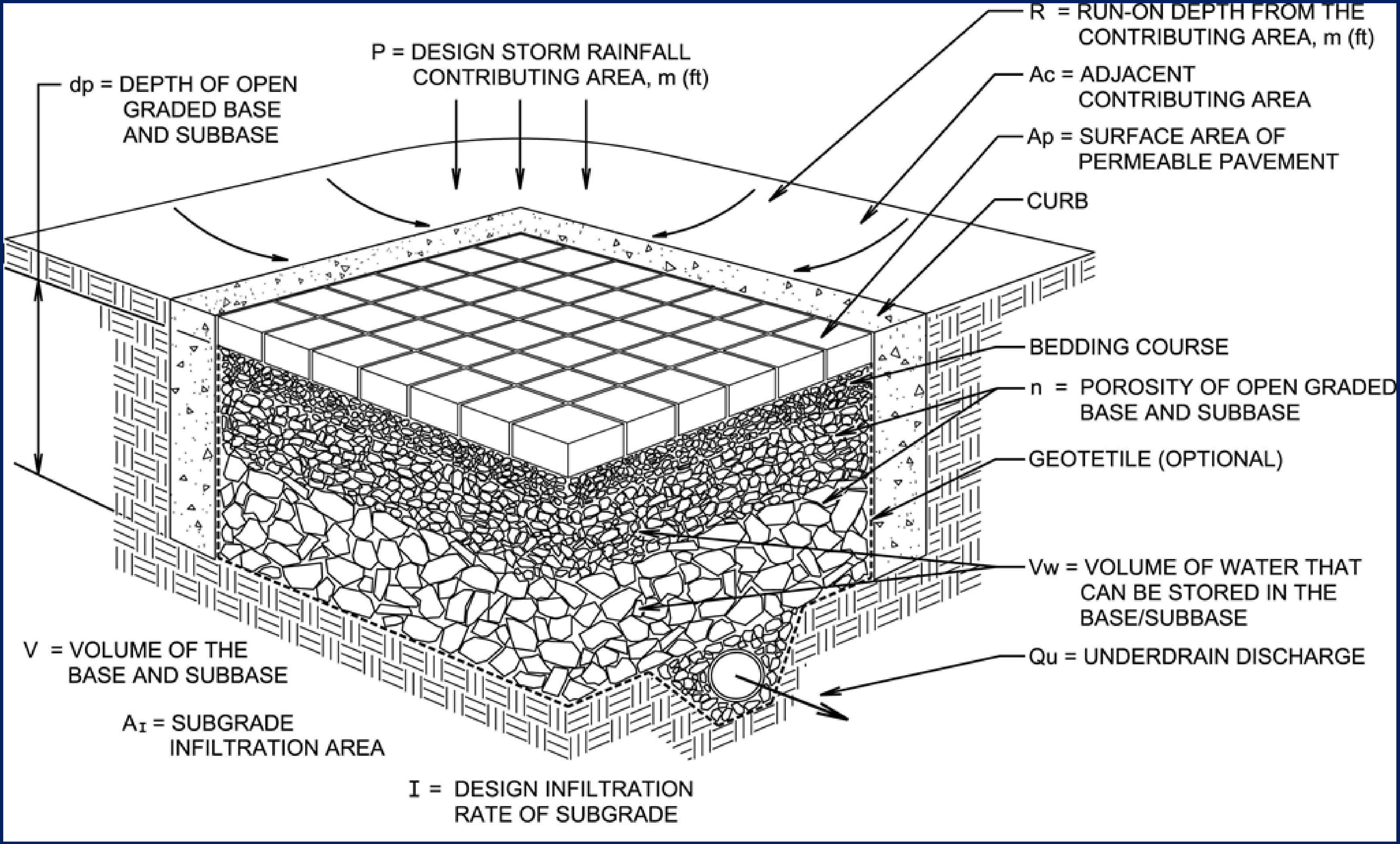
- **Traffic Type and Composition -** Permeable pavements can be used heavy vehicular applications, but a qualified pavement engineer should be consulted for these specific applications.
- **Limitations** – speed limit should be less than 65kph

Hydraulic Design (S3.3)

