Design of Geosynthetics for Paved Roads

Prof. Jie Han, Ph.D., PE

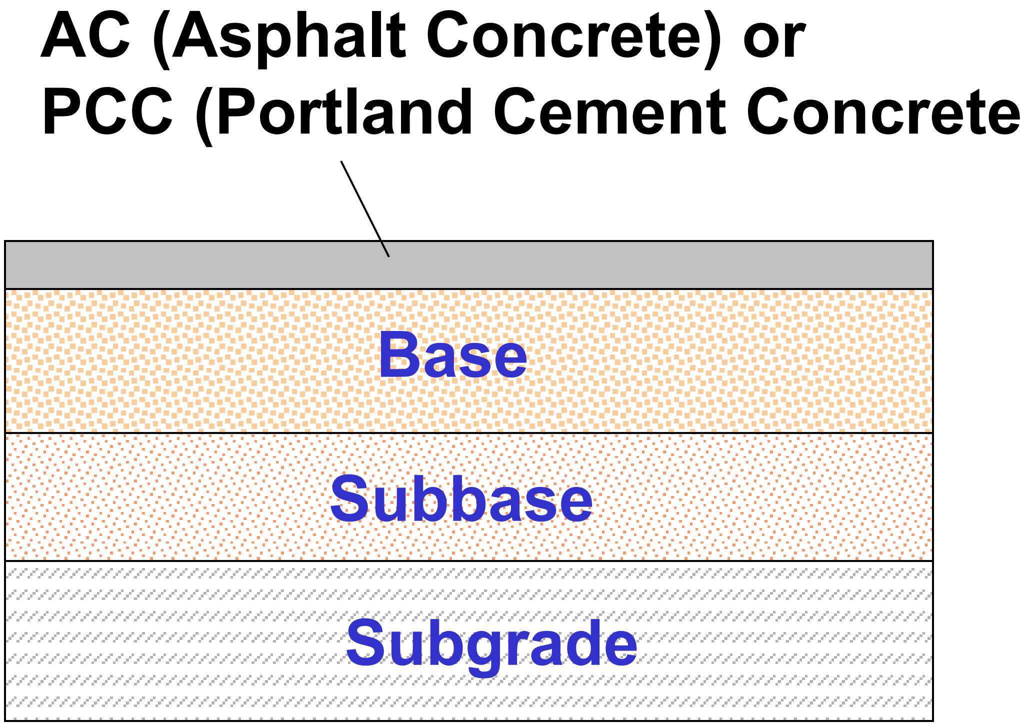
The University of Kansas

Outline of Presentation

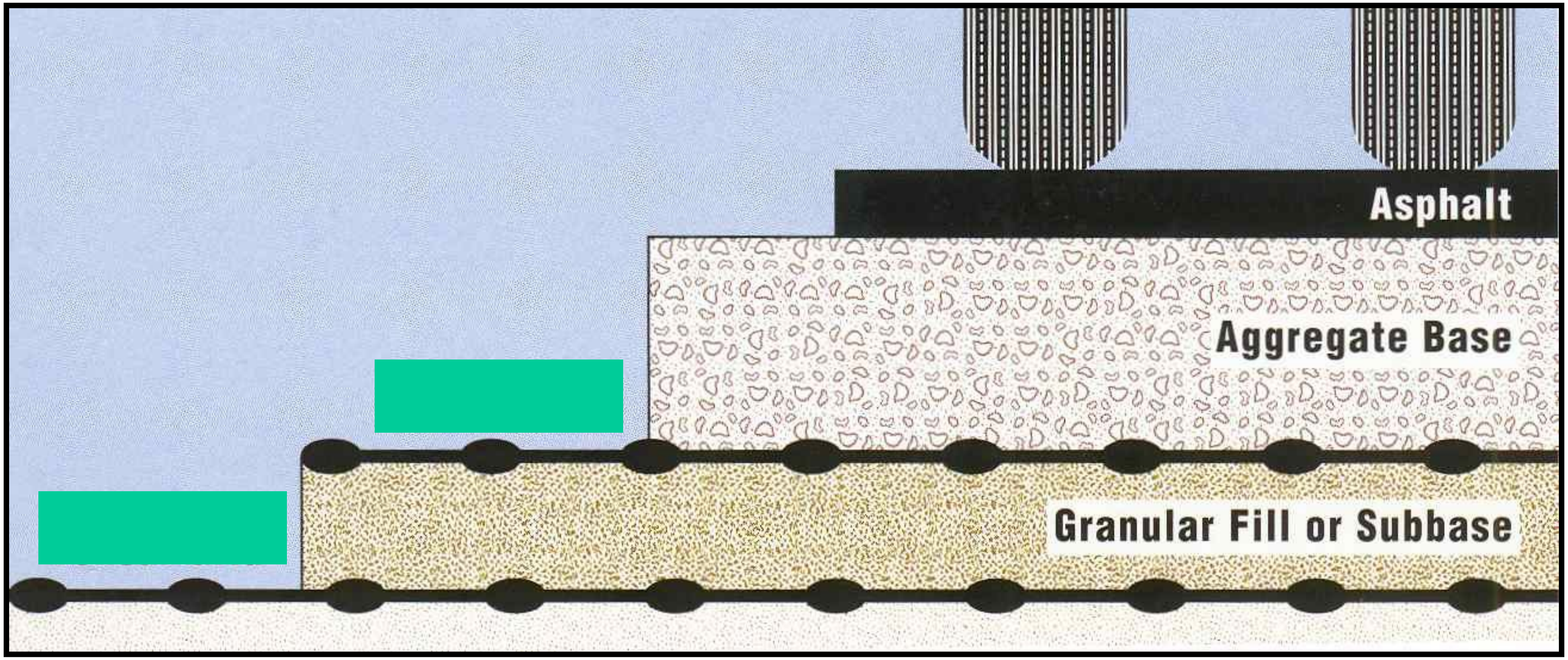
- Introduction
- Base Reinforcement Design
- Evaluation of Base Reinforcement
- Drainage Design

Introduction

Pavement Components



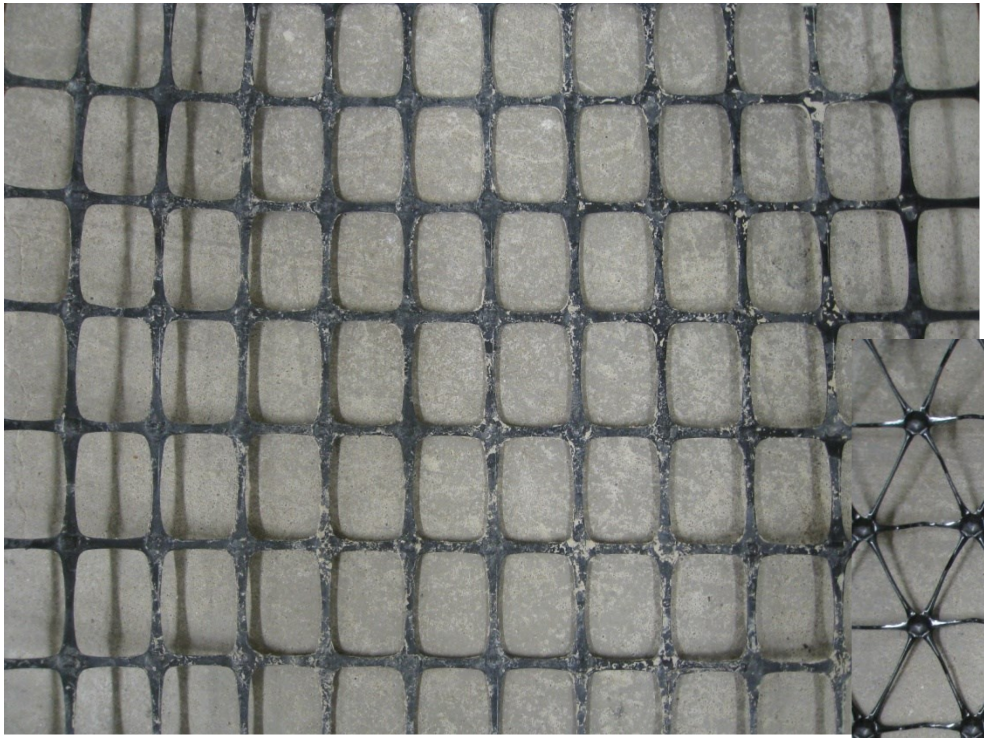
Base Reinforcement



- Prevent lateral spreading of base aggregate
- Increase confinement
- Reduce plastic deformation - rutting

