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IECA Great Lakes CHAPTER

Development of a National ASCE Standard for Permeable Interlocking Concrete Pavement

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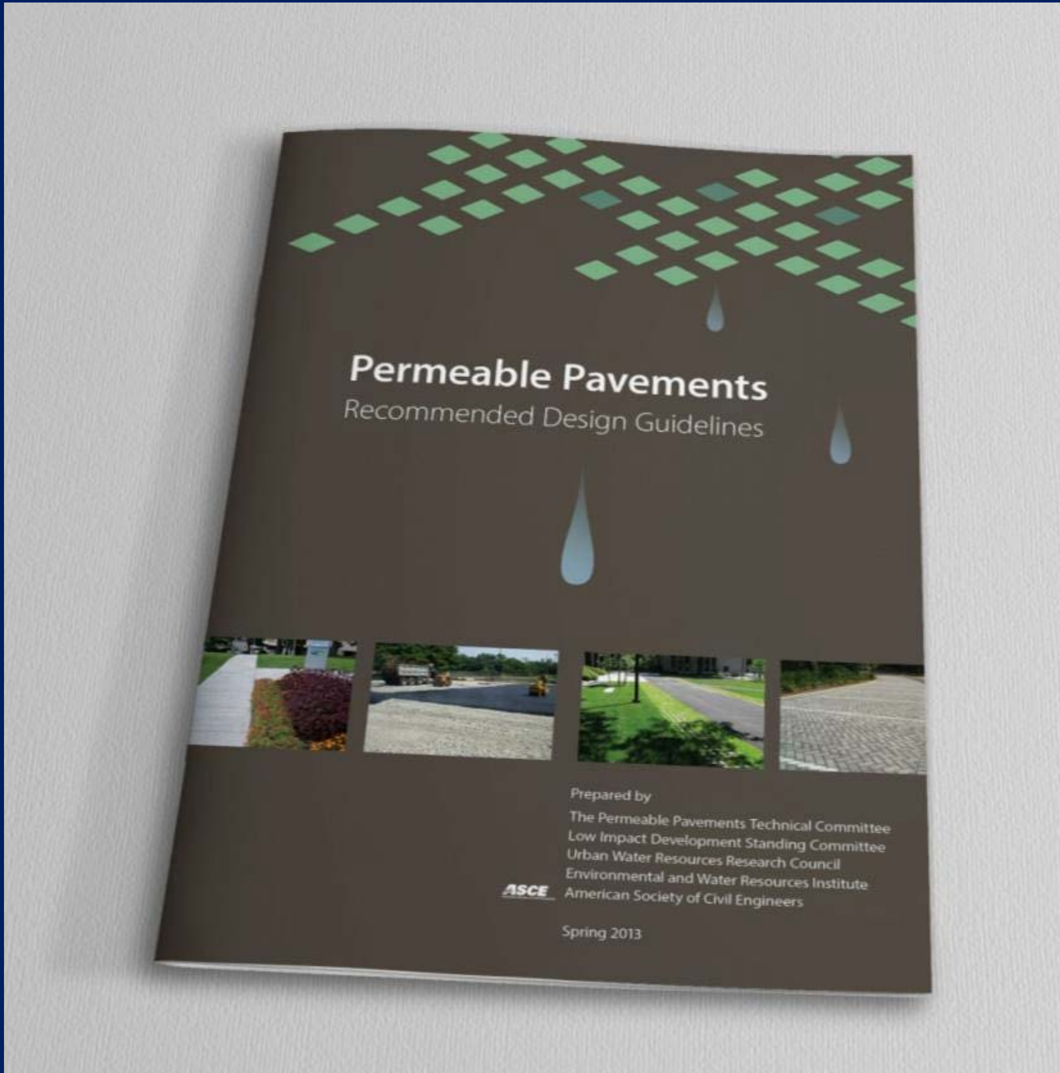
Oaks by Brampton Brick

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

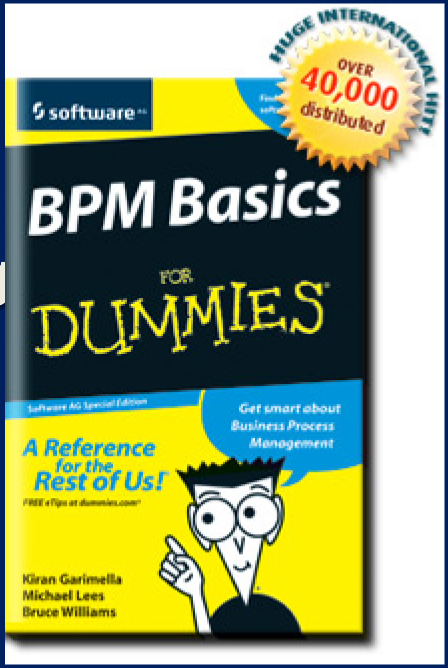
Section 1 – General Scope

Section 2 – Preliminary Assessment

Section 3 – Design (structural & hydraulic desig
additional considerations)

Section 4 – Construction

Section 5 – Maintenance



Goal: end of 2016 completion

Uses

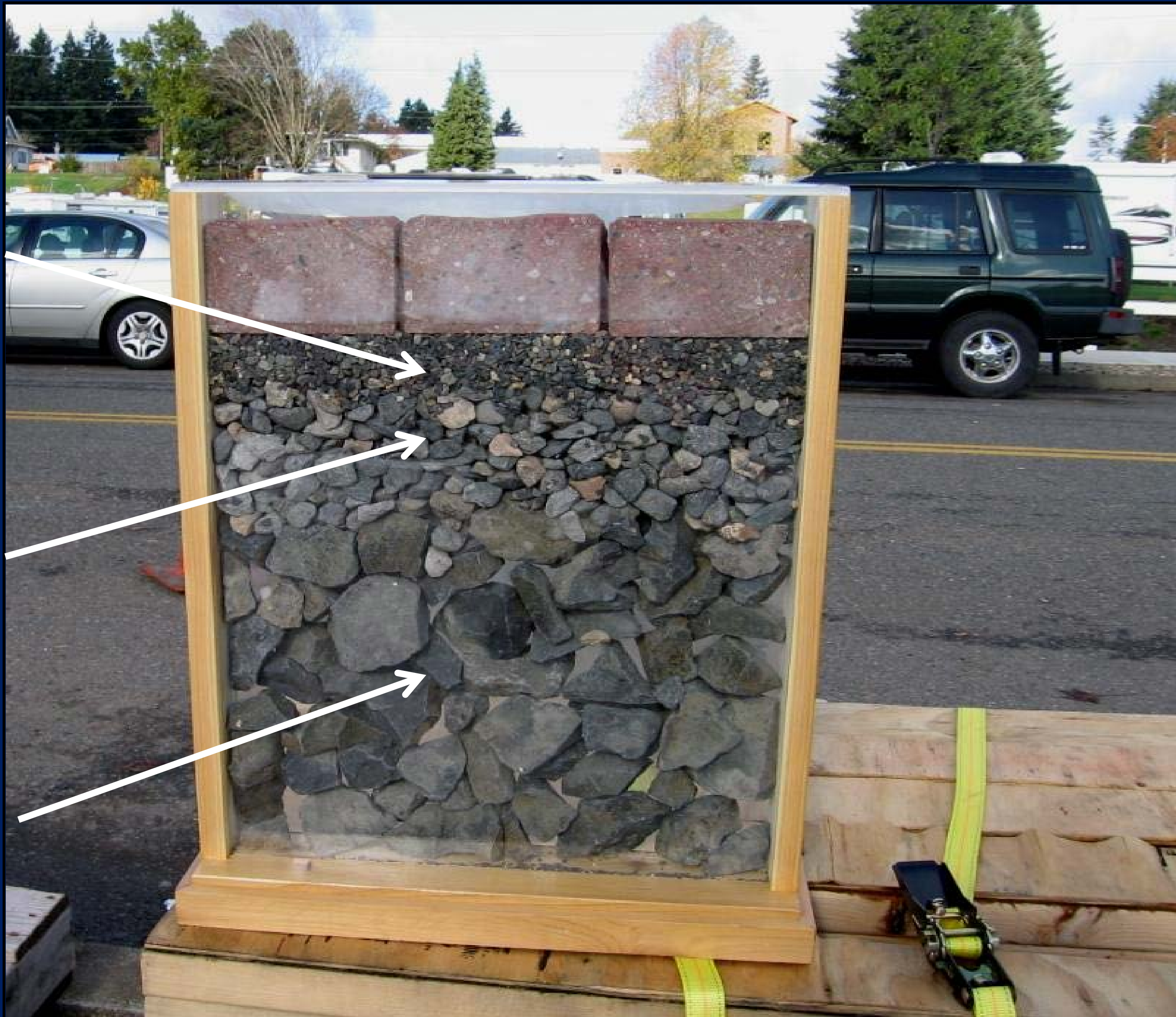
- Adoption by State, Provincial & Local agencies
- Design professional & contractor guidance

Permeable Interlocking Concrete Pavement (PICP)