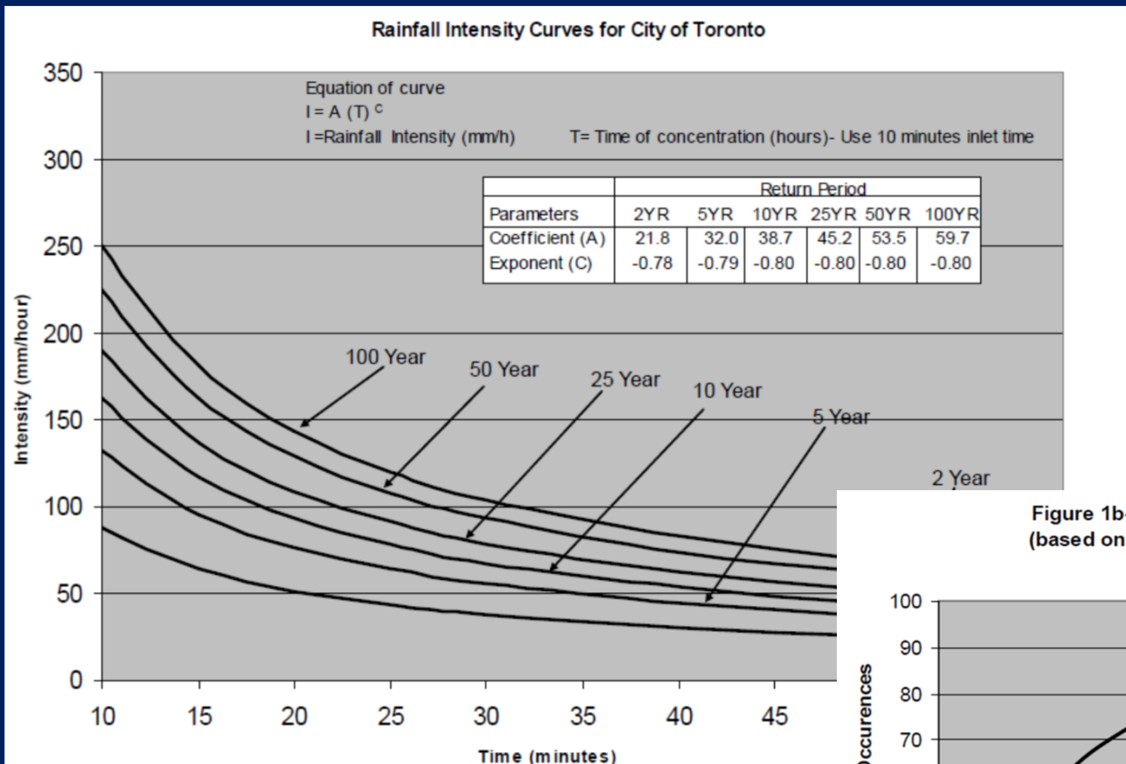
Determine Hydraulic Goals

- Volume control (maintain pre-development conditions)
- Water quality (catch first flush)
- Thermal quality
- Peak flow control
- Downstream erosion control
- Infiltration/recharge targets
- Ecosystem/habitat maintenance

Water Balance

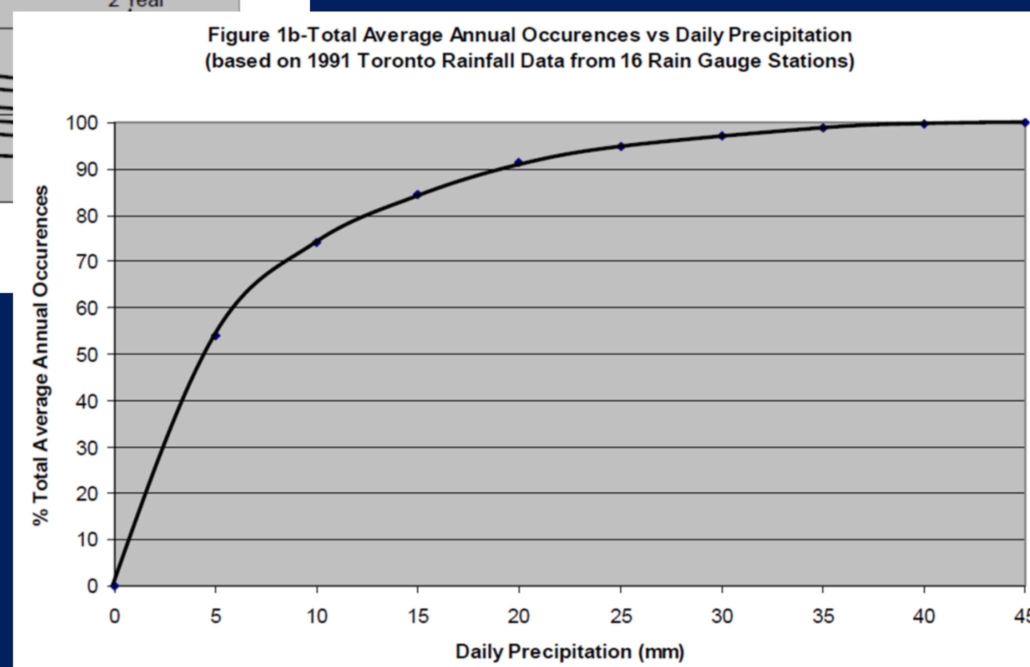


Input - Precipitation Data



Intensity Duration Frequency Curves

Percentile Storm Data



Output – Subgrade Infiltration

Double ring infiltrometer test
- Use avg. infiltration rate
- Apply safety factor for clogging & construction compaction