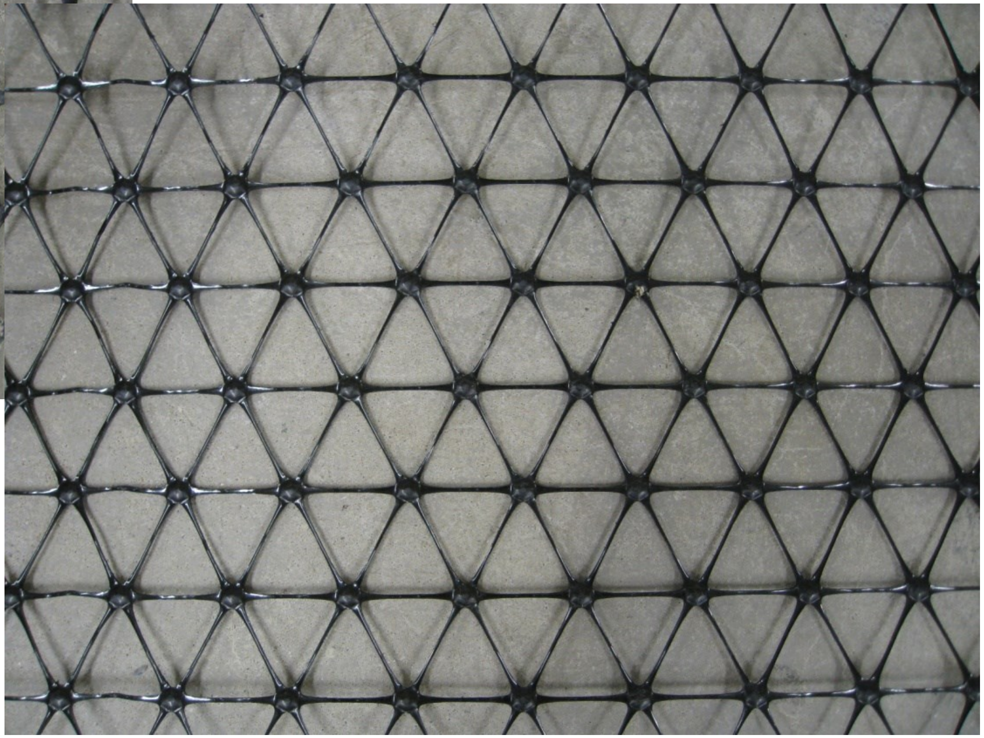
Courtesy of Reck

Current and New Types of Geogrid



Current

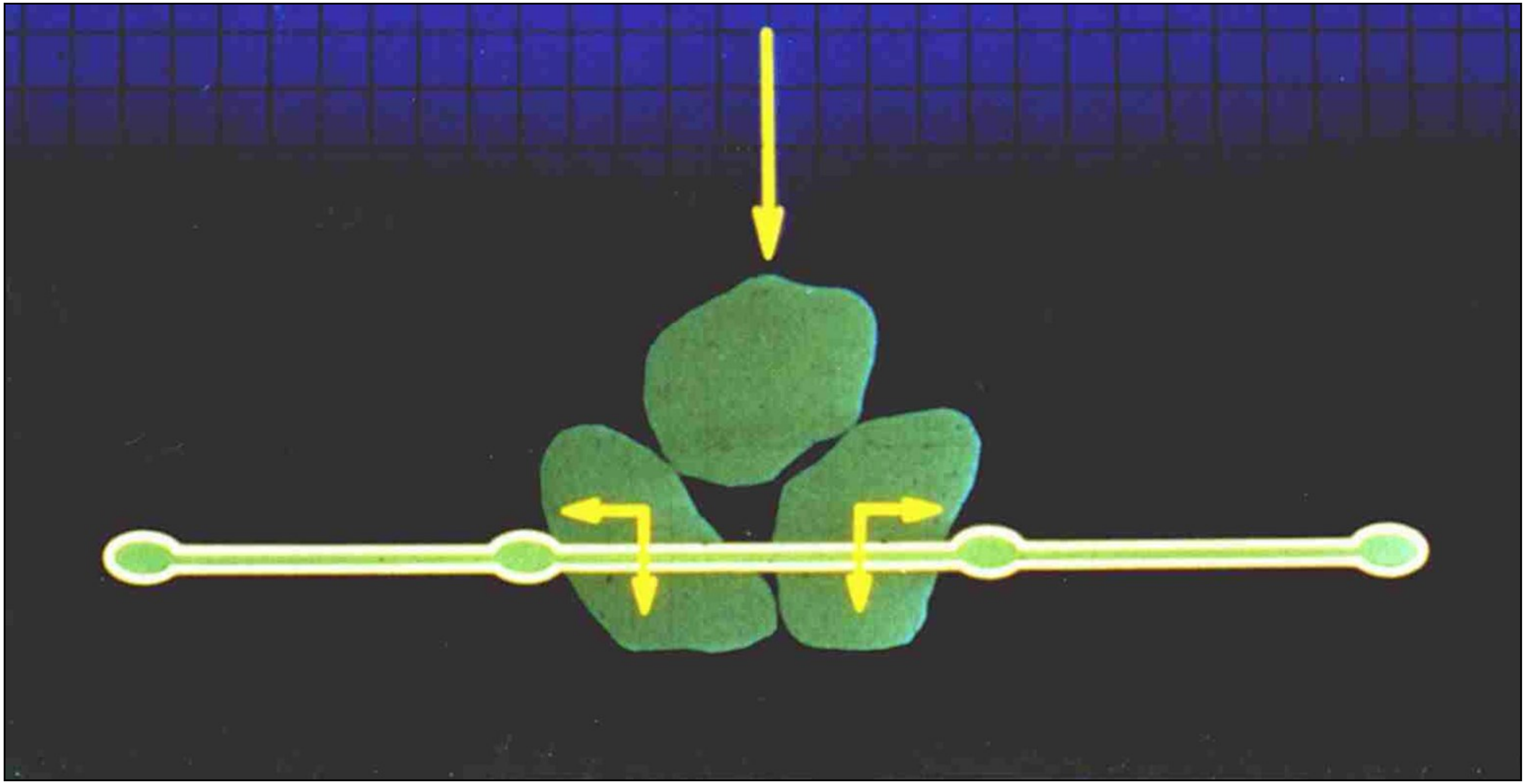
New



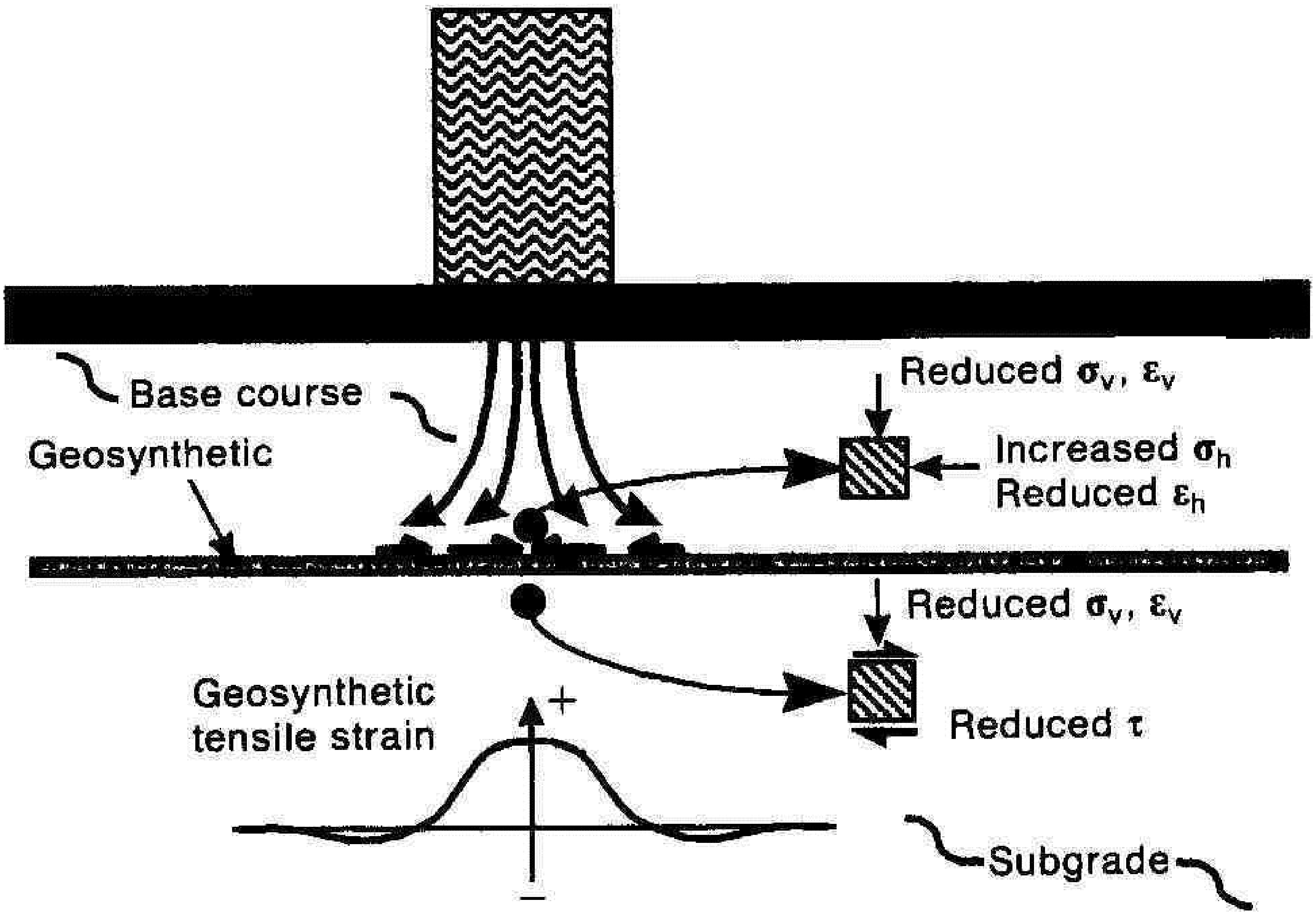
Triangular – A Stable Structure

Triangular – A Stable Structure

Triangular – Better for Confinement

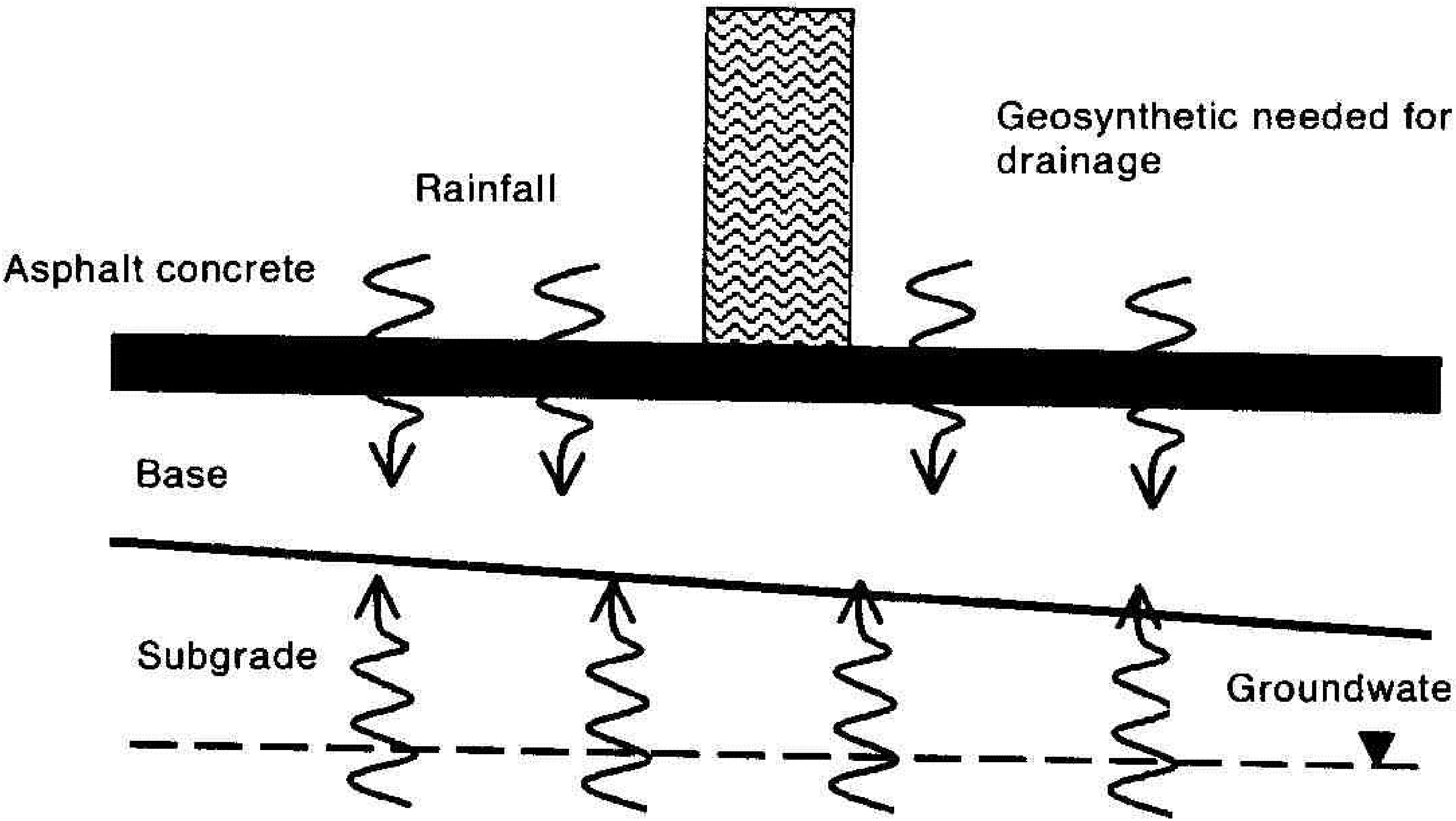


Base Reinforcement Mechanisms



Perkins (1999)

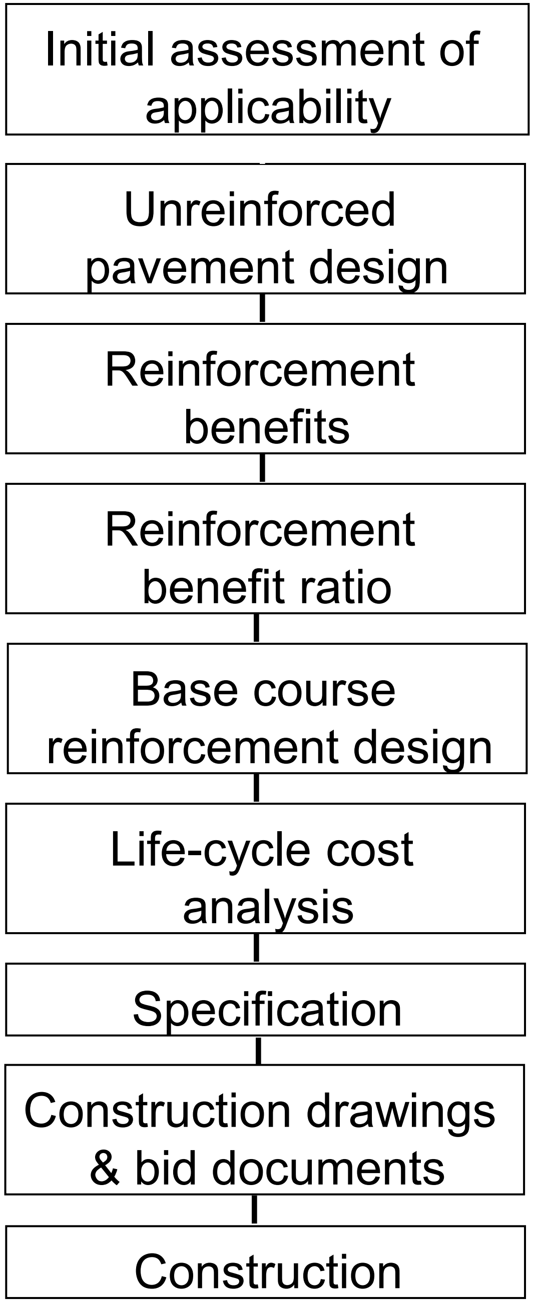
Drainage



Shukla (2002)