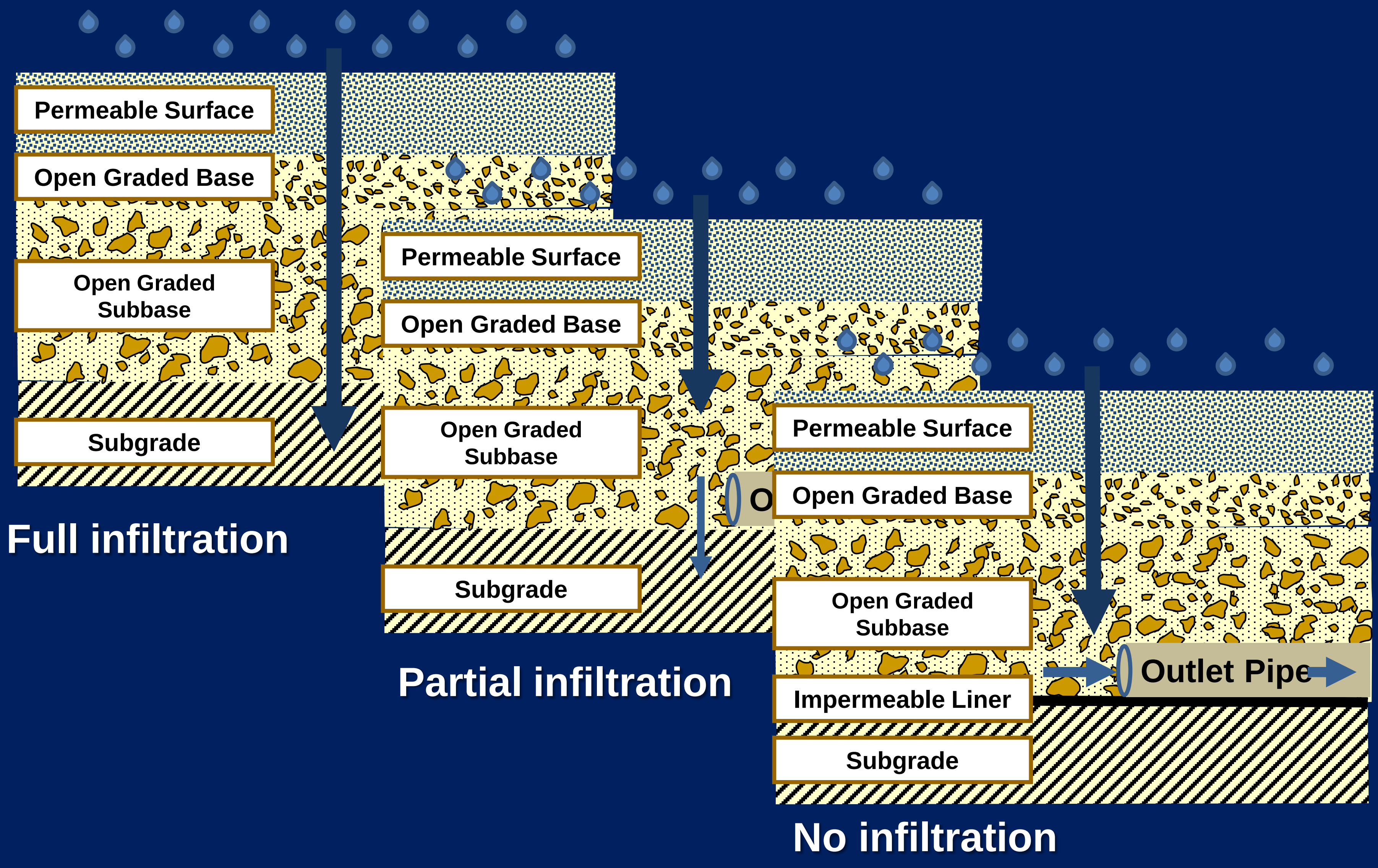
Pavers, bedding & jointing stones

Base reservoir Stone – 100 mm. thick

Subbase stone - thickness varies with water storage & traffic



Permeable Pavement Functions



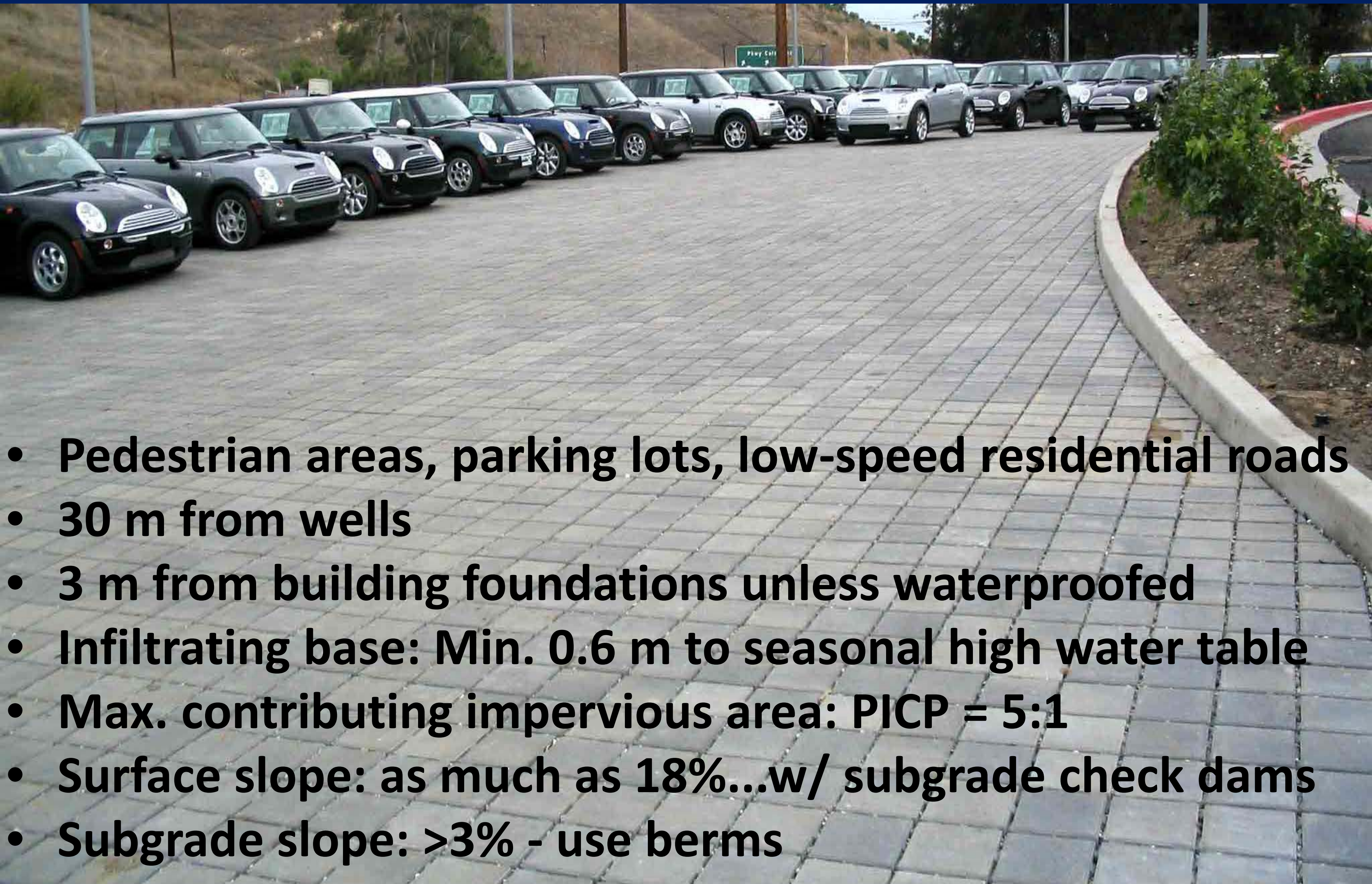
Assessing Suitability (S 2.1)

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).

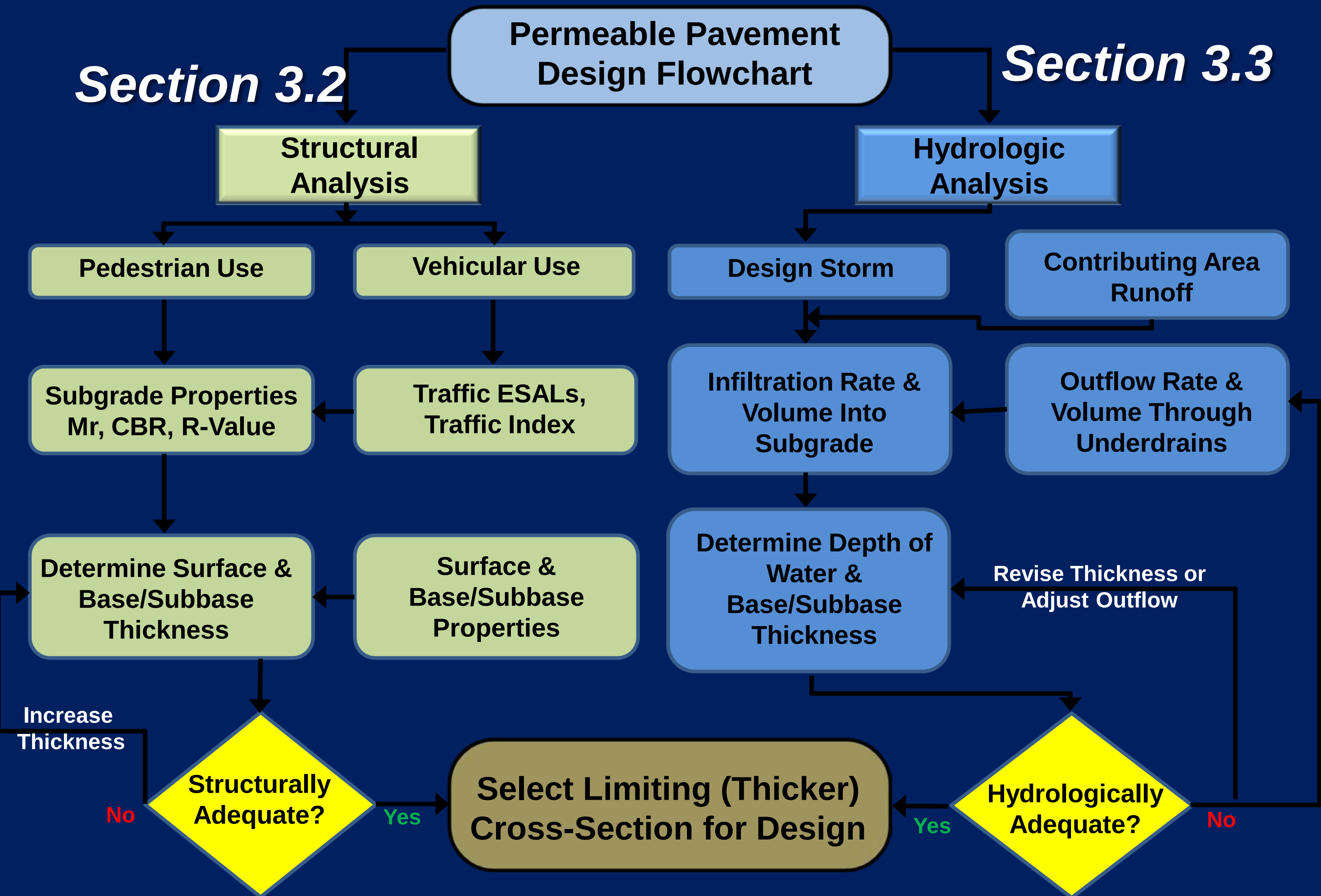
Assessing Suitability (cont.)