Multiple test holes

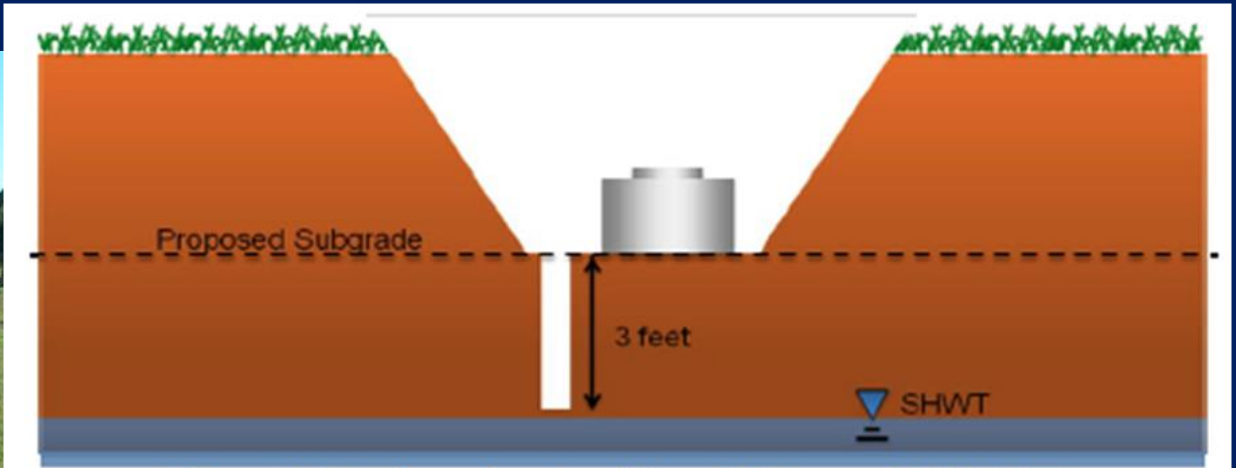
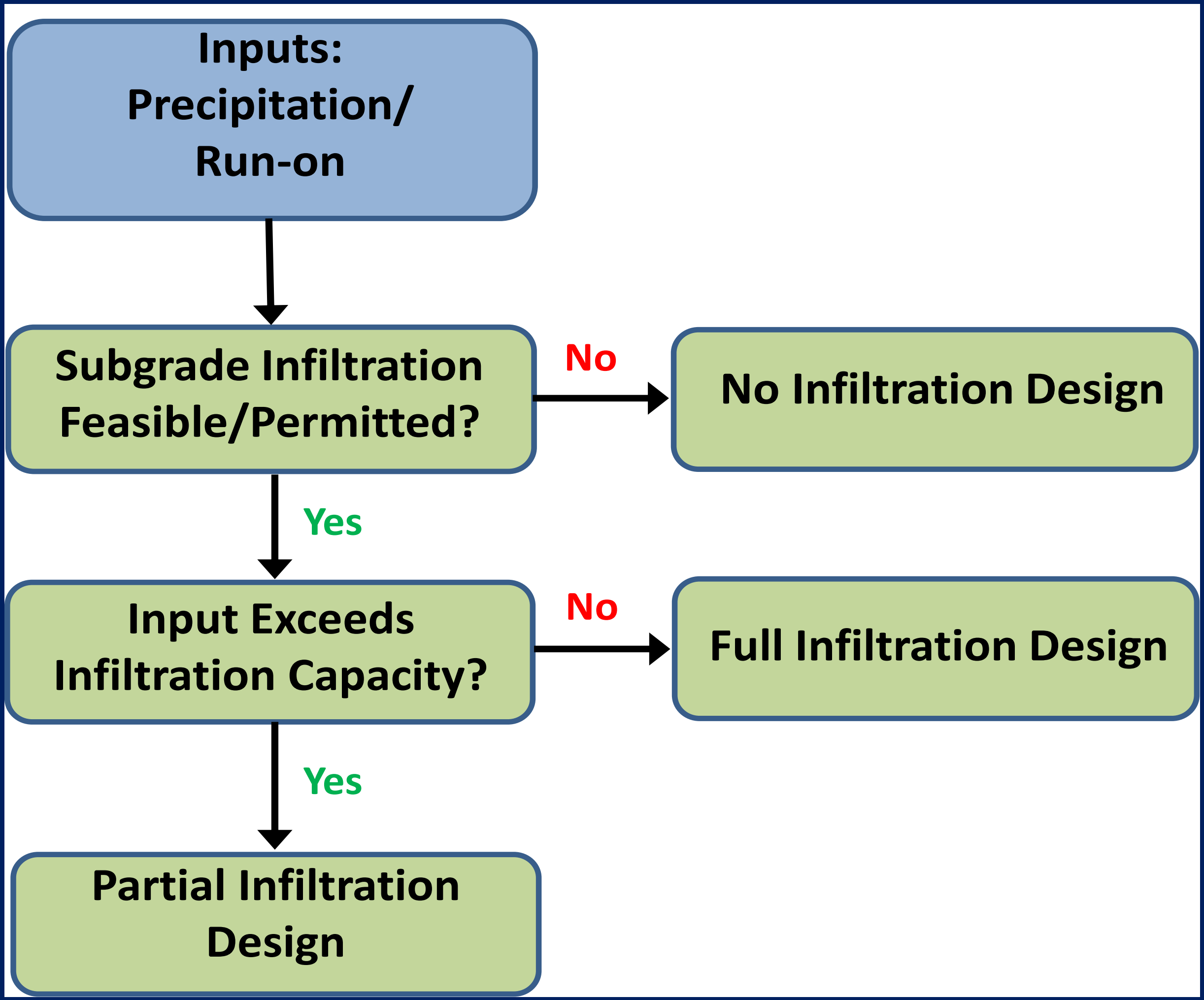
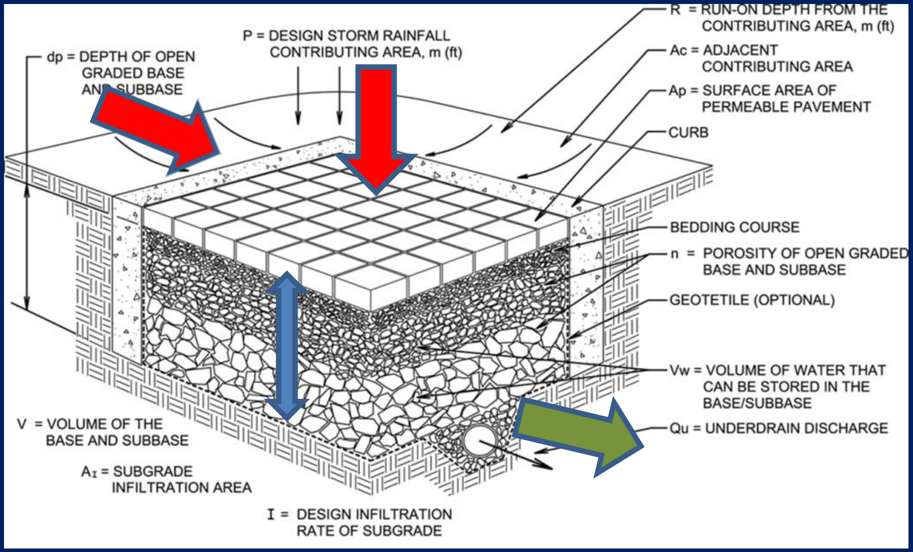


Figure 18-5. Schematic of a soil test pit (Source: NCSU-BAE)