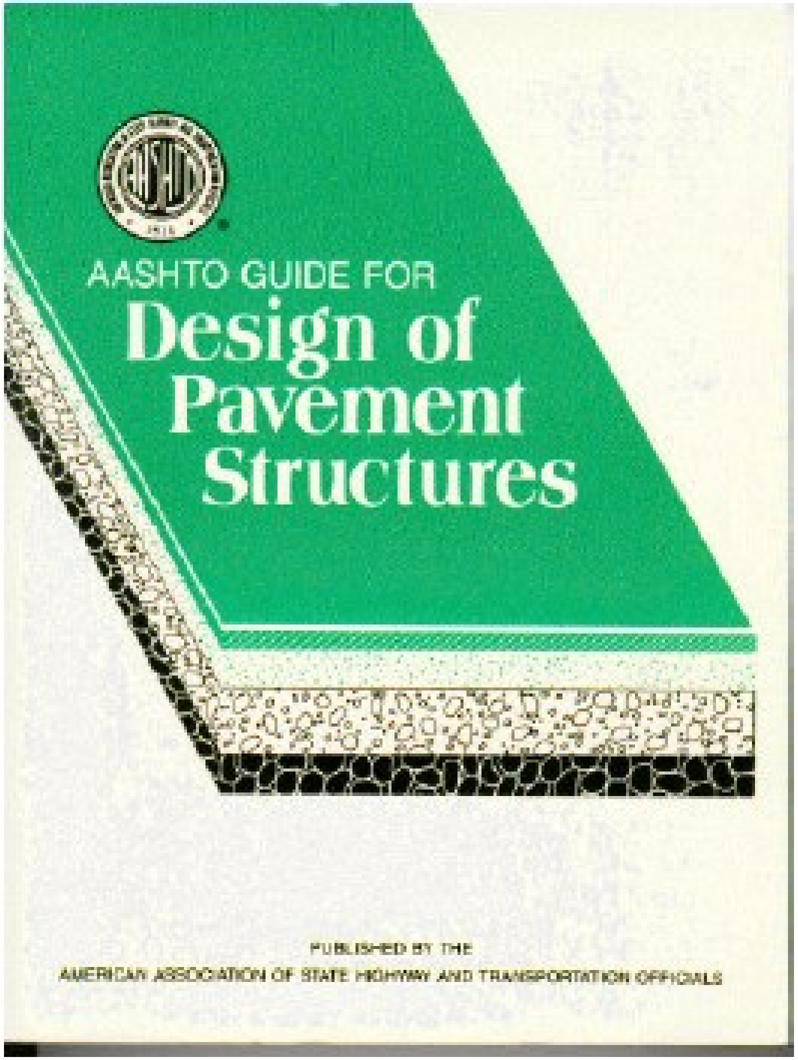
Base Reinforcement Design

Design Procedures



AASHTO Design Procedures

AASHTO Guide for Design of Pavement Structures



ESAL Provided by Flexible Pavement

$$\log_{10}(W_{18}) = Z_R\, S_0 + 9.36 \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\dfrac{\Delta PSI}{4.2 - 1.5}}{0.40 + \dfrac{1094}{(SN+1)^{5.19}}} + 2.32 \log_{10}(M_R) - 8.07$$

W_{18} = predicted number of 18-kip ESAL

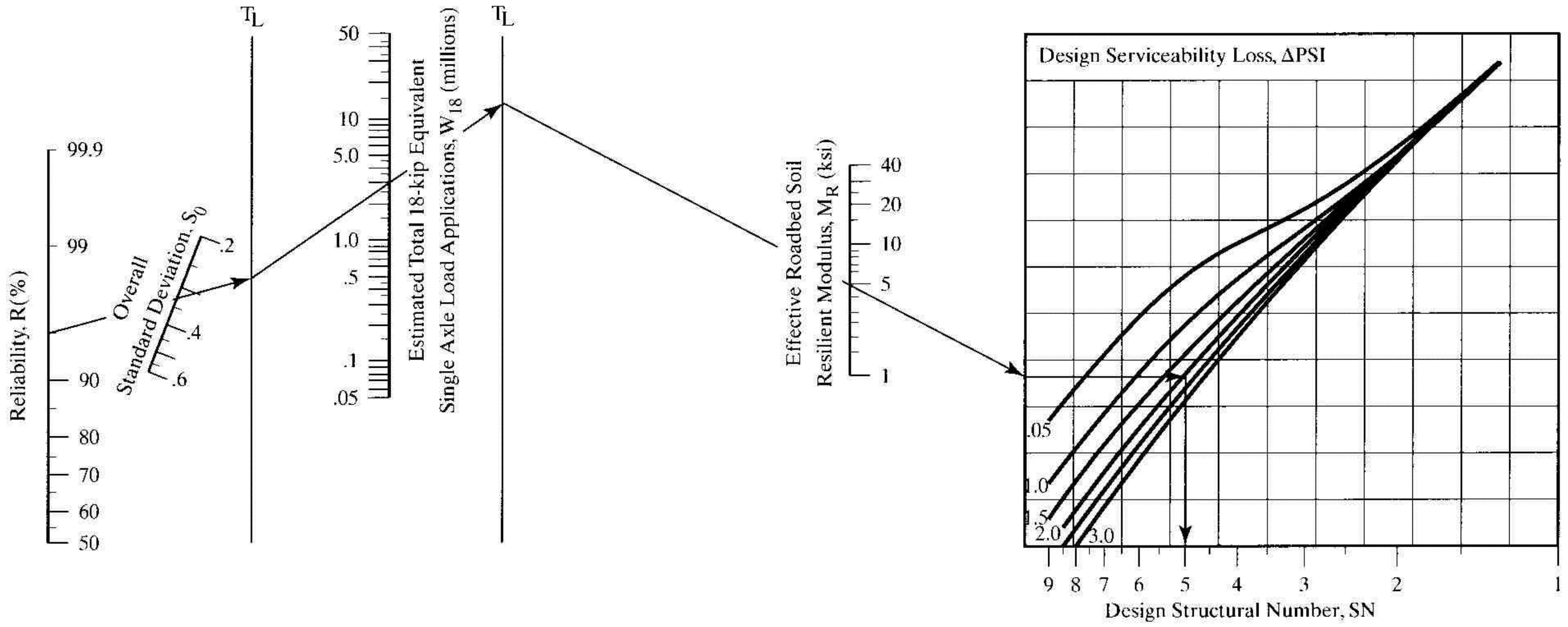
Z_R = standard normal deviate

S_0 = combined standard error of traffic prediction and performance prediction or overall std. deviation

ΔPSI = difference between the initial design serviceability index, p_0, and the terminal serviceability index, p_t

M_R = resilient modulus

Design Chart for Flexible Pavements



Standard Normal Deviate

Reliability, R(%)	Standard normal deviate, Z_R
50	0.000
60	-0.253
70	-0.524
75	-0.674
80	-0.841
85	-1.037
90	-1.282
92	-1.405
94	-1.555
96	-1.751
98	-2.054
99	-2.327

Suggested Levels of Reliability, R

Functional classification	Recommended level of reliability	
	Urban	Rural
Interstate and other freeways	85-99.9	80-99.9
Principal arterials	80-99	75-95
Collectors	80-95	75-95
Local	50-80	50-80

Overall Standard Deviation, S_0

0.30 - 0.40	Rigid pavement
0.40 - 0.50	Flexible pavement

Structural Number (AASHTO 1993)

$$SN = a_1D_1 + a_2m_2D_2 + a_3m_3D_3$$

a_i = ith layer coefficient

D_i = ith layer thickness (inches)

m_i = ith layer drainage coefficient

Layer Coefficients

Average values of layer coefficients for materials used in the AASHTO Road Test

Asphalt concrete surface course	0.44
Crushed stone base course	0.14
Sandy gravel subbase	0.11

Layer Coefficient of Dense-Graded Asphalt Concrete

Elastic modulus, E_{AC} (psi) of asphalt concrete (at 68°F)	Structural layer coefficient, a_1, for asphalt concrete surface course
110,000	0.20
150,000	0.25
200,000	0.30
250,000	0.34
300,000	0.37
350,000	0.39
400,000	0.42
450,000	0.45

Layer Coefficient of Granular Base

Granular base CBR (%)	Structural layer coefficient, a_2
20	0.07
30	0.09
35	0.10
45	0.11
55	0.12
70	0.13
100	0.14

Layer Coefficient of Granular Subbase

Granular subbase CBR (%)	Structural layer coefficient, a_3
10	0.08
25	0.10
30	0.11
40	0.12
70	0.13
100	0.14

Recommendation for Drainage Factor (AASHTO 1993)

Quality of Drainage	% time pavement is exposed to moisture levels approaching saturation			
	< 1%	1 to 5%	5 to 25%	> 25%
Excellent	1.40-1.35	1.35-1.30	1.30-1.20	1.20
Good	1.35-1.25	1.25-1.15	1.15-1.00	1.00
Fair	1.25-1.15	1.15-1.05	1.00-0.80	0.80
Poor	1.15-1.05	1.05-0.80	0.80-0.60	0.60
Very poor	1.05-0.95	0.95-0.75	0.75-0.40	0.40

Drainage Quality

Quality of Drainage	Water Removed Within
Excellent	2 hours
Good	1 day
Fair	1 week
Poor	1 month
Very poor	(water will not drain)

Note: the drainage conditions at the AASHO Road Test are considered to be fair

Empirical Correlation between M_R and CBR

$$M_R \text{ (psi)} = 1{,}500 \times CBR$$

For fine-grained soil with a soaked CBR of 10 or less

Minimum Thickness

Traffic, ESAL's	Asphalt Concrete (mm)	Aggregate Base (mm)
Less than 50,000	25 (or suraface treatment)	100
50,001-150,000	50	100
150,001-500,000	63	100
500,001-2,000,000	75	150
2,000,001-7,000,000	87	150
Greater than 7,000,000	100	150

Note: Individual design agencies may modify the above minimum thickness for their own use.