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

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 <u>and</u> horizontal shear

Used in California & a few other states

Strengths correlate to each other

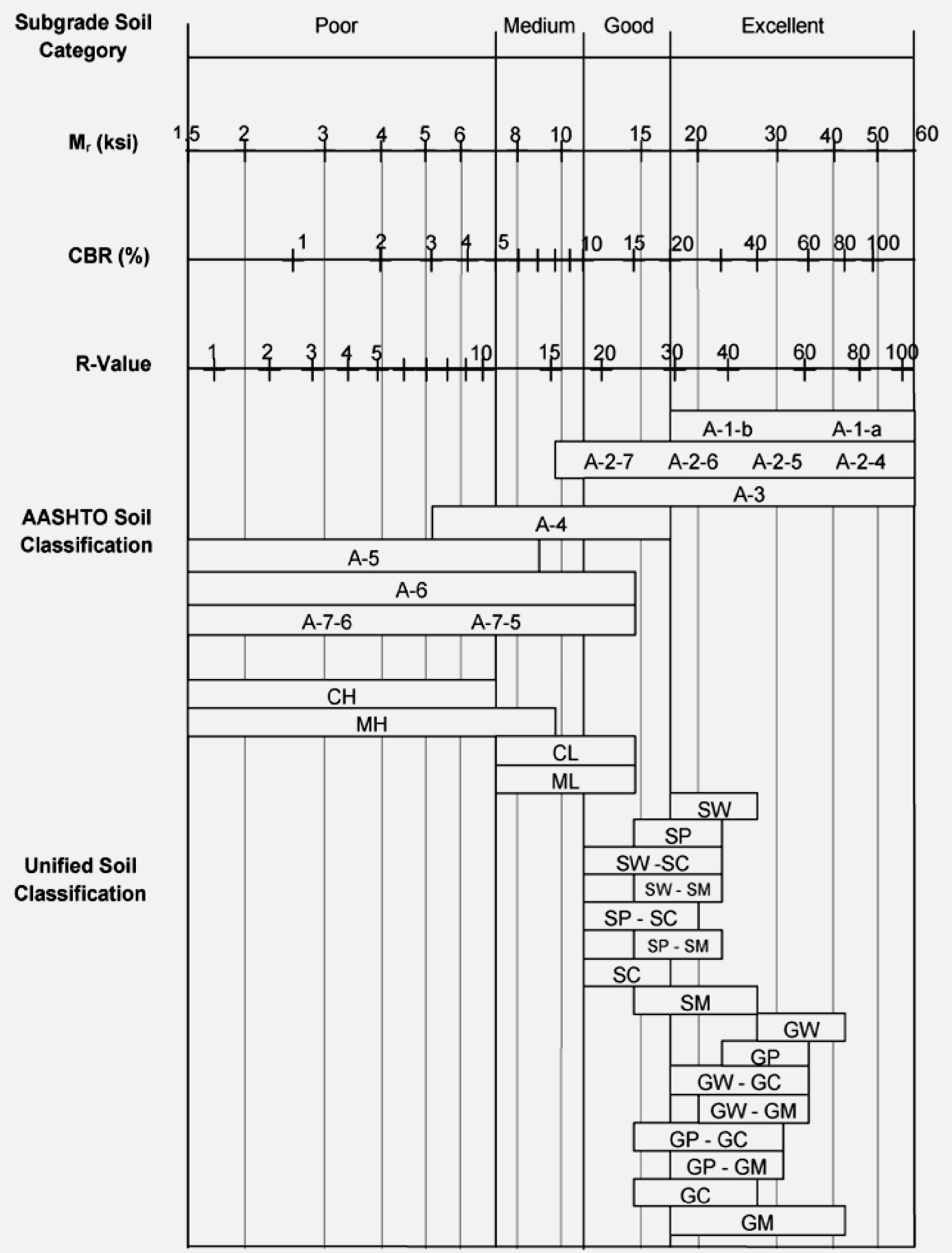
Resilient Modulus, M_r
AASHTO T-307

CBR ASTM D1883

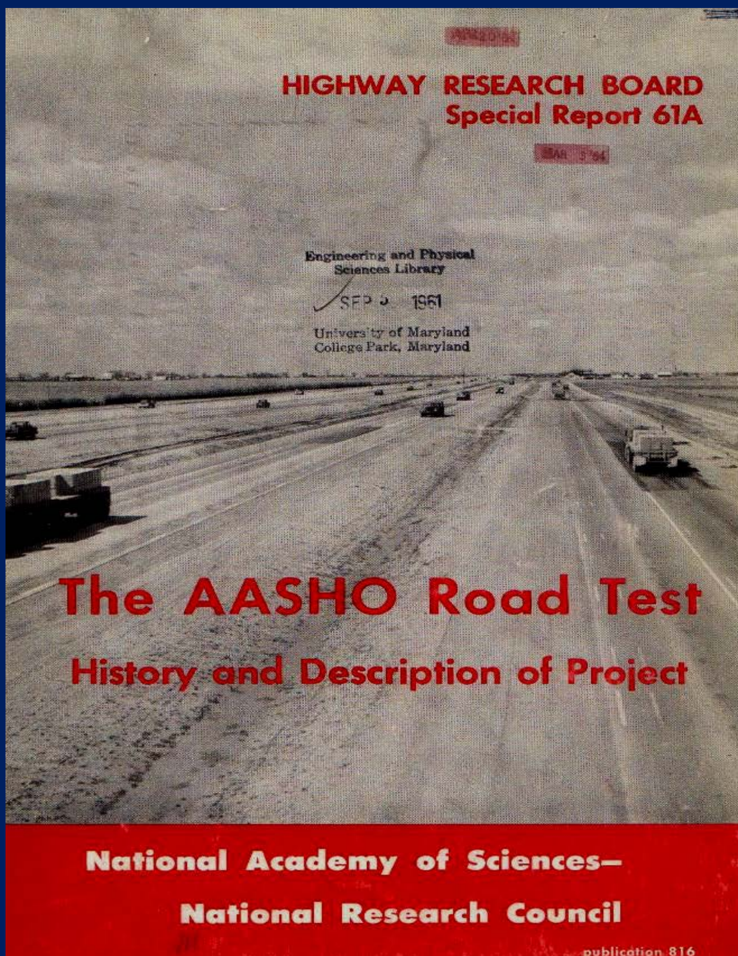
R-value ASTM D2844

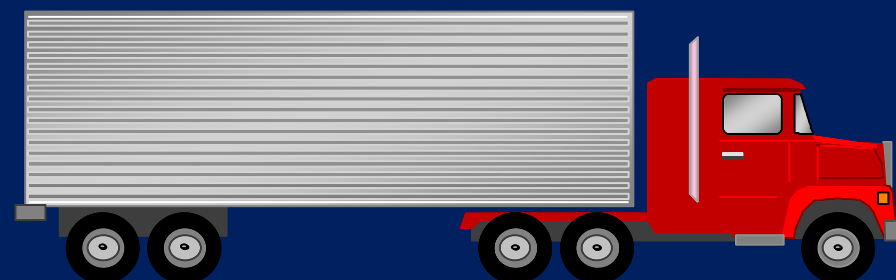
AASHTO Soil Classification AASHTO M-45

Unified Soil Classification ASTM D2487



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

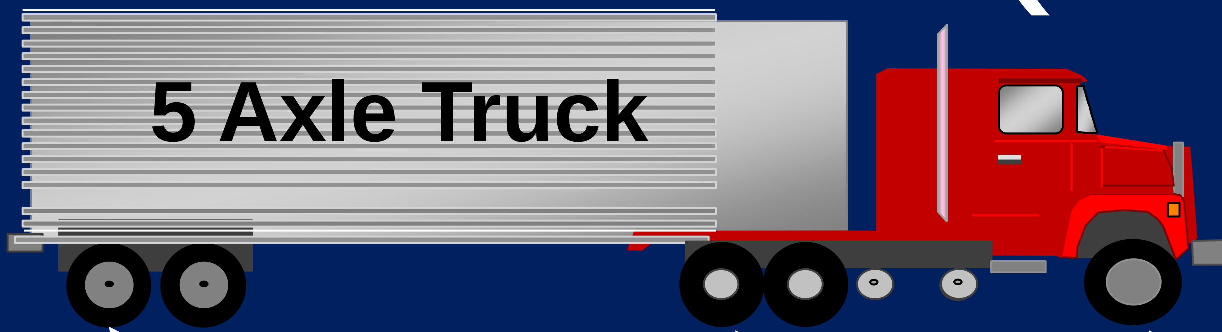




What is an ESAL?