Selecting the PICP System Type

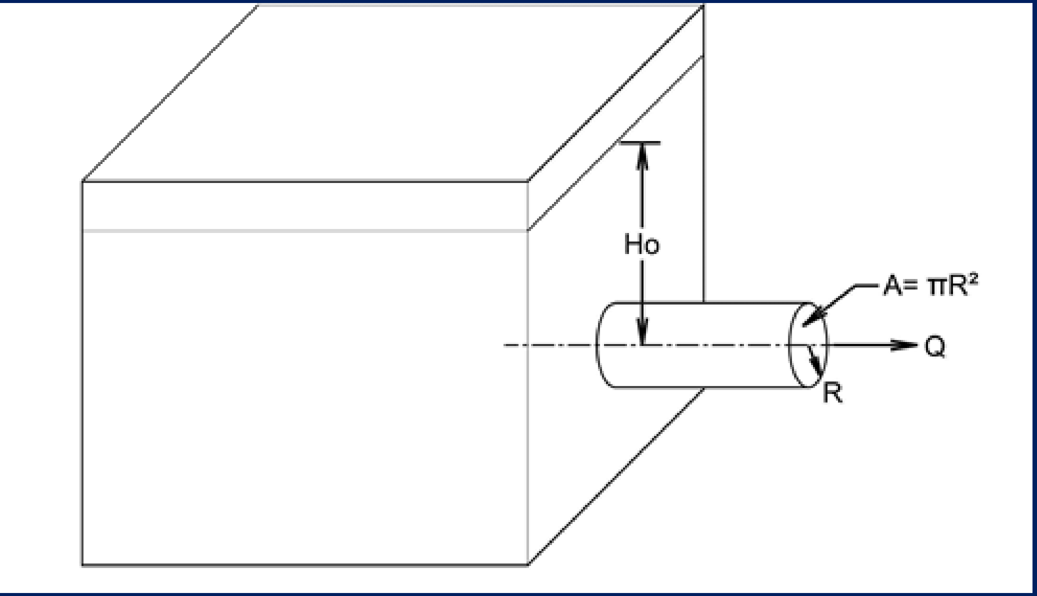


No-infiltration Design

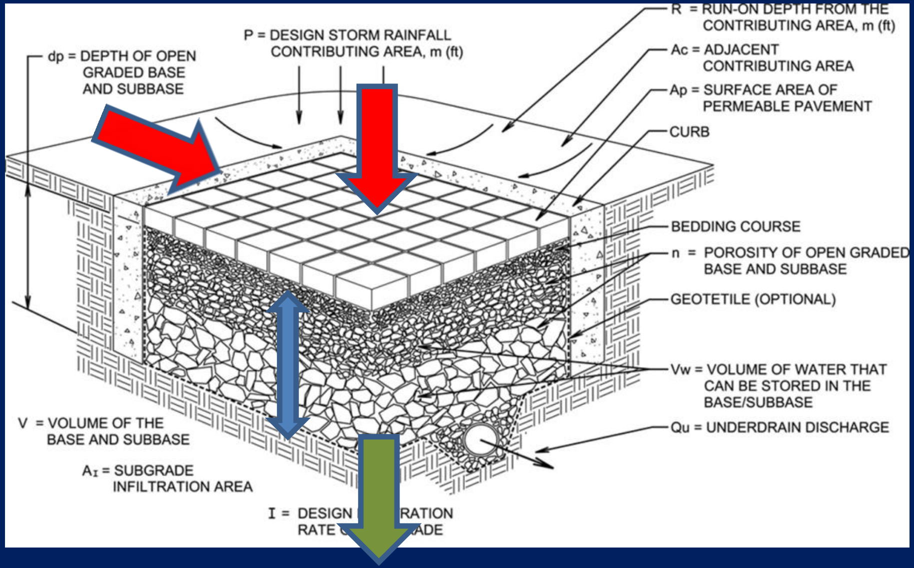


$$V_W = P(A_P) + R(A_C) - Q_U T_S$$

Pipe flow can be calculated using the orifice equation



Full-infiltration Design



$$V_W = P(A_P) + R(A_C) – I(T_S)A_I$$

If Vw > 0, then make sure the subgrade is not saturated for too long (T_D) using:

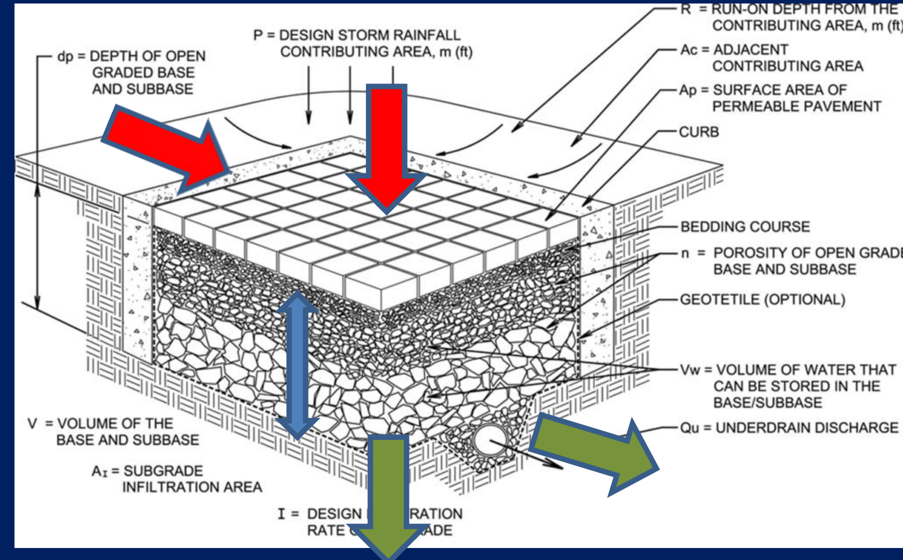
$$T_D \geq \frac{V_W}{A_I * I}$$

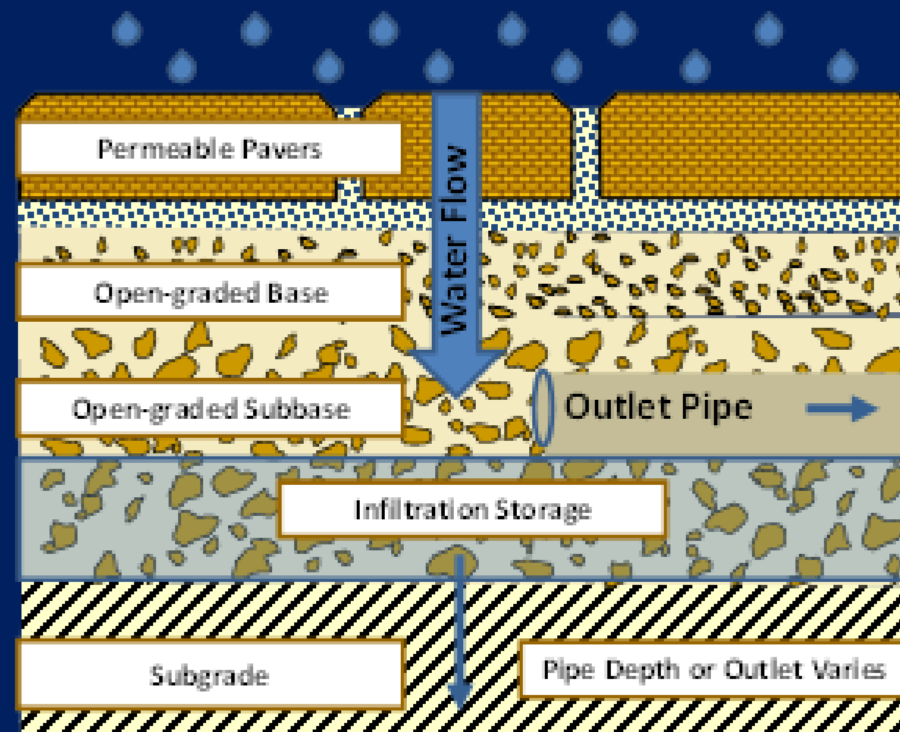
Partial-infiltration Design

$$V_W = P(A_P) + R(A_C) - I(T_S)A_I - Q_U T_S Z$$

Infiltration Storage volume dictates pipe location (elevation).

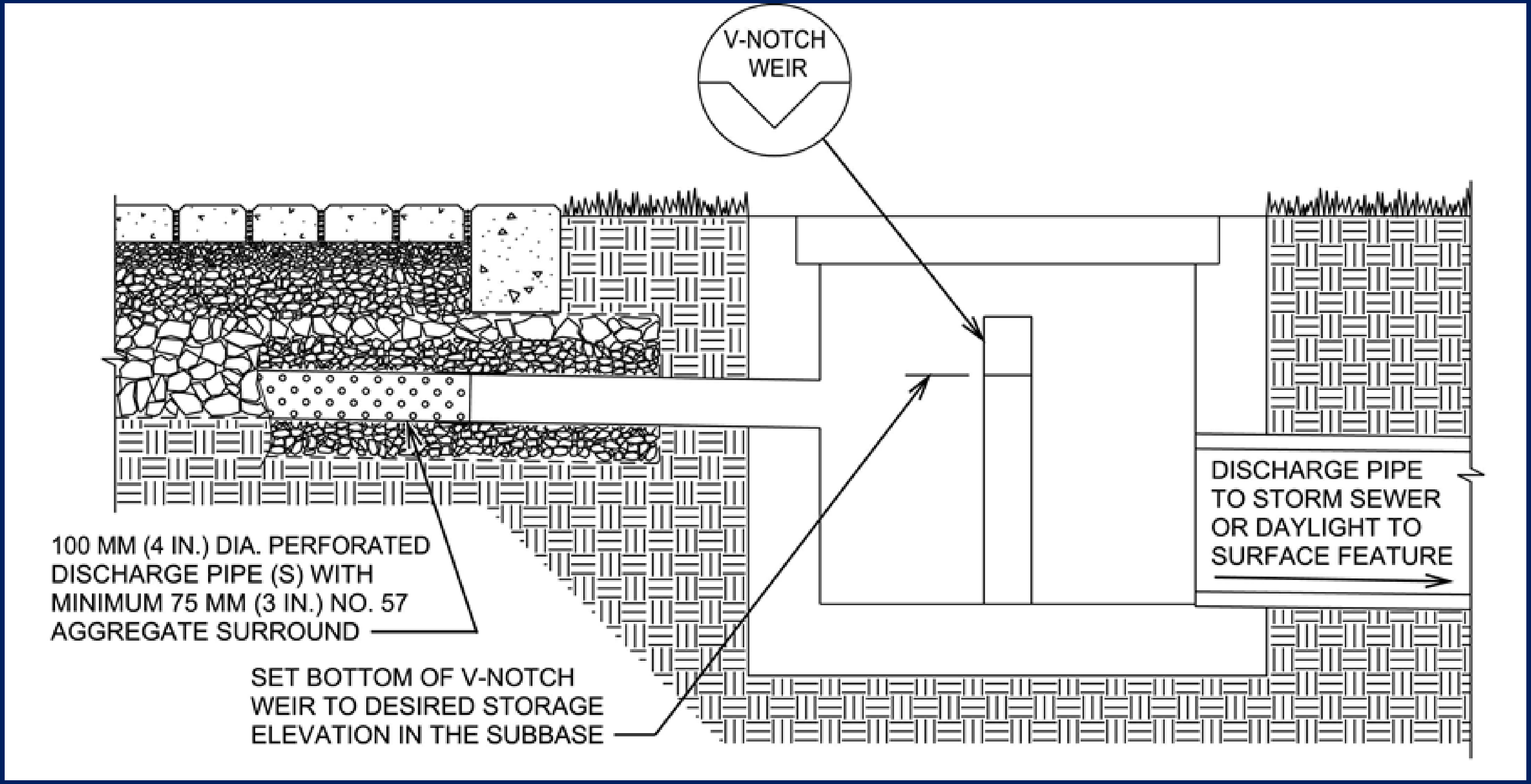
Underdrain elevation factor (Z) used to adjust for duration of pipe flow