Traffic Benefit Ratio Using Geosynthetics

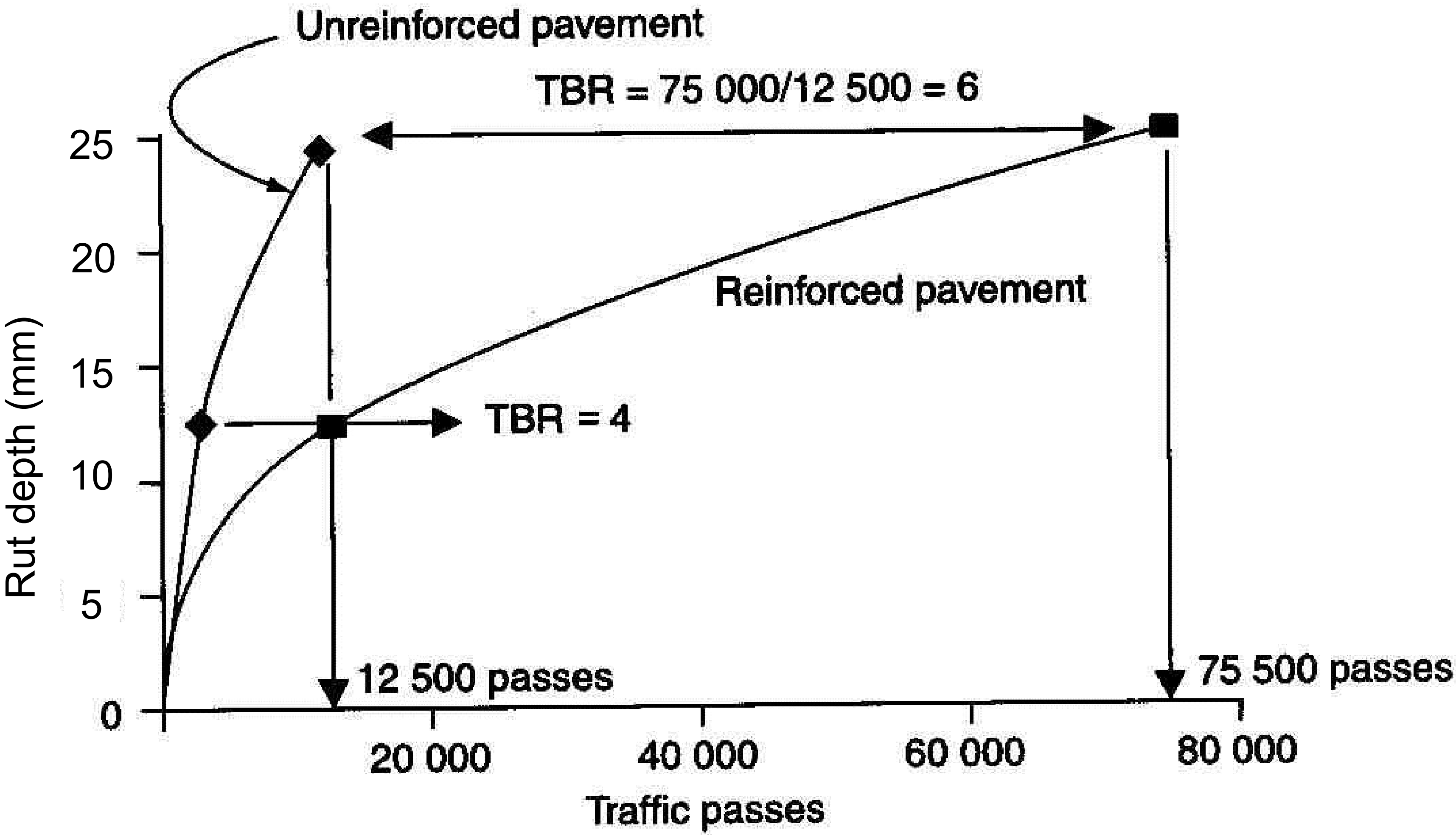
Traffic benefit ratio (TBR) is defined as:

the ratio of the number of cycles necessary to reach A given rut depth for a test section containing Reinforcement divided by the number of cycles necessary to reach this same rut depth for an unreinforced section with the same section thickness and subgrade properties

TBR = 1.5 to 10 for geotextiles

TBR = 1.5 to 70 for geogrids

Determination of TRB



Shukla (2002)

Extension of Pavement Life

Extended pavement life can be estimated by:

$$W_{18}\text{ (reinforced)} = \text{TBR } W_{18}\text{ (unreinforced)}$$

Layer Coefficient Ratio

Layer coefficient ratio (LCR) is defined as:

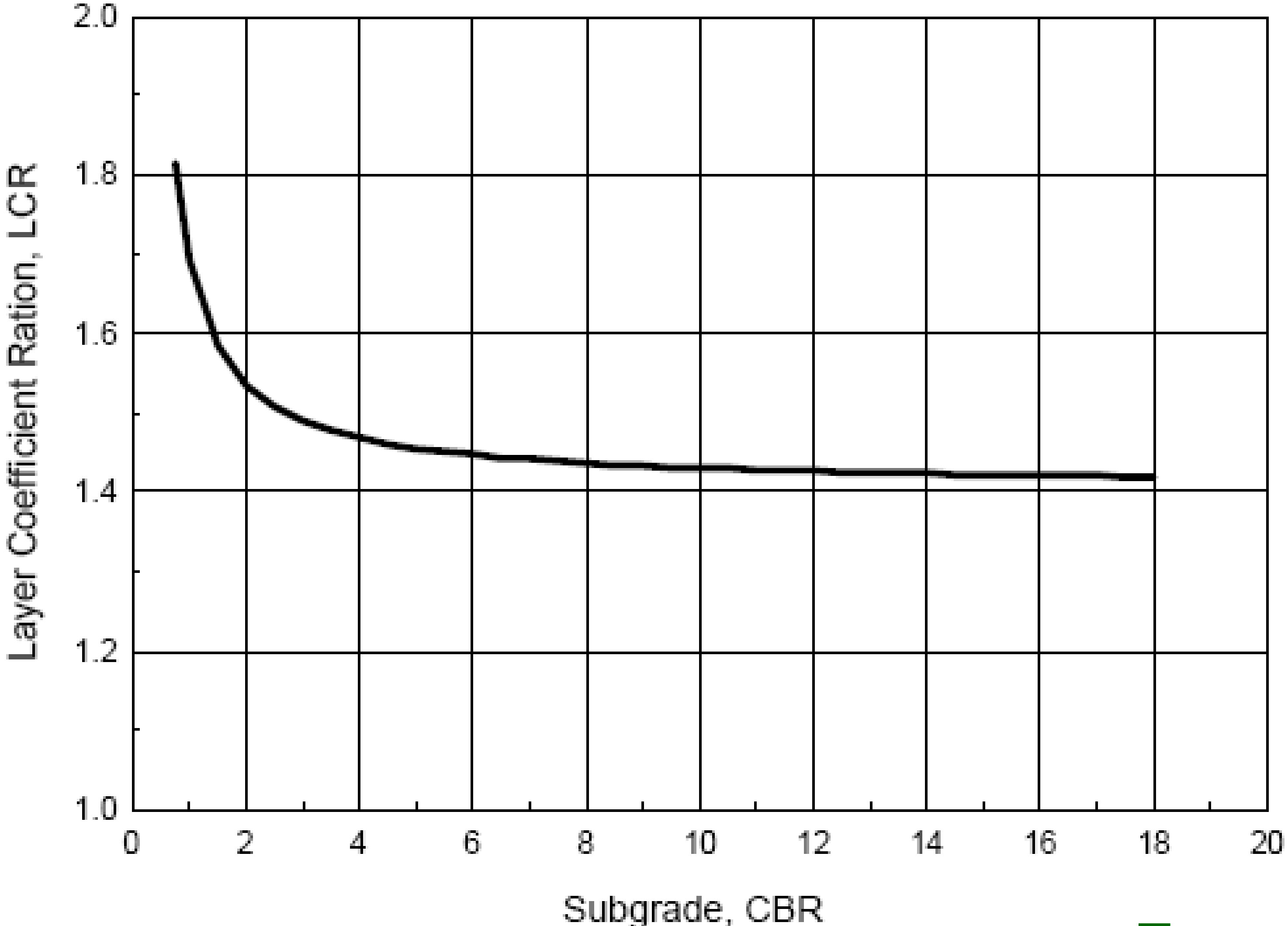
A modifier applied to the layer coefficient of the aggregate

$$SN = a_1D_1 + LCR\ a_2m_2D_2 + a_3m_3D_3$$

LCR is determined from lab and field tests

$$LCR = \frac{SN_r - a_1D_1}{SN_u - a_1D_1}$$

Layer Coefficient Ratio



Tenax

Design for Base Reinforcement

Option 1: Extension of performance period

Option 2: Reduction of base course

Option 3: Extension of performance period & reduction of base course

Design for Extension of Performance Period

Design with a TBR:

$$W_{18R} = TBR\ W_{18}$$

Design with a LCR:

$$SN_R = a_1 D_1 + LCR\ a_2 m_2 D_2 + a_3 m_3 D_3$$

$$SN_R \Rightarrow W_{18R}$$

Design for Reduction of Base Thickness with a TBR

Step 1: $(W_{18})_R = W_{18}/TBR$

Step 2: $(W_{18})_R \Rightarrow SN_R$

Step 3: $D_{2(R)} = \dfrac{SN_R - a_1 D_1}{a_2 m_2}$

Design for Reduction of Base Thickness with a LCR

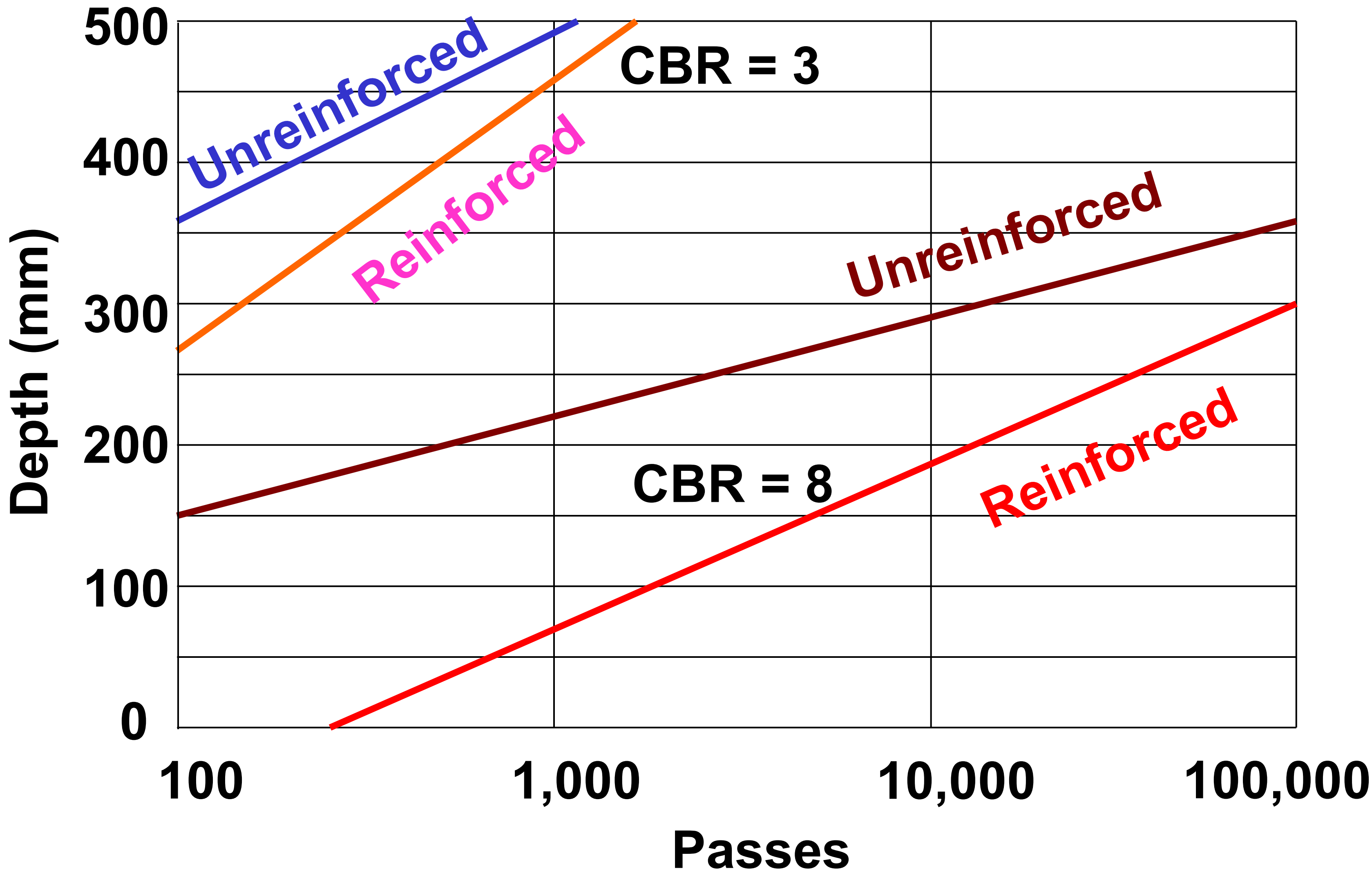
Step 1: $W_{18} \Rightarrow SN$

Step 2:

$$D_{2(R)} = \frac{SN - a_1 D_1}{LCR\ a_2\ m_2}$$

Army Corp's Field Study (Webster, 1992)