ESALs per Truck

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



2 x 80 kN | 2 x 70 kN | 50 kN

LEF = $\left(\frac{80}{80}\right)^4$ = 1 x 2 LEF = $\left(\frac{70}{80}\right)^4$ = 0.6 x 2 LEF = $\left(\frac{50}{80}\right)^4$ = 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

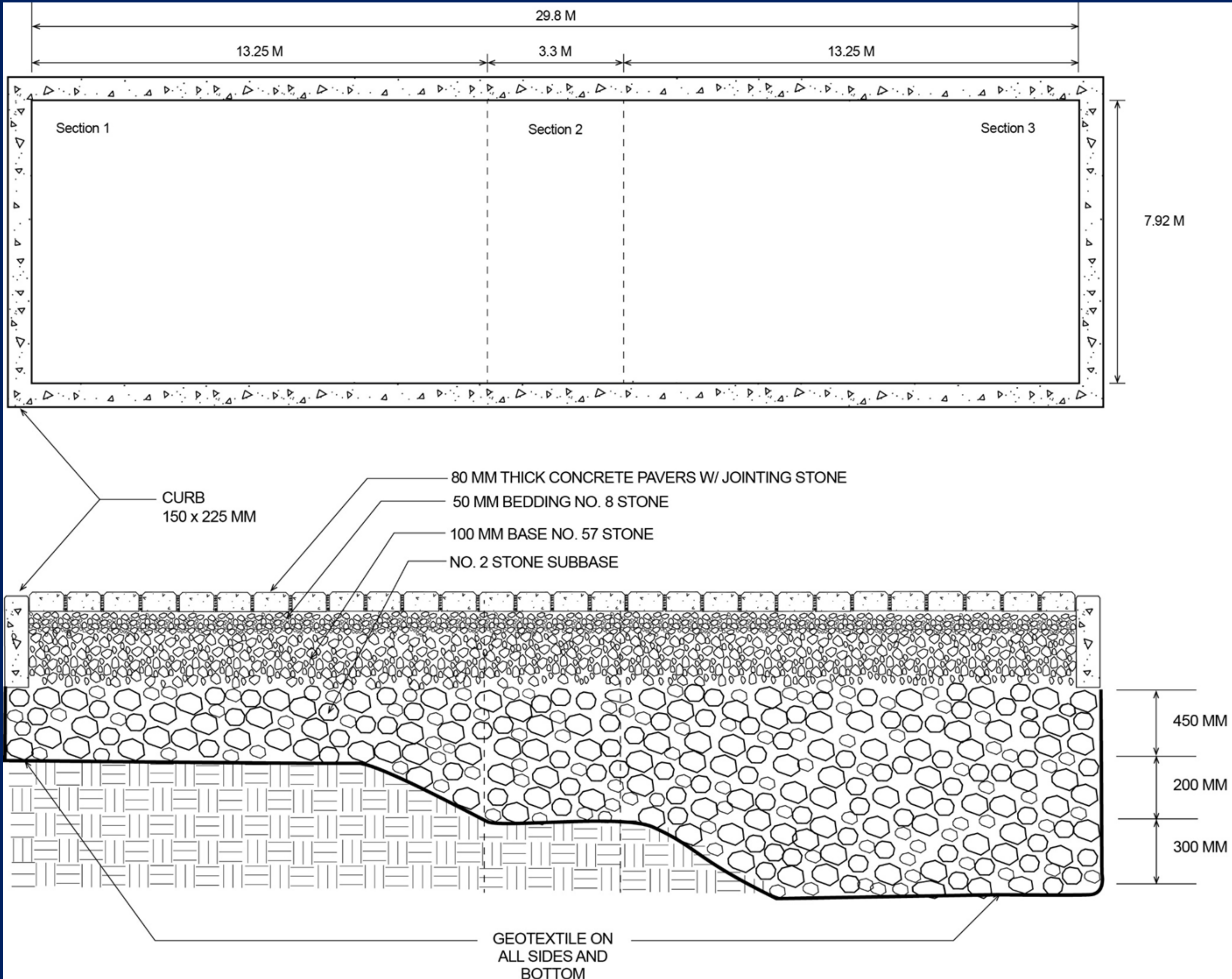
Pavement Class	Description	Design ESALs	Design TI
Arterial	Through traffic with access to high-density, regional, commercial and office developments or downtown streets. General traffic mix.	9,000,000	11.5
Major Collector	Traffic with access to low-density, local, commercial and office development or 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
Sponsors: CA Paver Manufacturers, ICPI Foundation, CA Cement Assoc.

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



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

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)	**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)		**Minimum Subbase Thickness in mm ASTM #2 for 25 mm Allowable Rut Depth (All designs have 80 mm Paver, 50 mm ASTM #8 Bedding Layer, & 100 mm ASTM #57 Base Layer)**											
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				90				120			
Resilient Modulus of Subgrade (MPa)	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)		**Minimum Subbase Thickness in mm ASTM #2 for 25 mm Allowable Rut Depth (All designs have 80 mm Paver, 50 mm ASTM #8 Bedding Layer, & 100 mm ASTM #57 Base Layer)**											
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

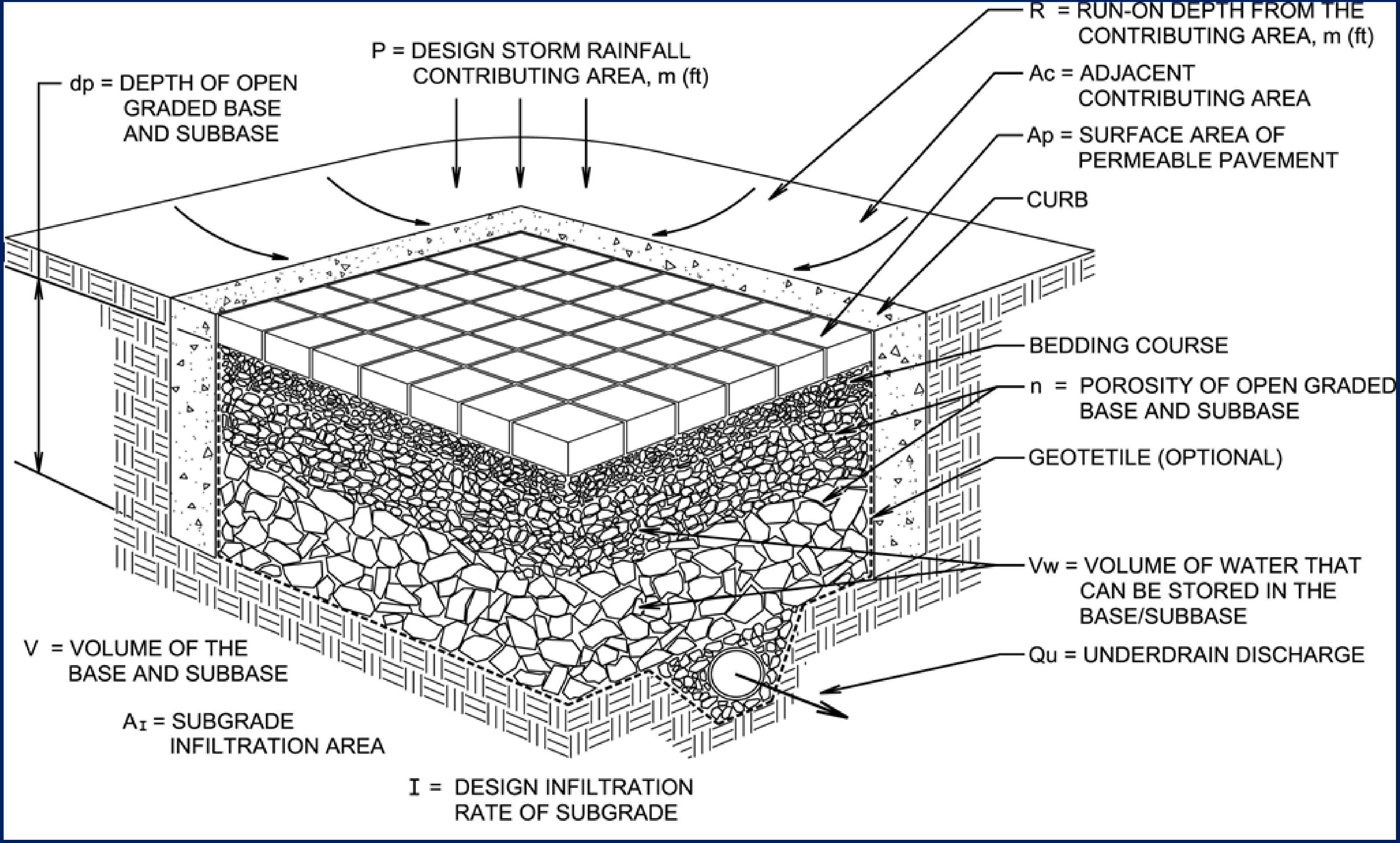
- **Traffic Type and Composition -** Permeable pavements can be used heavy vehicular applications, but a qualified pavement engineer should be consulted for these specific applications.
- **Limitations** – speed limit should be less than 65kph (40 mph)

Hydraulic Design (S3.3)