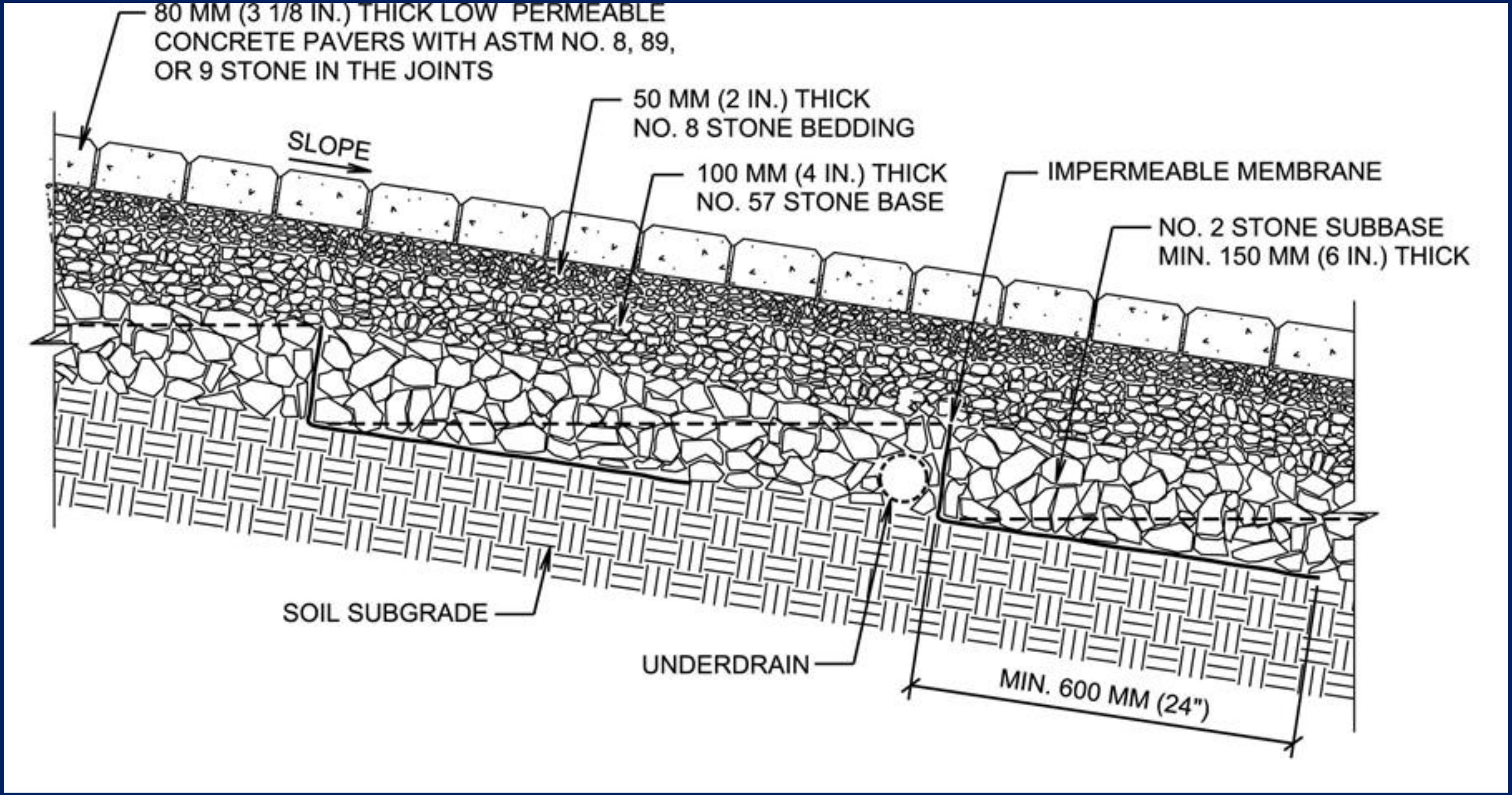
Additional Design Considerations (S3.5)

- Outlet structures provide for future modifications to the storage depth, and provide a convenient monitoring location