Army Corp's Field Study (Webster, 1992)

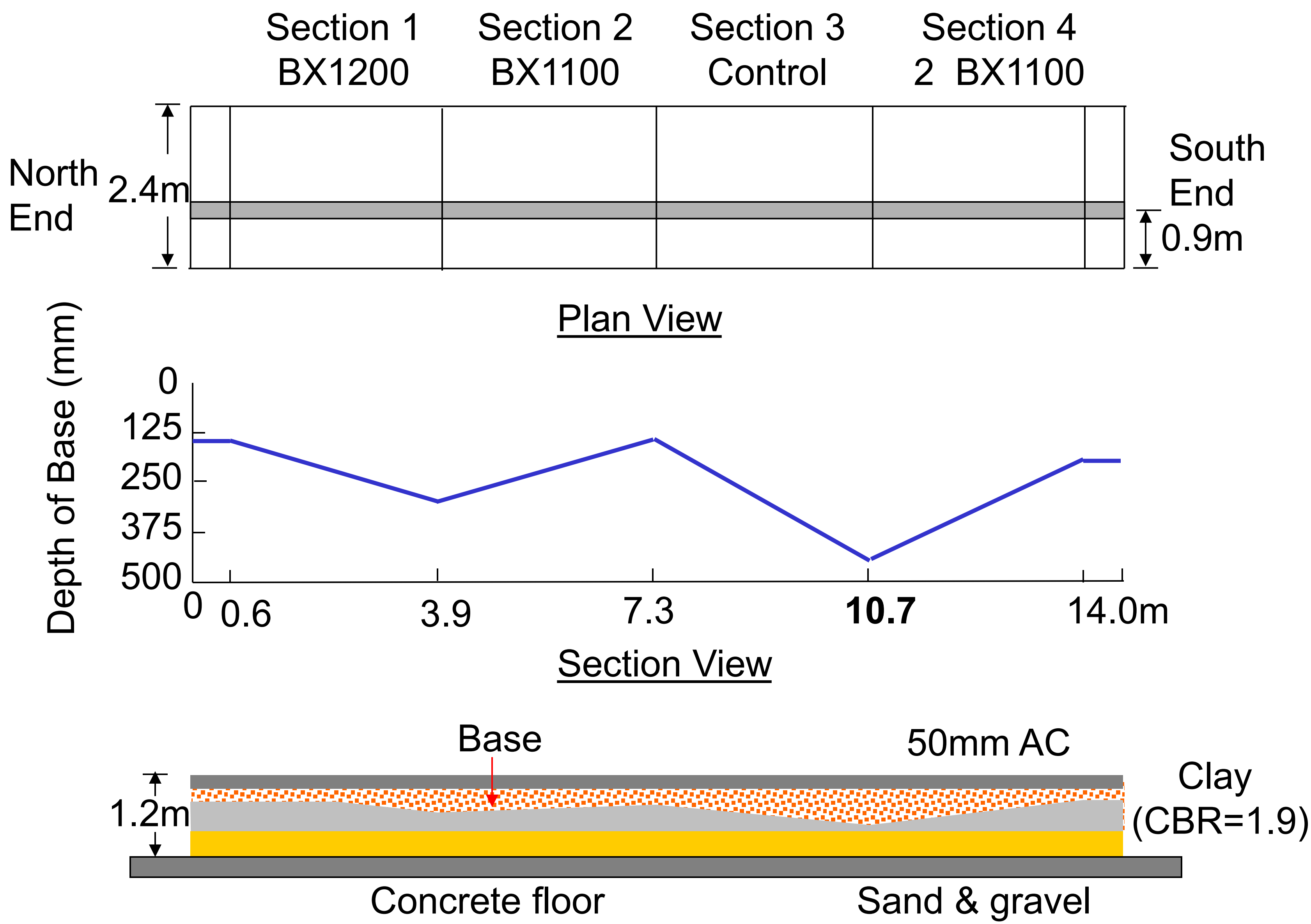


Geogrid Properties Affecting Base Reinforcement

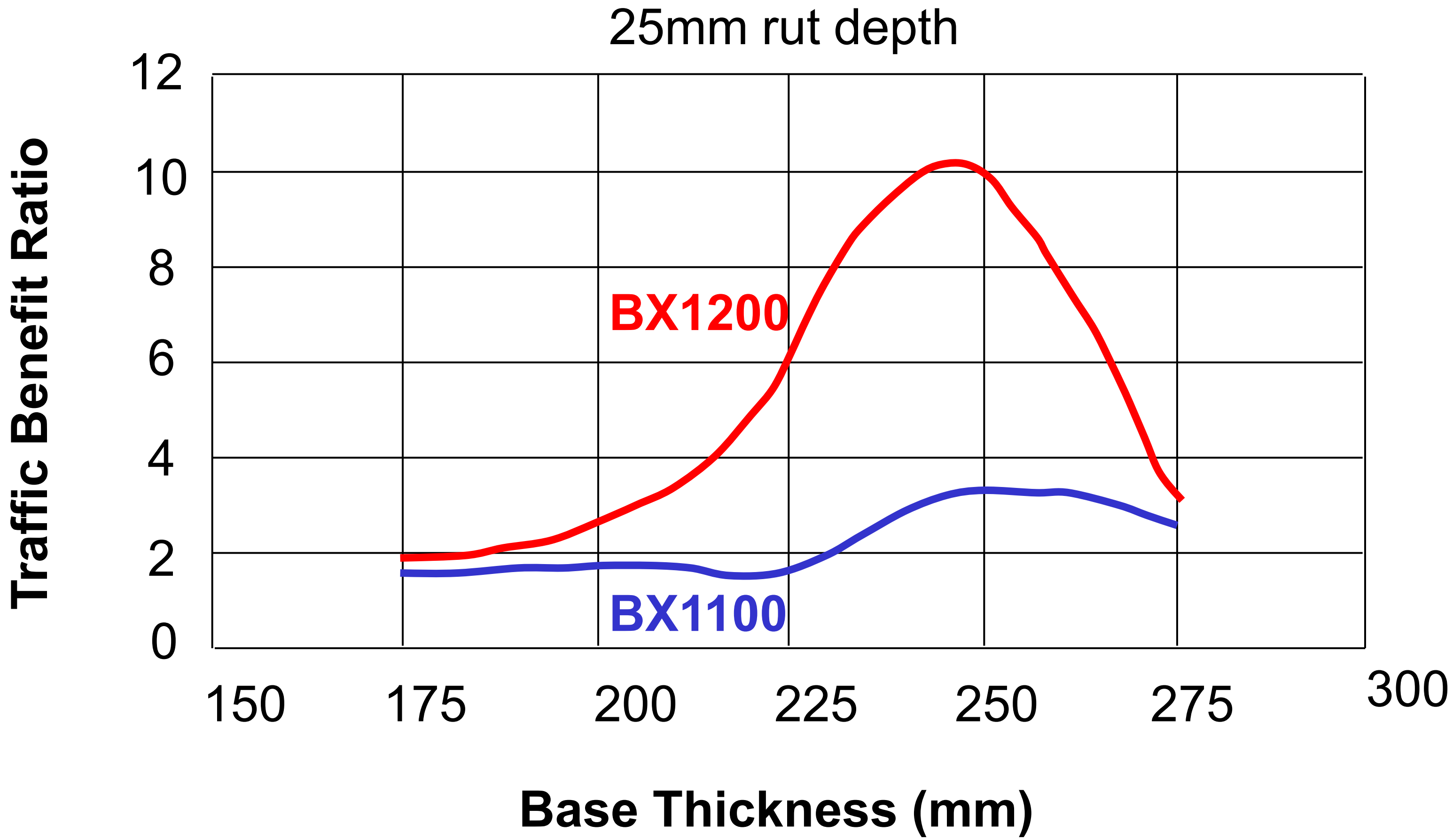
Geogrid item	Property	Better Performance
Rib	Thickness Stiffness Shape	Thicker Stiffer Square or rectangular
Aperture	Size Shape Rigidity	0.75 - 1.5in. Round or square Stiffer
Junction	Strength	Adequate strength
Grid	Secant modulus Stability	Adequate strength A good index

(Webster, 1992)

University of Alaska Study (Kinney)



Traffic Benefit Ratio (Kinney)



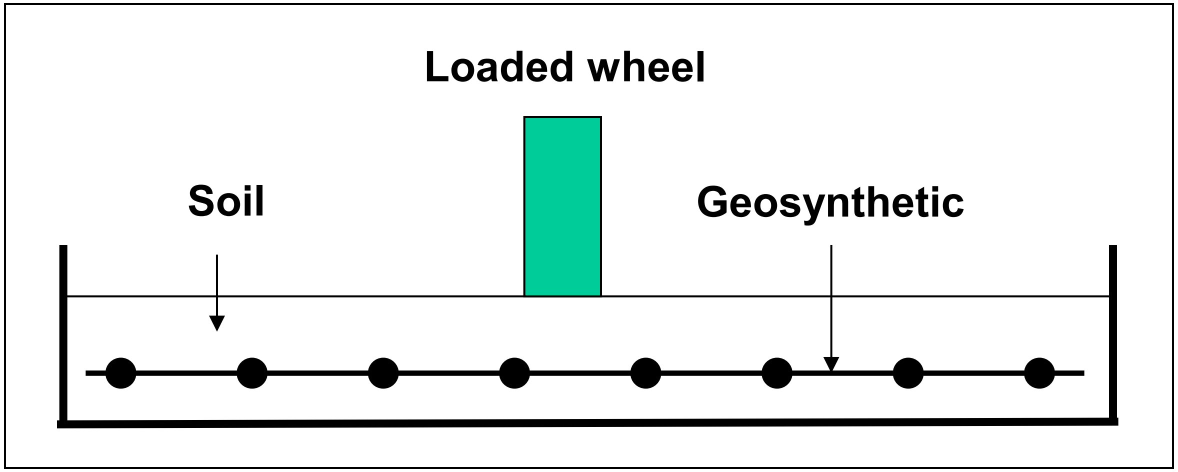
Evaluation of Base Reinforcement

Current Test Methods

Test Method	Features					
	Applicable to all geosynthetics	Geosynthetics interacting with base	Local deformation	Repeated loading	Wheel tracking	Easy, quick, inexpensive
Aperture rigidity	N	N	Y	N	N	Y
Bending stiffness	Y	Y	N	P	N	Y
Push test	Y	Y	Y	N	N	Y
Cyclic plate load test	Y	Y	Y	Y	N	N
Accelerated pavement test	Y	Y	Y	Y	Y	N
Field trafficking	Y	Y	Y	Y	Y	N
Proposed method	Y	Y	Y	Y	Y	Y

Y = Yes, N = No, and P = possible

Concepts for New Method



- Geosynthetic interacting with base course material
- Suitable for geosynthetics
- Simulate localized deformations
- Under repeated wheel loads
- Proved test method for asphalt mixture
- Machine available in many state DOTs in the U.S.
- Easy, quick, and cost effective