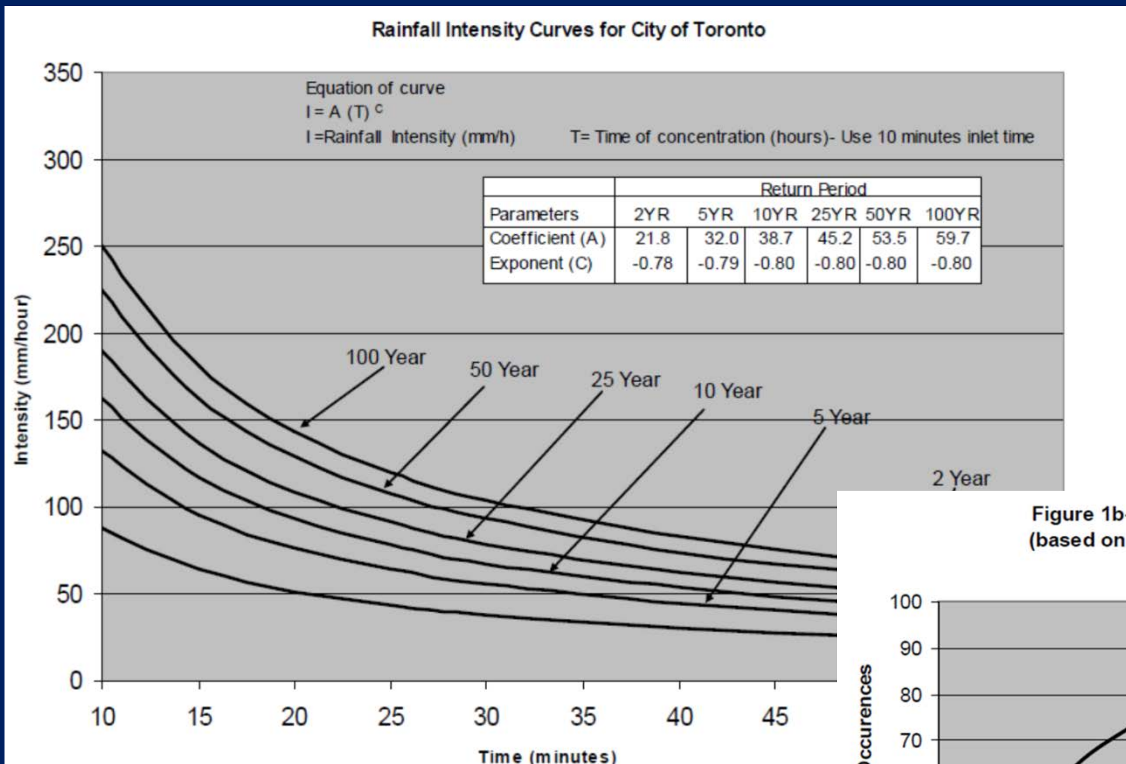
Determine Hydraulic Goals

- 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

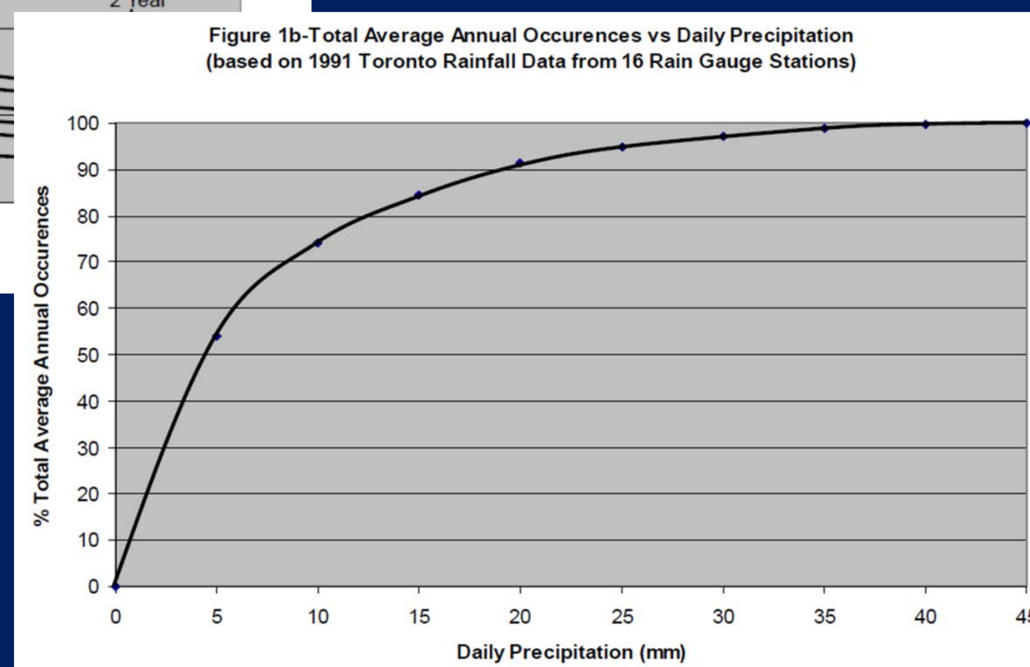


Input - Precipitation Data



Parameters	Return Period 2YR	5YR	10YR	25YR	50YR	100YR
Coefficient (A)	21.8	32.0	38.7	45.2	53.5	59.7
Exponent (C)	-0.78	-0.79	-0.80	-0.80	-0.80	-0.80

Percentile Storm Data



Intensity Duration Frequency Curves

Output – Subgrade Infiltration

Double ring infiltrometer test

- Use avg. infiltration rate
- Apply safety factor for clogging & construction compaction

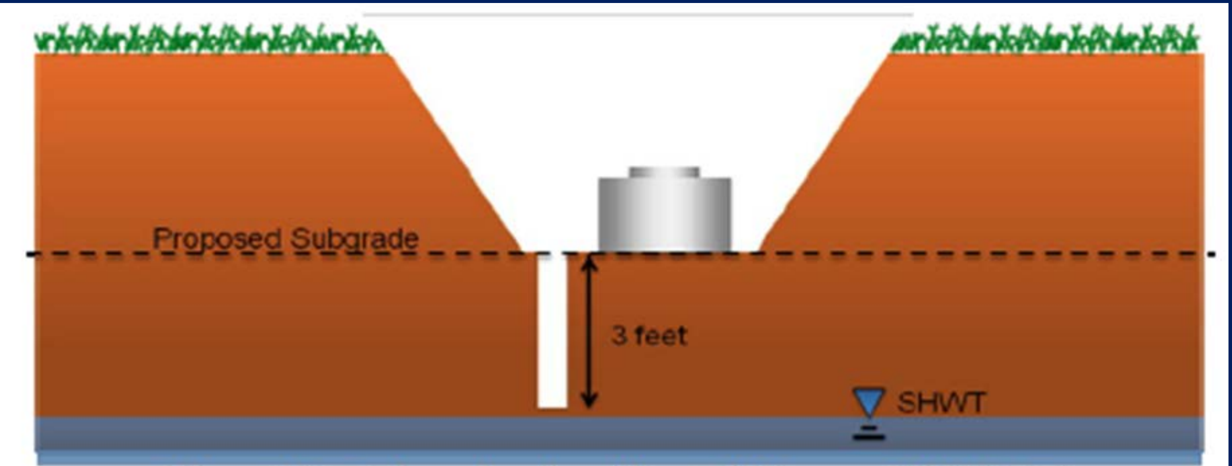


Figure 18-5. Schematic of a soil test pit (Source: NCSU-BAE)

Multiple test holes

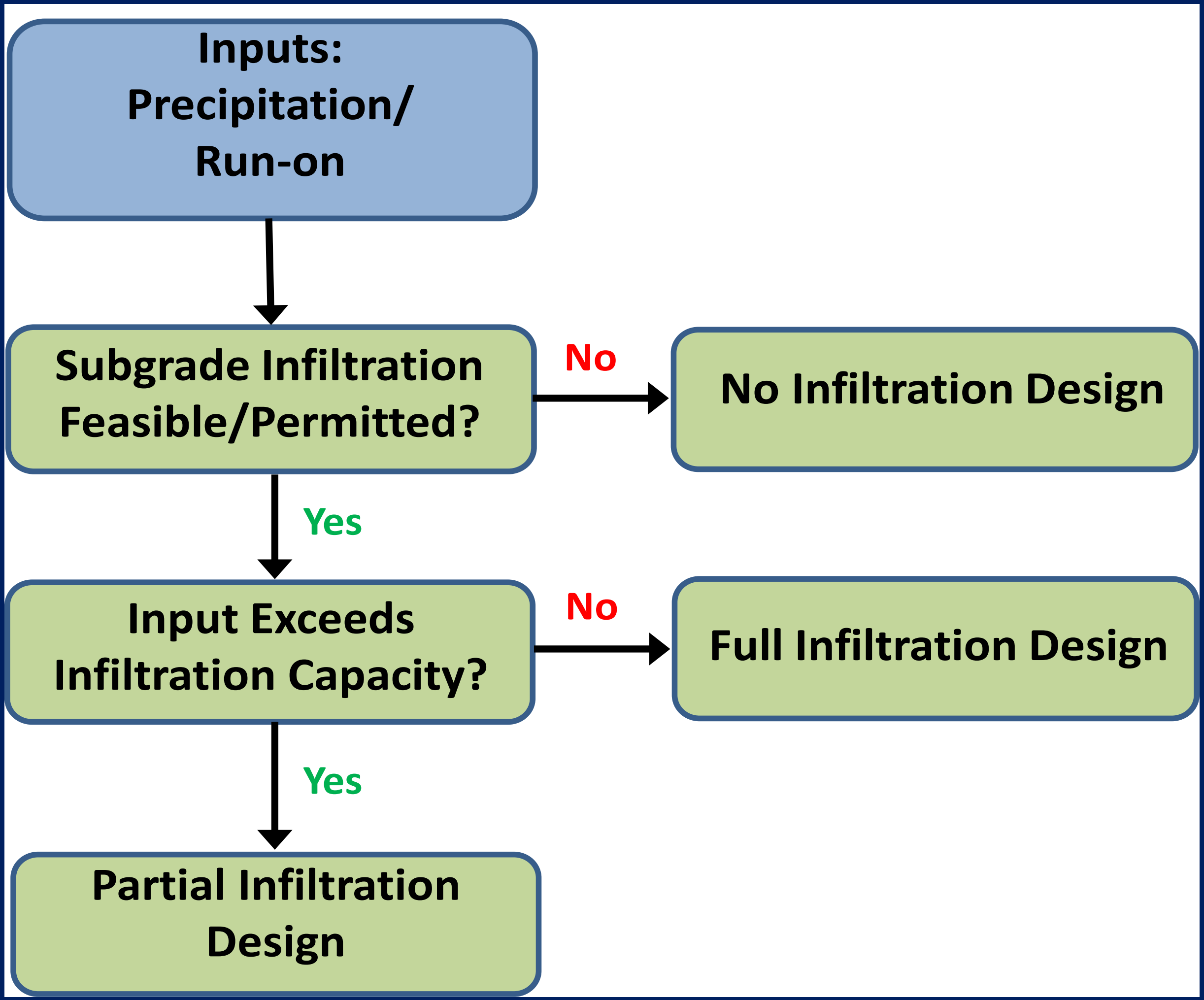
Output – Subgrade Infiltration

WHAT IS ENOUGH?