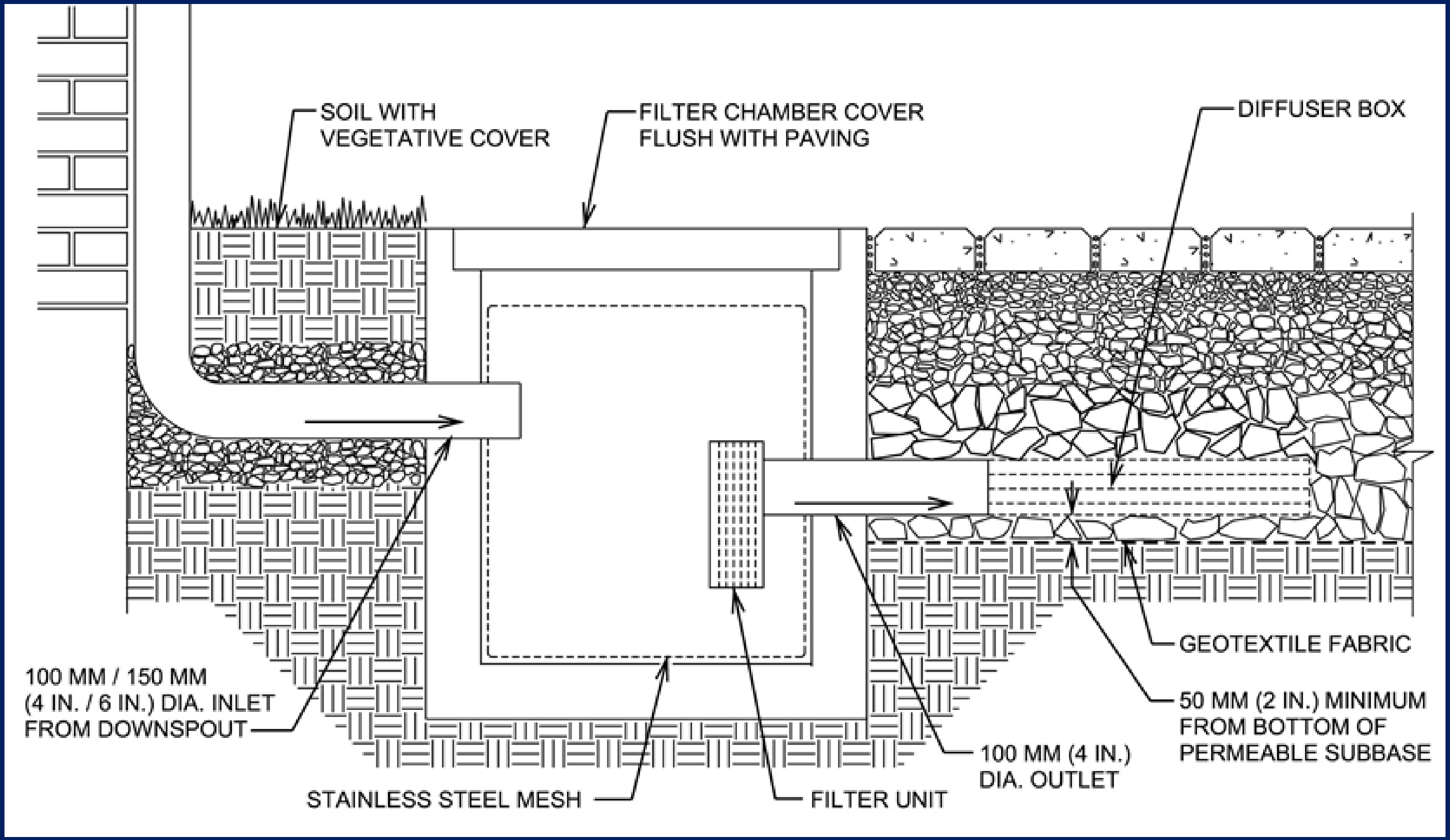
Additional Design Considerations

- Sites with subgrade slopes over 3% often require buffers, weirs, check dams, etc. to control water flow