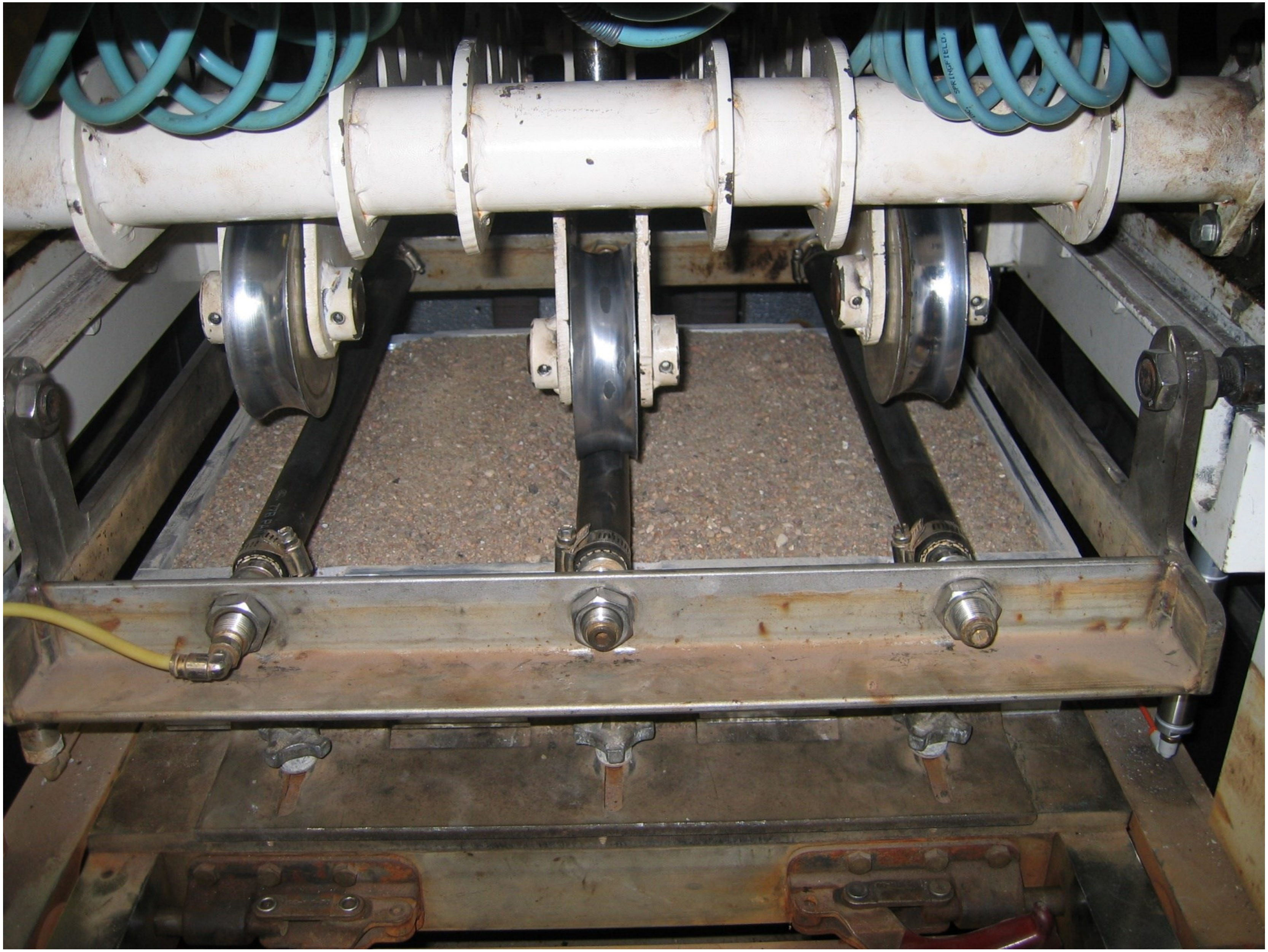
Testing Machine

Placement of Geogrid

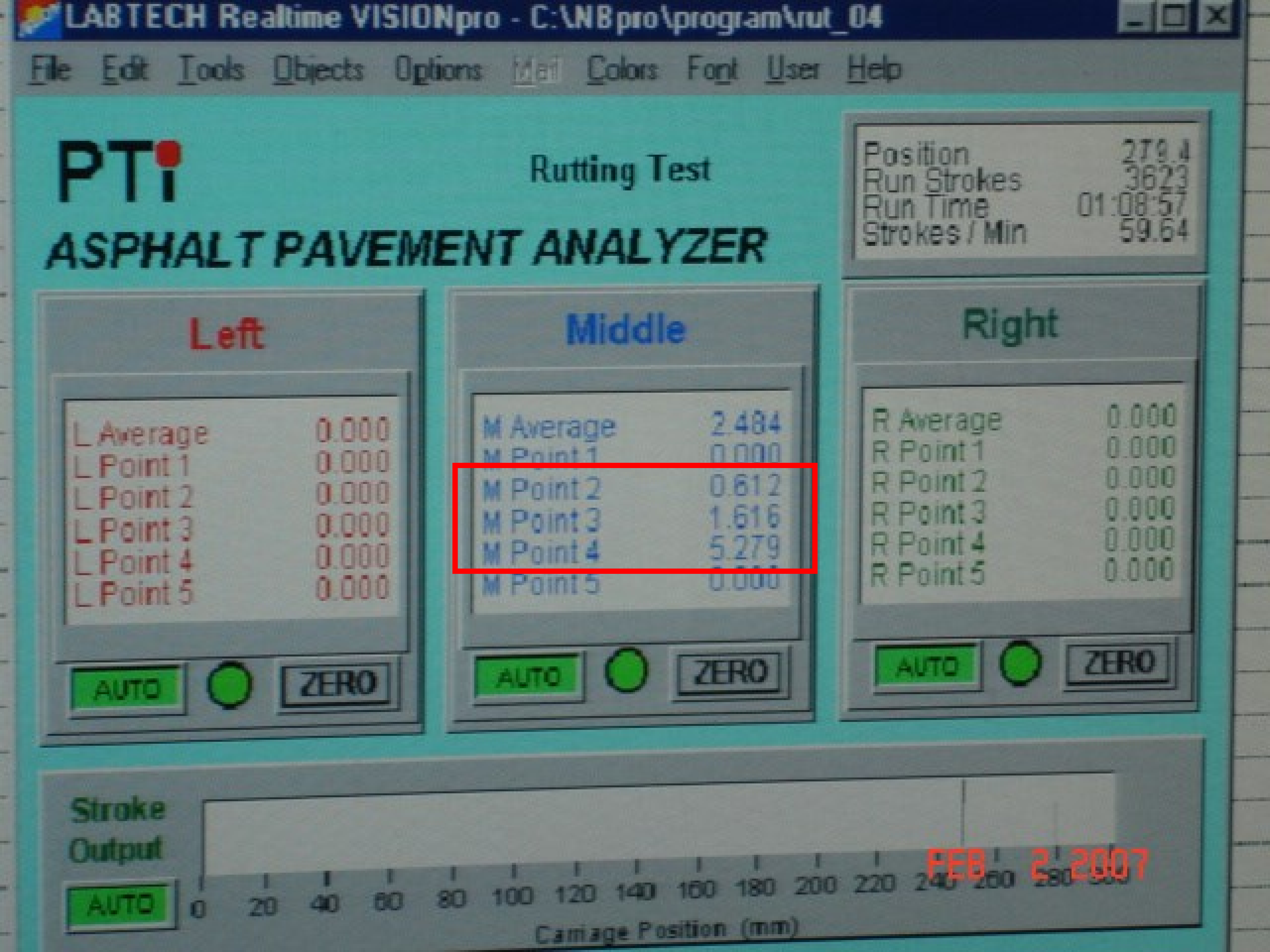
Placement of Aggregate above Geogrid


70 148
76 157
SEP 6 2006

Loaded Wheel Test



Rutting after Testing



LABTECH Realtime VISIONpro - C:\NBpro\program\rut_04
File Edit Tools Objects Options Colors Font User Help
PTi
Rutting Test
ASPHALT PAVEMENT ANALYZER
Position 279.4
Run Strokes 3623
Run Time 01:08:57
Strokes / Min 59.64
Left
L Average 0.000
L Point 1 0.000
L Point 2 0.000
L Point 3 0.000
L Point 4 0.000
L Point 5 0.000
AUTO
ZERO
Middle
M Average 2.484
M Point 1 0.000
M Point 2 0.612
M Point 3 1.616
M Point 4 5.279
M Point 5 0.000
AUTO
ZERO
Right
R Average 0.000
R Point 1 0.000
R Point 2 0.000
R Point 3 0.000
R Point 4 0.000
R Point 5 0.000
AUTO
ZERO
Stroke Output
AUTO
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300
Carriage Position (mm)
FEB 2 2007

Manual Measurement

Test Conditions

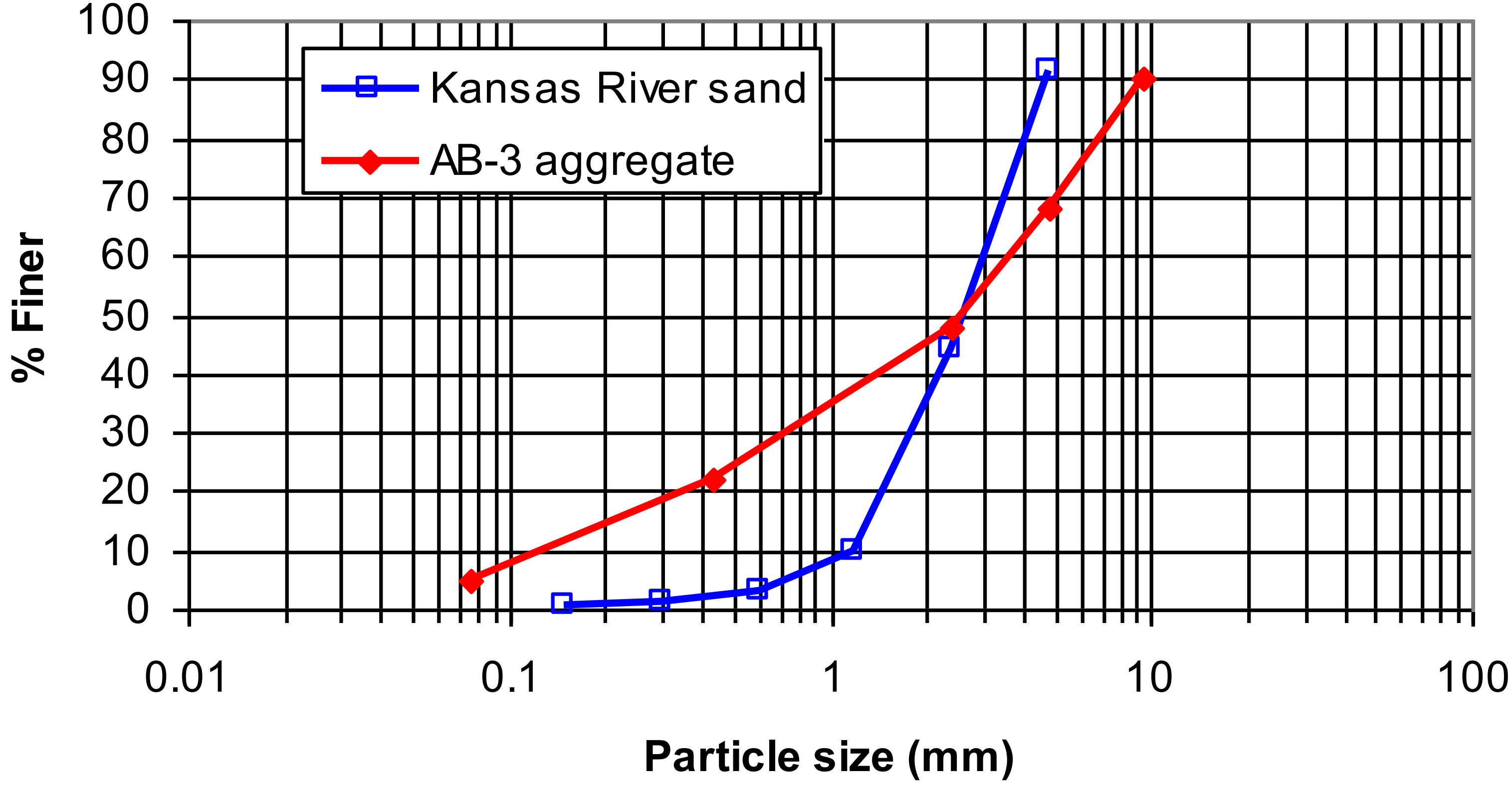
Wheel load = 89 or 355N, hose pressure = 138 or 552kPa
Hose dia. = 19mm, rut width = 25mm