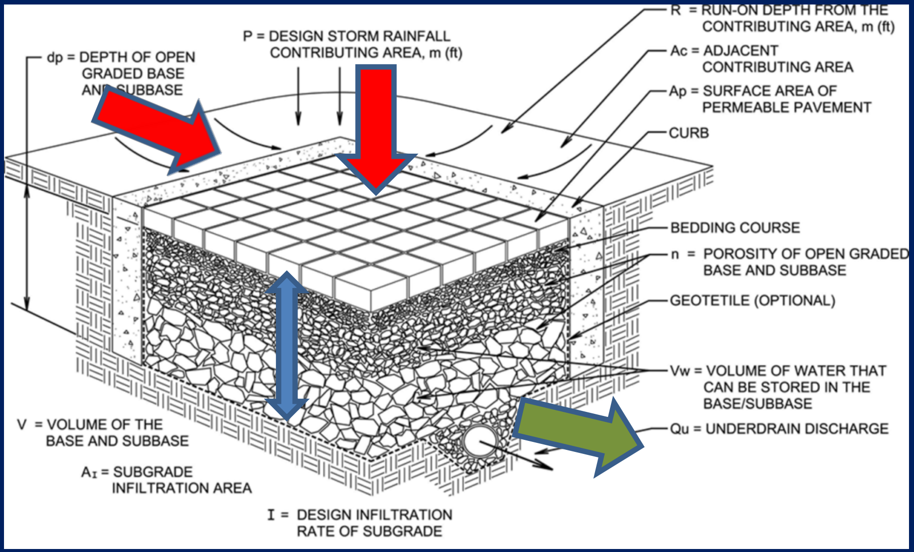
TEXTURE CLASS	MINIMUM FILTRATION RATE (f) inch per hour		HYDROLOGIC SOIL GROUPING
Sand	8.27	5,251 mm/d	A
Loamy Sand	2.41	1,469 mm/d	A
Sandy Loam	1.02	621 mm/d	B
Loam	0.52	317 mm/d	B
Silt Loam	0.27	165 mm/d	C
Sandy Clay Loam	0.17	104 mm/d	C
Clay Loam	0.09	55 mm/d	D
Silty Clay Loam	0.06	37 mm/d	D
Sandy Clay	0.05	31 mm/d	D
Silty Clay	0.04	24 mm/d	D
Clay	0.02	12 mm/d	D

Source: *Virginia Stormwater Management Program Manual*

Selecting the PICP System Type

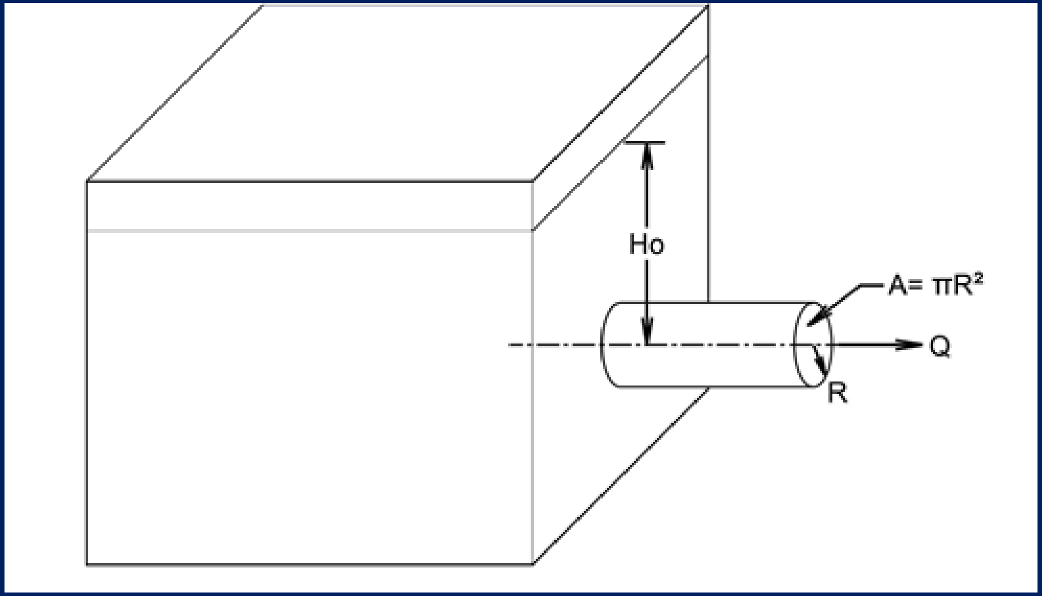


No-infiltration Design

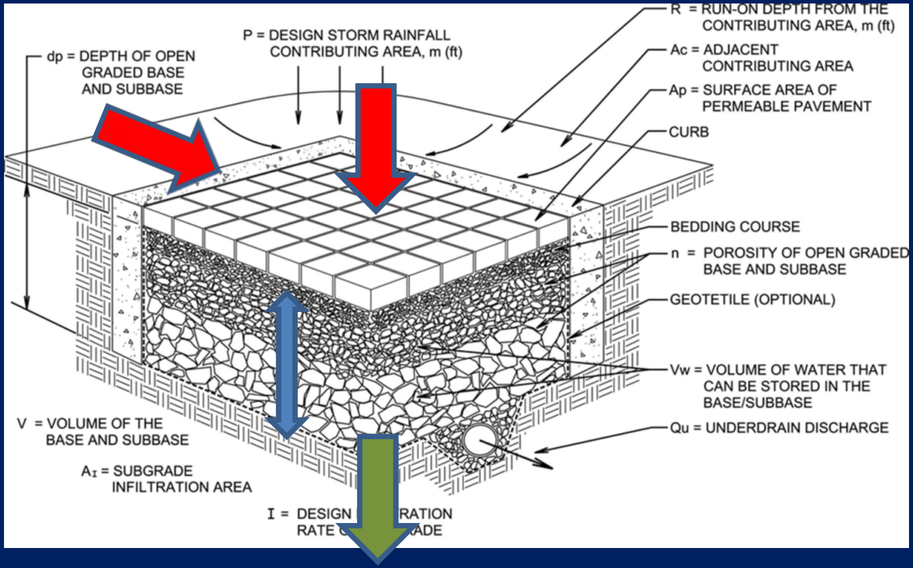


$$V_W = P(A_P) + R(A_C) - Q_U T_S$$

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:

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

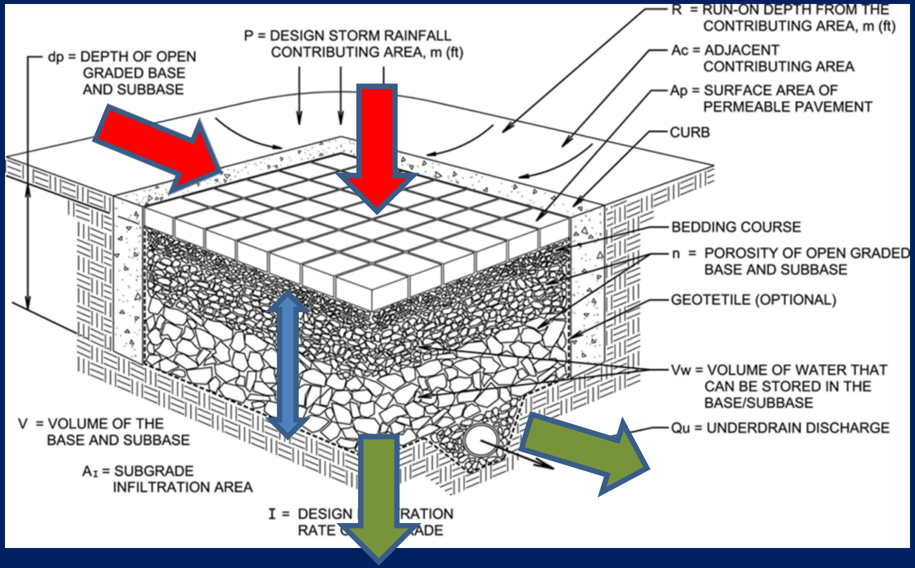
Partial-infiltration Design

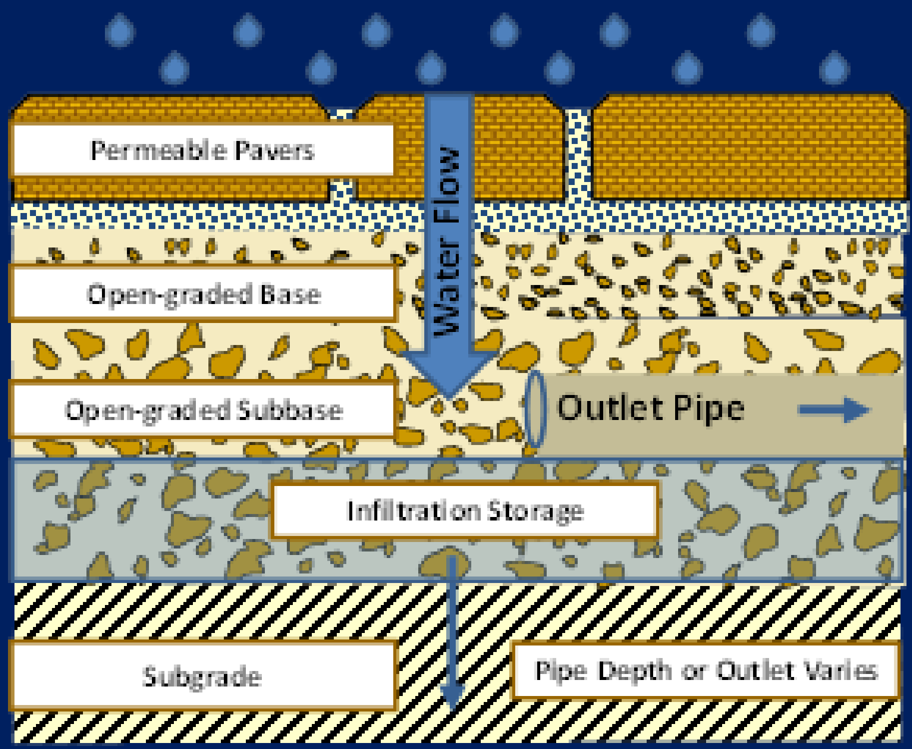
$$V_W = P(A_P) + R(A_C)$$

$$- I(T_S)A_I - Q_U T_S\, Z$$

Infiltration Storage volume dictates pipe location (elevation).