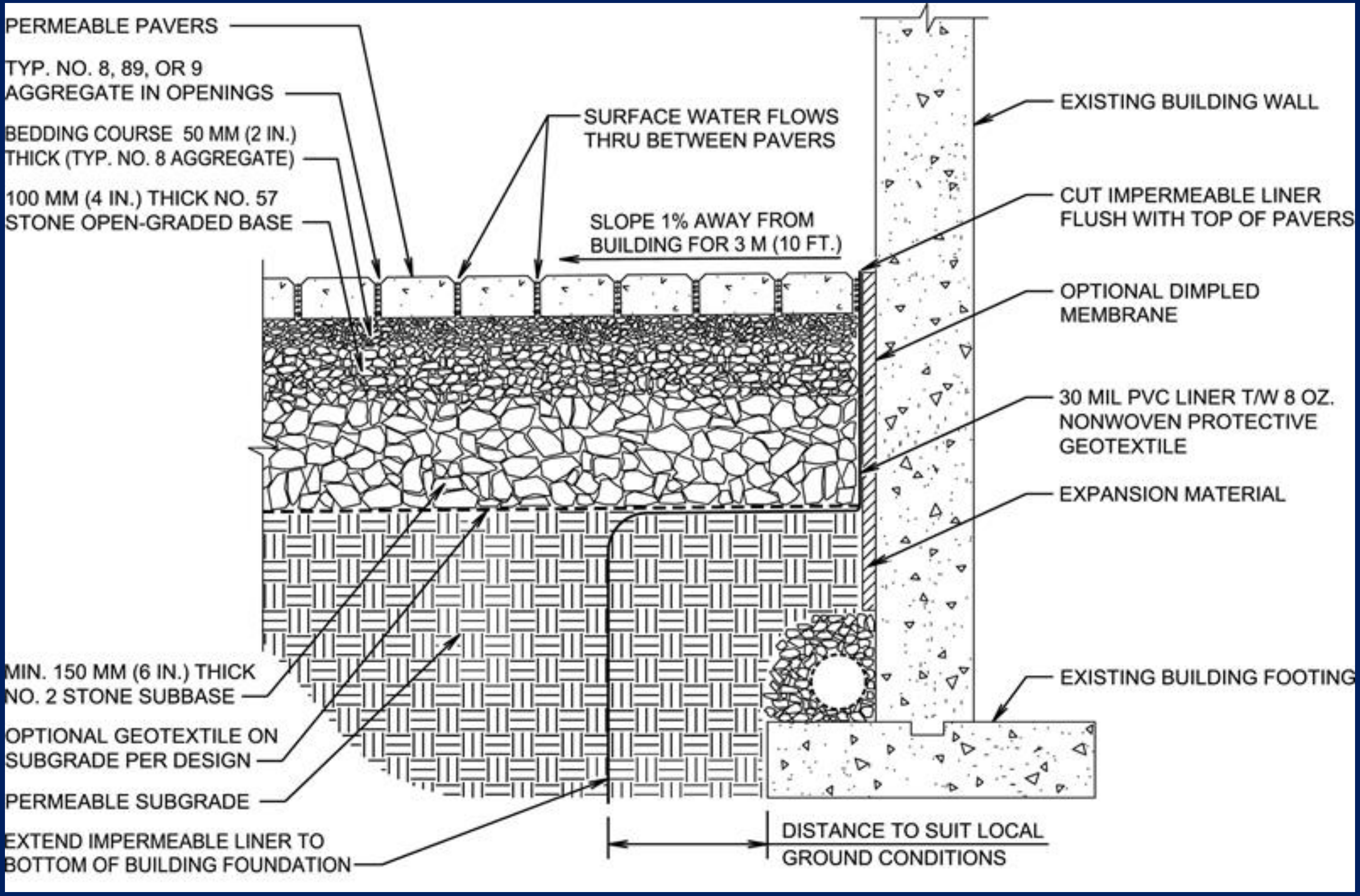
Additional Design Considerations

- Roof water can be discharged onto, or into, the pavement



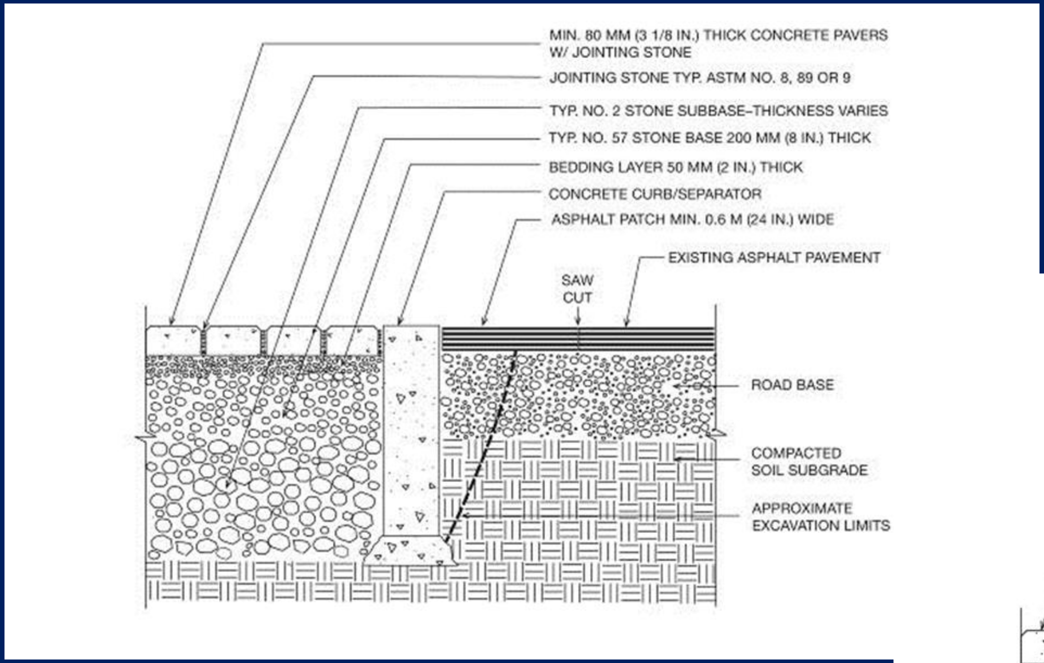
Additional Design Considerations

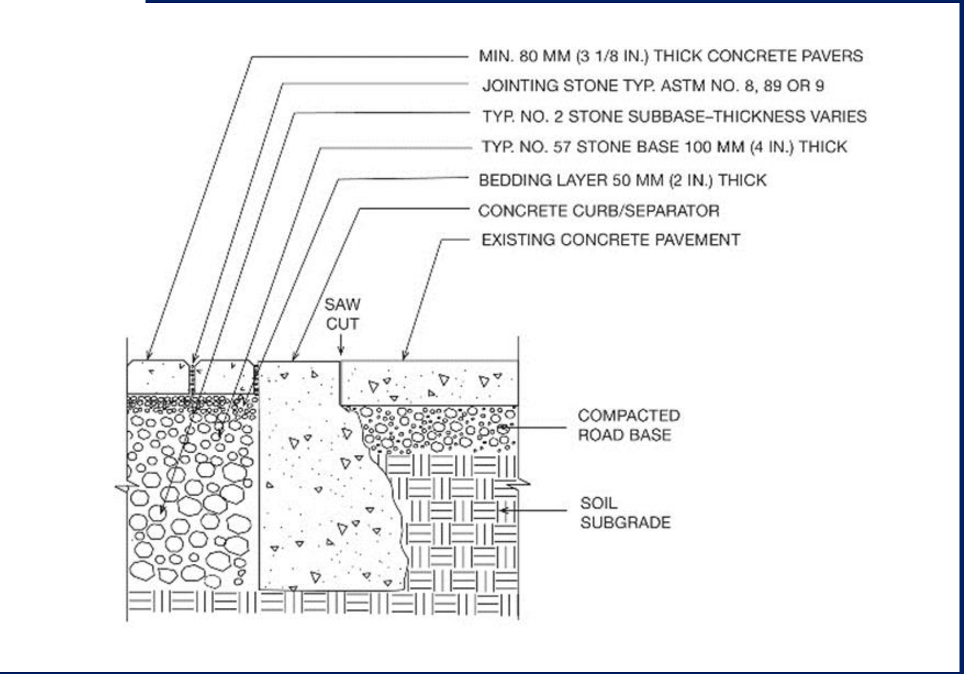
- Impermeable liners can be used adjacent to buildings



Additional Design Considerations

- Separation is required between permeable and traditional base materials





Pre-Construction Meeting (S4.2)

- PICP construction sequence
- Erosion & sediment control plan
- Subgrade protection
- Material storage
- Paver stitching
- Inspection criteria
- Contractor certification

Erosion and Sediment Control (S4.3)

Construction Inspection Checklist (S4.4)

Minimizing compaction

DO NOT scarify

Construction Inspection Checklist

Place geomembranes and geotextiles as specified

Construction Inspection Checklist

Underdrain placement

Construction Inspection Checklist

Aggregate placement, compaction and testing

Maintenance Guidelines (S5)

- **Contaminant Loading –** Minimize/remove potential contaminants such as winter sand, biomass (tree leaves and needles, grass clippings, etc.) and sediment

Maintenance Guidelines

- **Infiltration Testing –** Test surface infiltration rate using ASTM C1781

Routine and Remedial Maintenance

- Regenerative air vacuum sweeper
  - Routine cleaning
  - Removes loose sediment,
    leaves, etc.
  - More common
  - ~$2,500/ha

- True vacuum sweeper
  - 2X more powerful
  - Restores highly clogged surfaces
  - Narrower suction

Winter Maintenance

- Snow melts– lower risk of ice
- Does not heave when frozen
- Use normal plows - dirty snow piles clog surface
- Deicing salts okay
- Sand will clog system – use jointing material for traction

Status of ASCE Standard Guideline

- **Full Standard will undergo editing before going to public comment for 45 days late in 2016**
- **Expect to publish the final standard early in 2017**