Base material – Kansas river sand or AB-3 aggregate
(Dr = 70%)

Depth of reinforcement – at depth of 25mm or 13mm

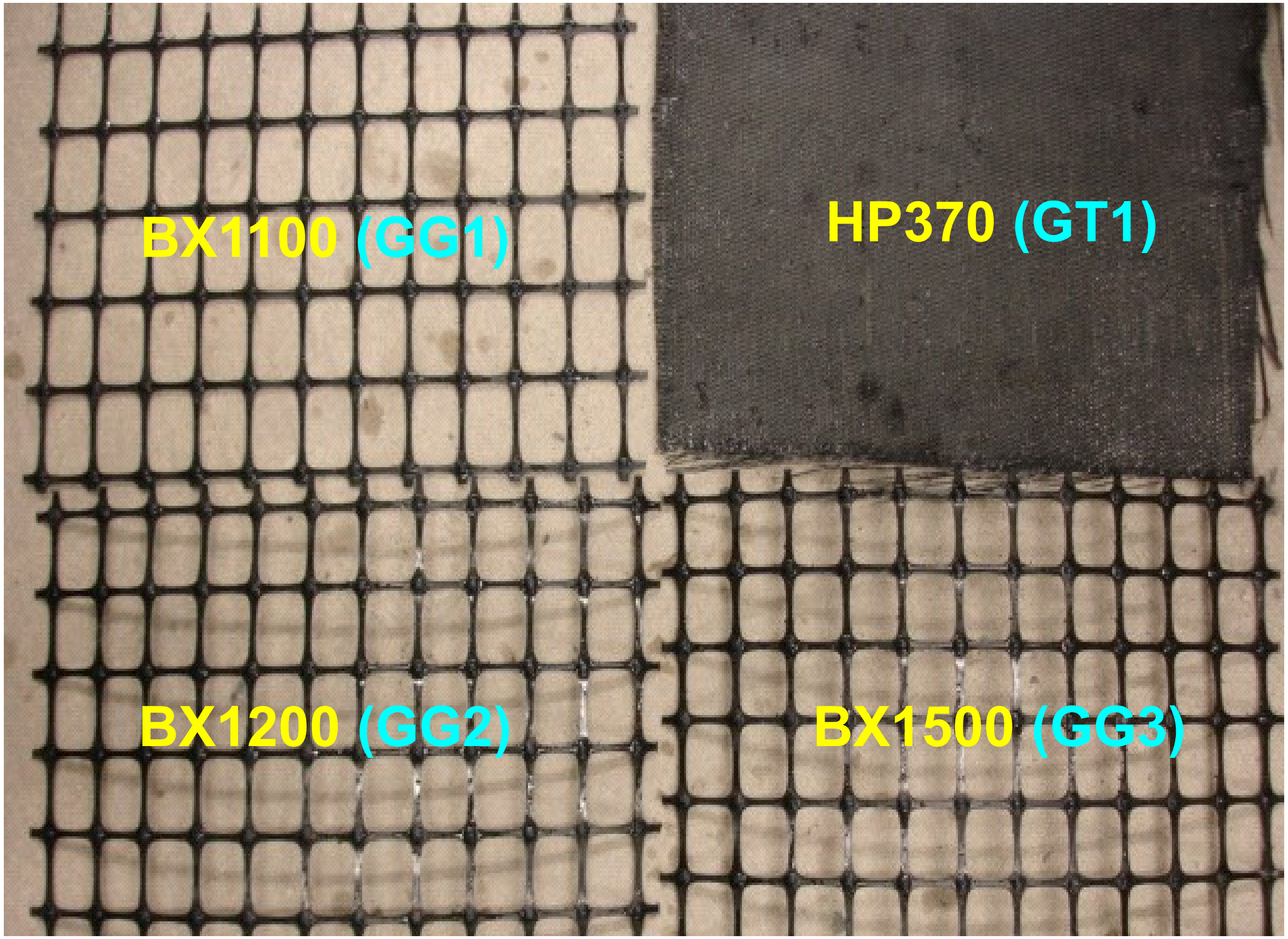
Surcharge = 0 or 2.9kPa

Base Materials



Kansas River Sand: sub-round, poorly-graded
AB-3 Aggregate: Angular, well-graded

Geosynthetic Specimens

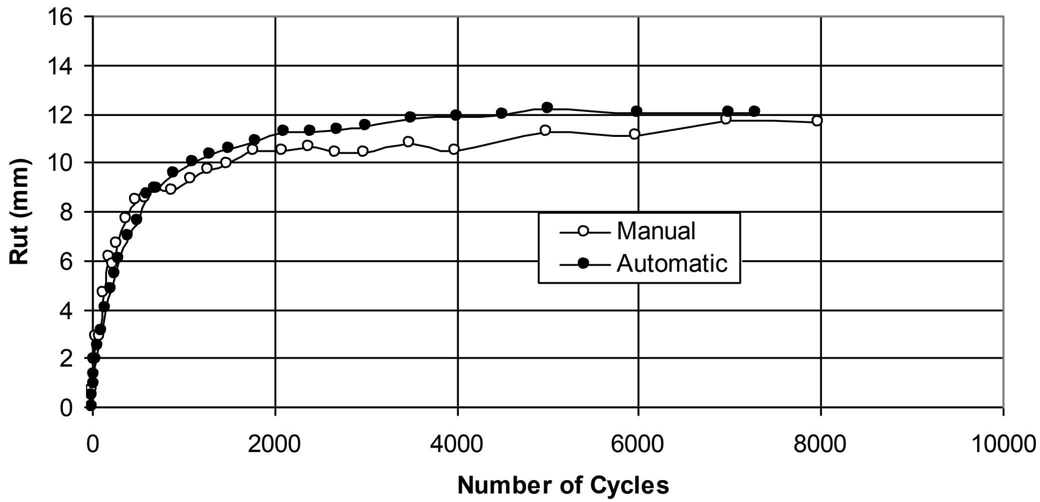


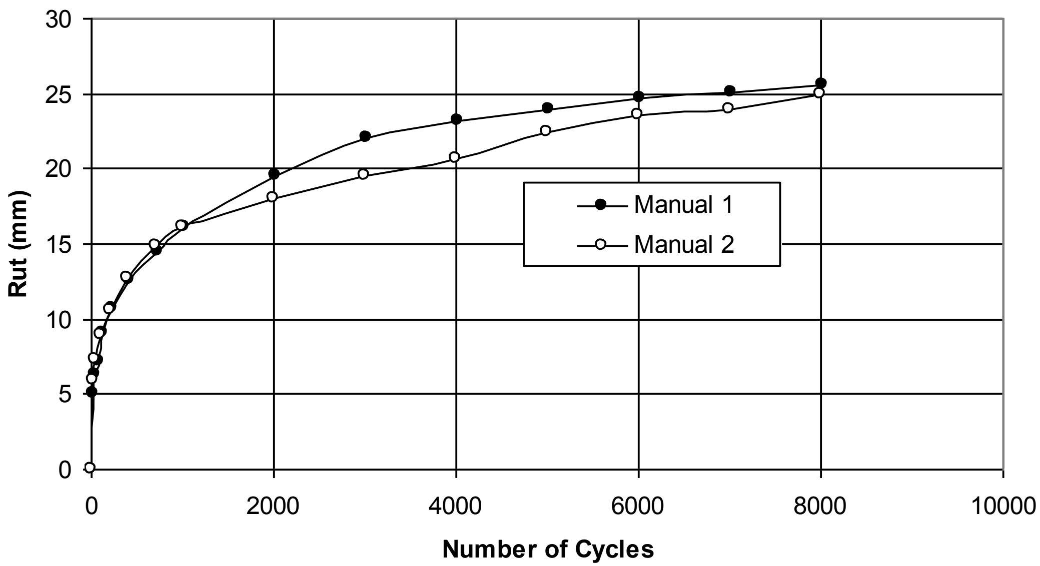
Properties of Geosynthetics

Geosynthetic	Property	MD	XMD
GG1	Tensile strength @5% strain (kN/m)	8.3	13.4
	Aperture stability modulus (m-N/deg)	0.32	
GG2	Tensile strength @5% strain (kN/m)	11.8	19.6
	Aperture stability modulus (m-N/deg)	0.65	
GG3	Tensile strength @5% strain (kN/m)	17.5	20.0
	Aperture stability modulus (m-N/deg)	0.75	
GT1	Tensile strength @5% strain (kN/m)	19.8	22.3

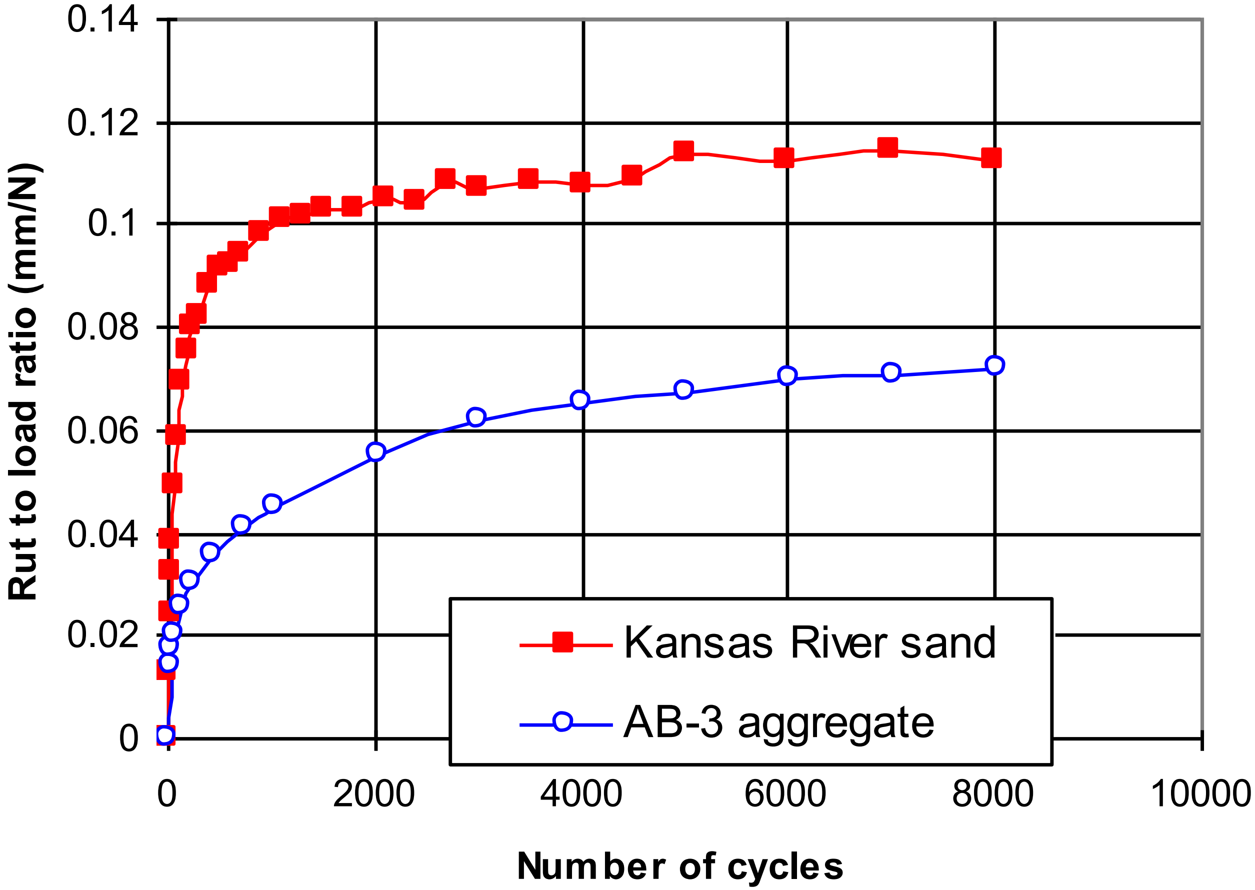
Surcharge (2.9kPa)