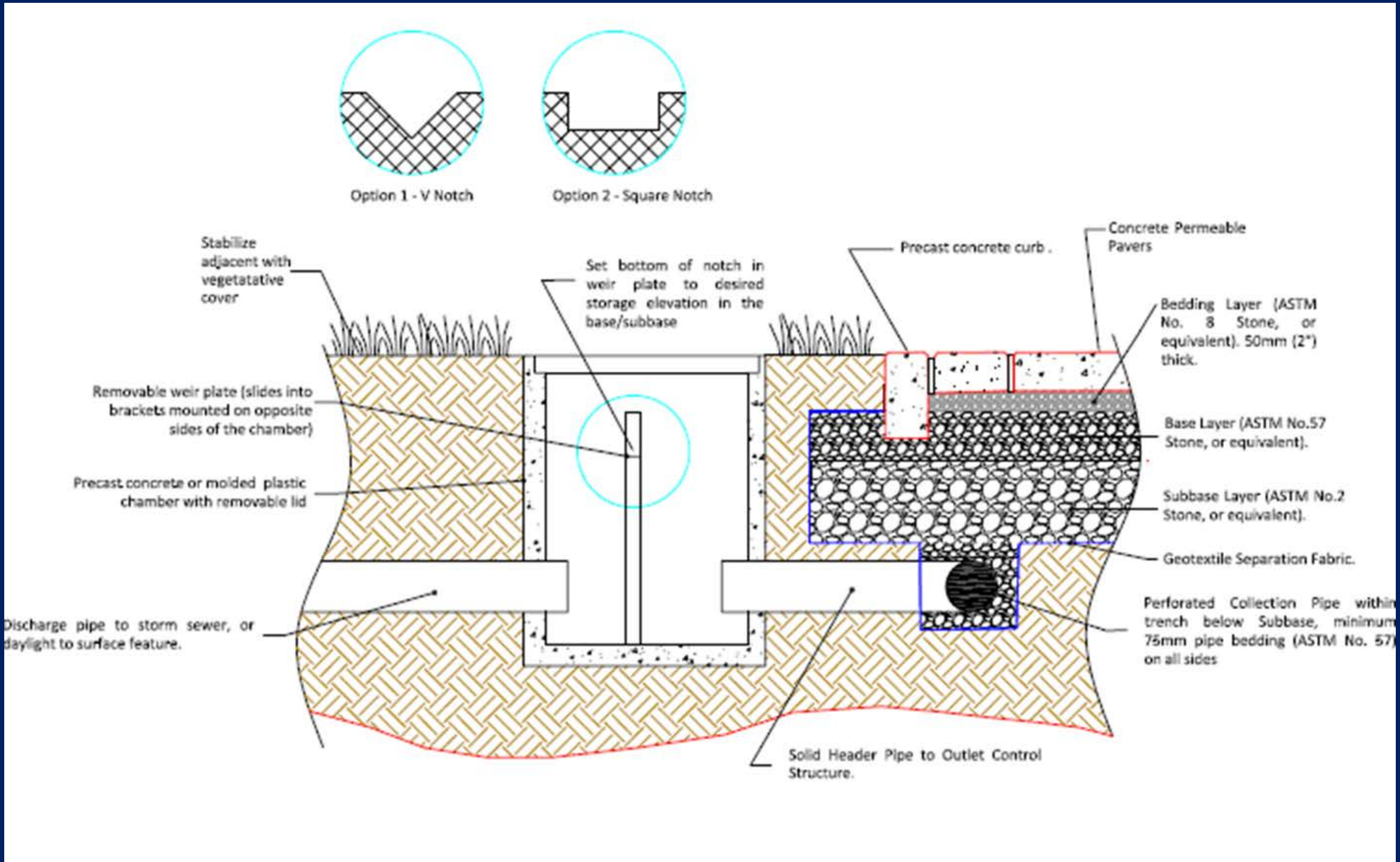
Underdrain elevation factor (Z) used to adjust for duration of pipe flow





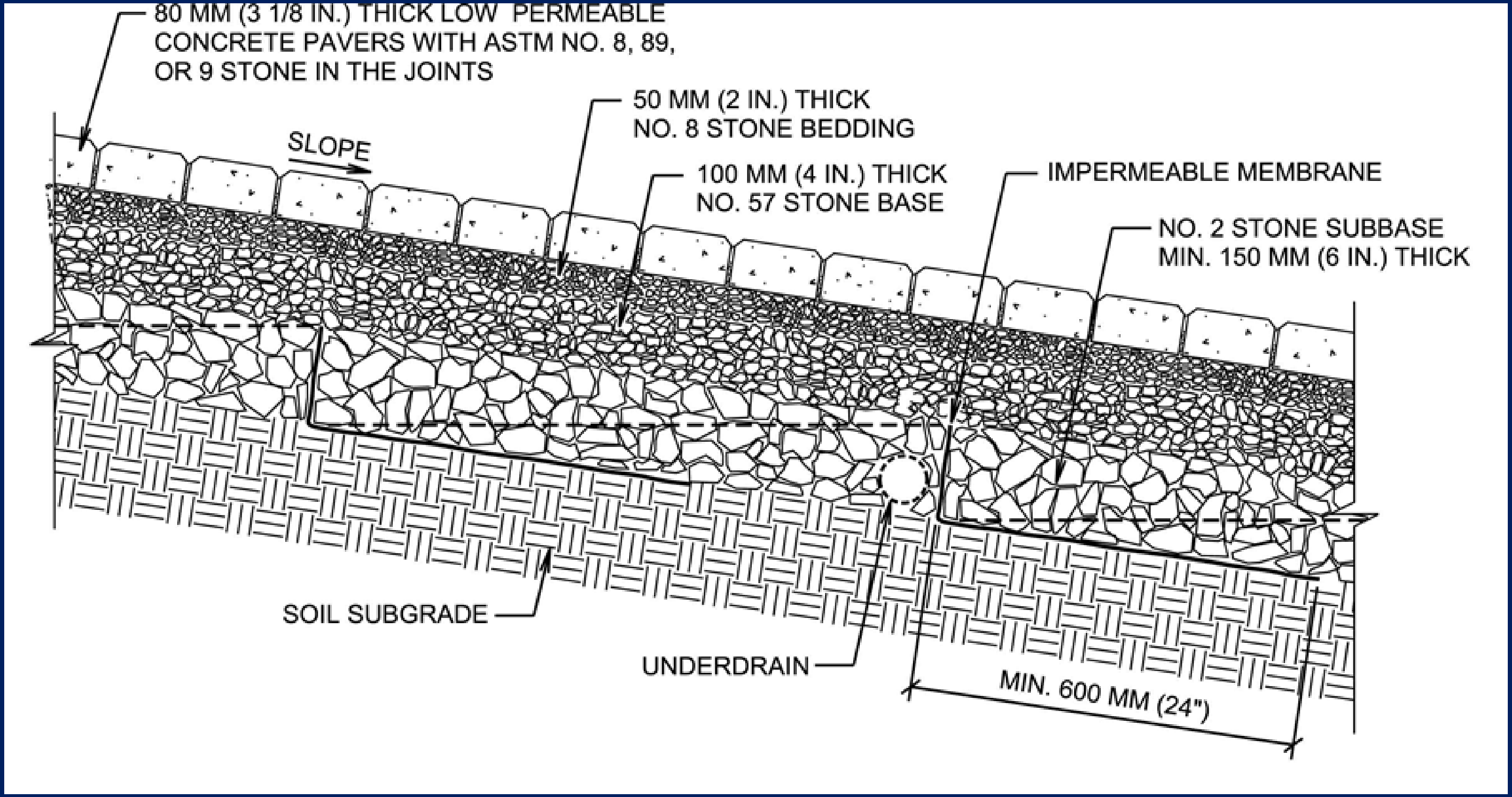
Additional Design Considerations (S3.5)

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



Additional Design Considerations

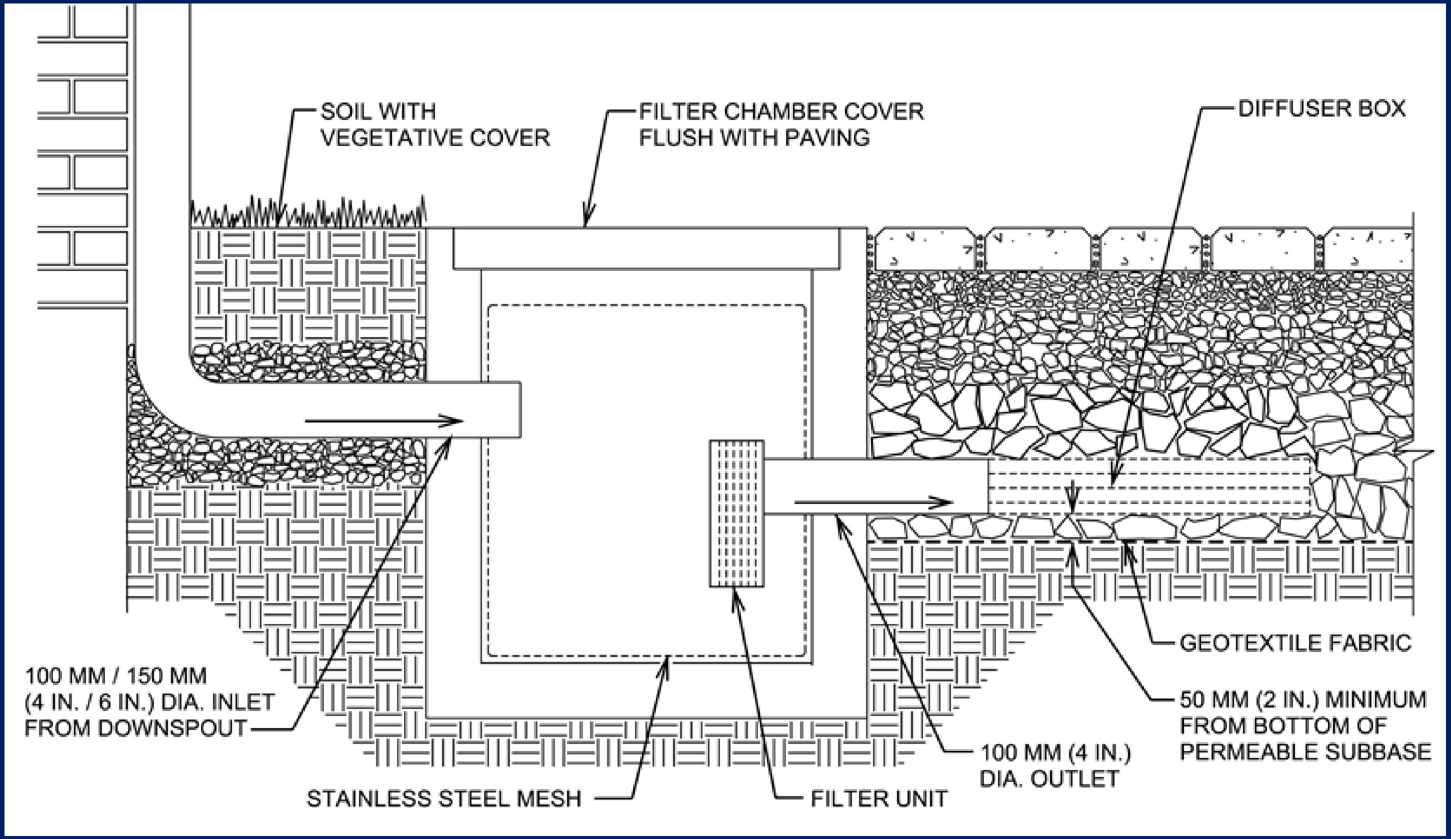
- Sites with subgrade slopes over 3% often require buffers, weirs, check dams, etc. to control water flow



Additional Design Considerations

Additional Design Considerations

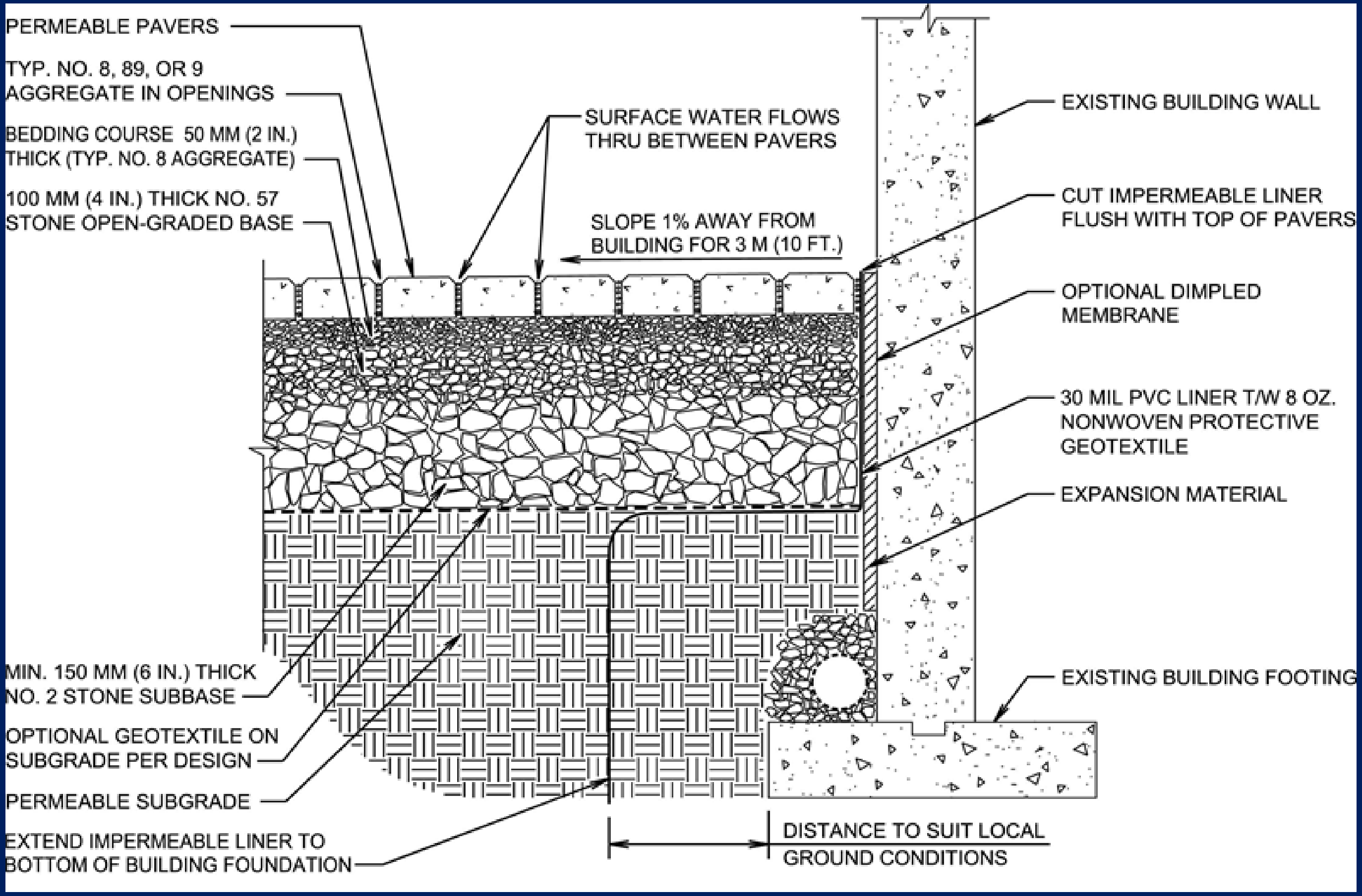
- Roof water can be discharged onto, or into, the pavement.



Additional Design Considerations

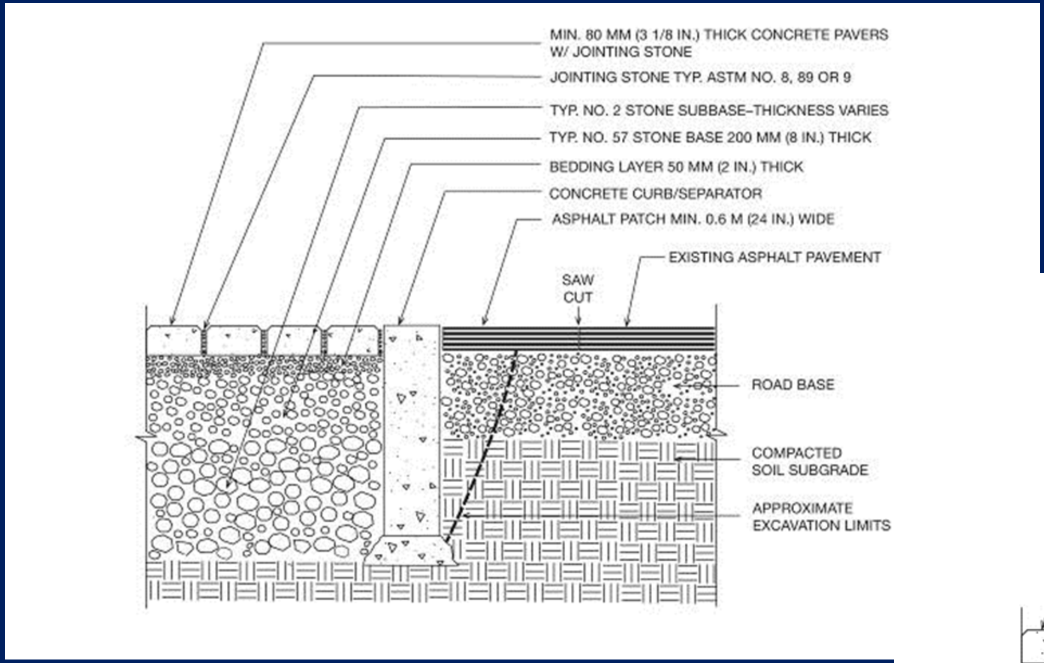
Additional Design Considerations

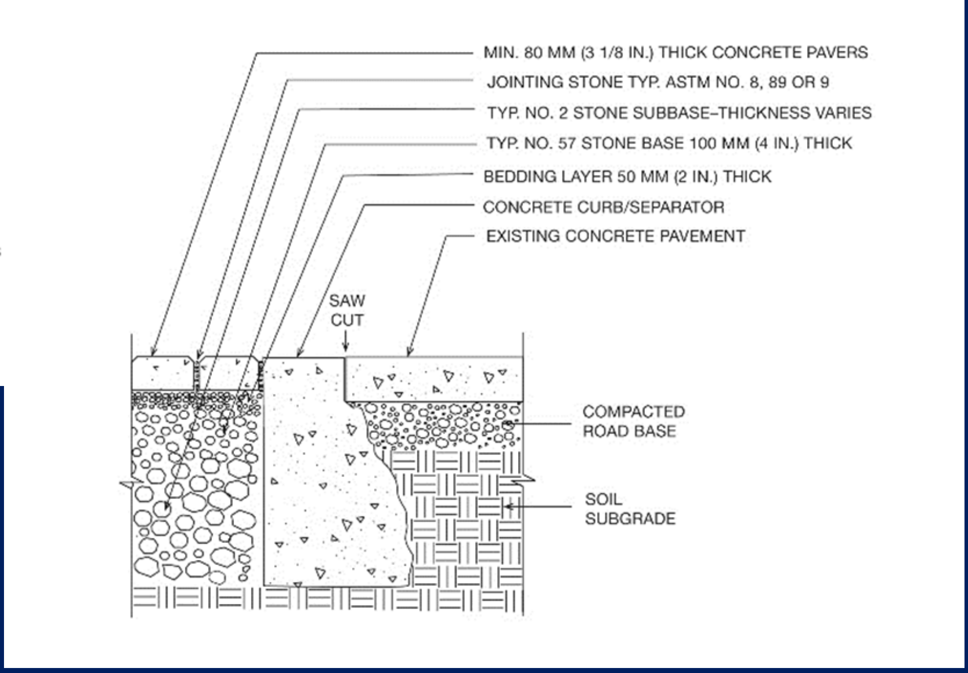
- Impermeable liners can be used adjacent to buildings.



Additional Design Considerations

- Separation is required between permeable and traditional base materials.





Additional Design Considerations

- Use anti-seep collars along utility trenches that bisect the PICP pavement area to prevent lateral migration of water.

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

Mechanical PICP Installation

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
  - ~$1000/acre

- 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

- Final Standard Development Meeting to be held in Houston in June 2016
- Full Standard will undergo editing before going to public comment for 45 days in the summer of 2016
- Intent to publish the standard by the end of 2016

Projections for Euro 2016?