Repeatability of Test Results



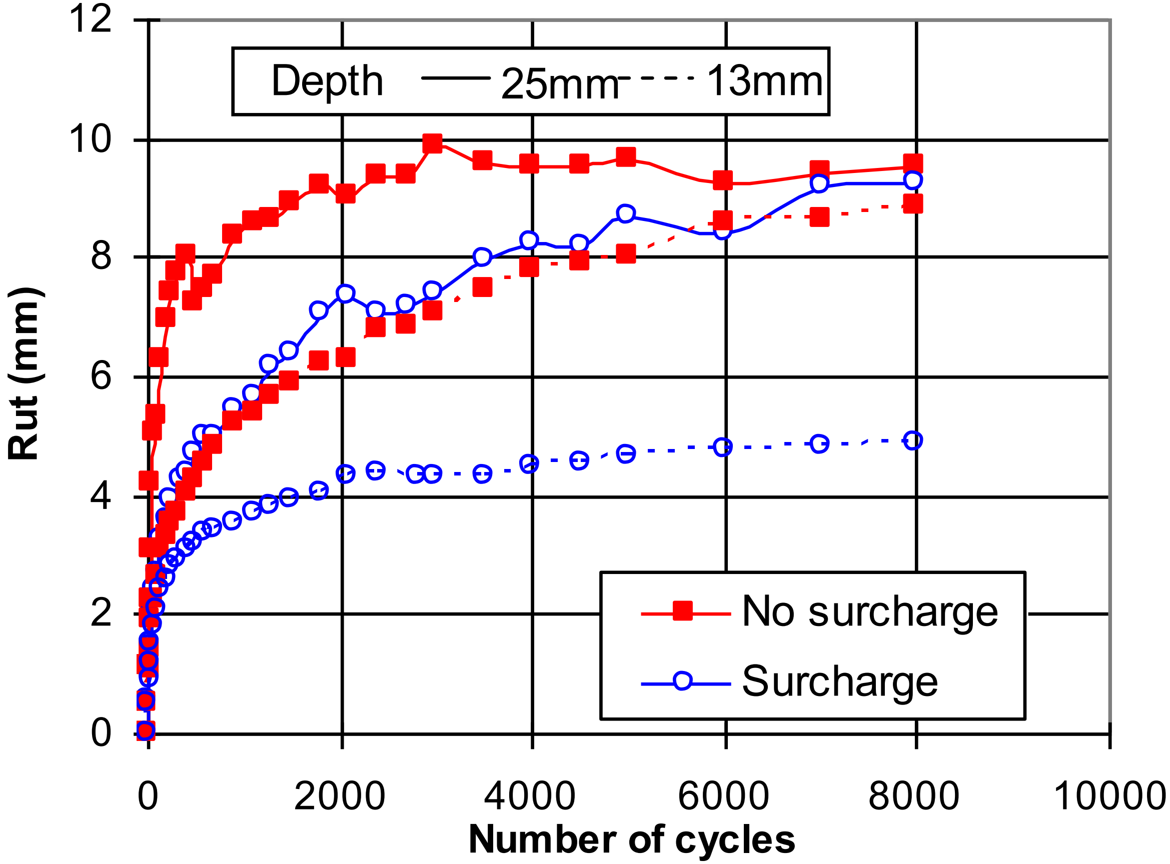


Effect of Base Material



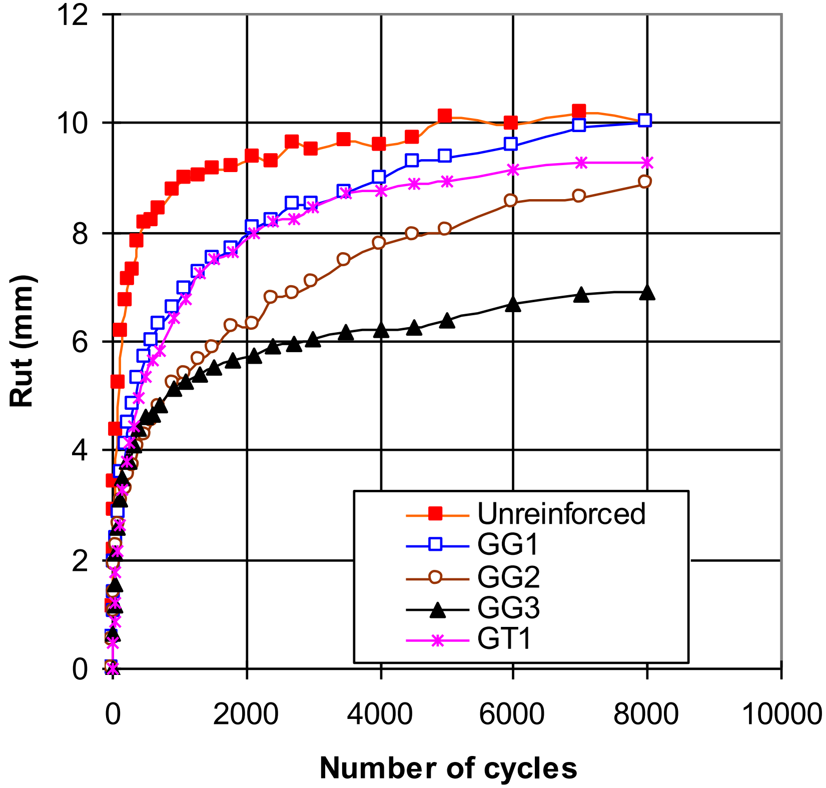
Unreinforced

Effect of Surcharge

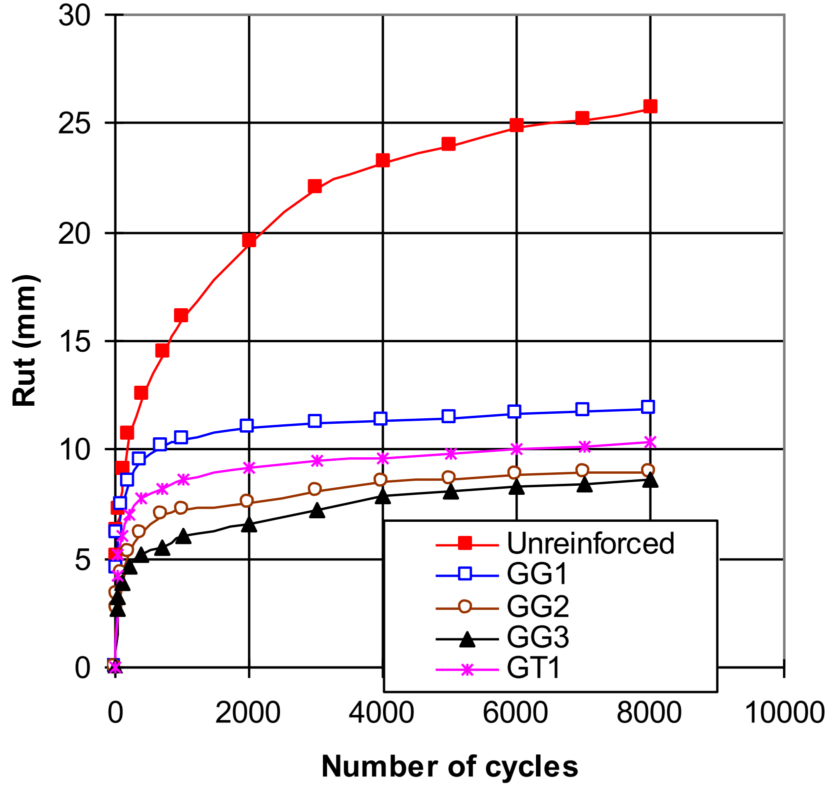


GG2

Effect of Geosynthetic Type

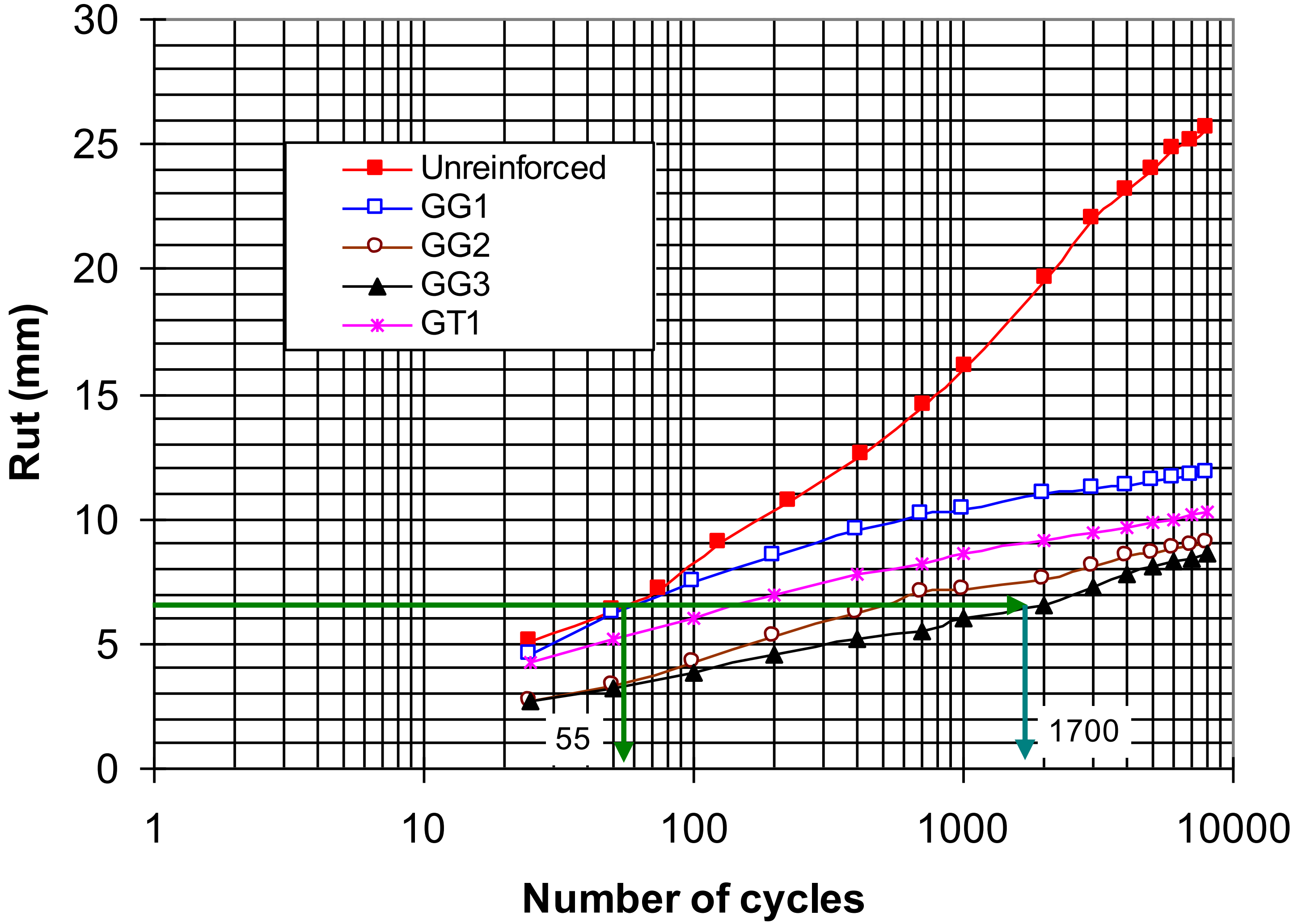


Kansas River sand



AB-3 aggregate

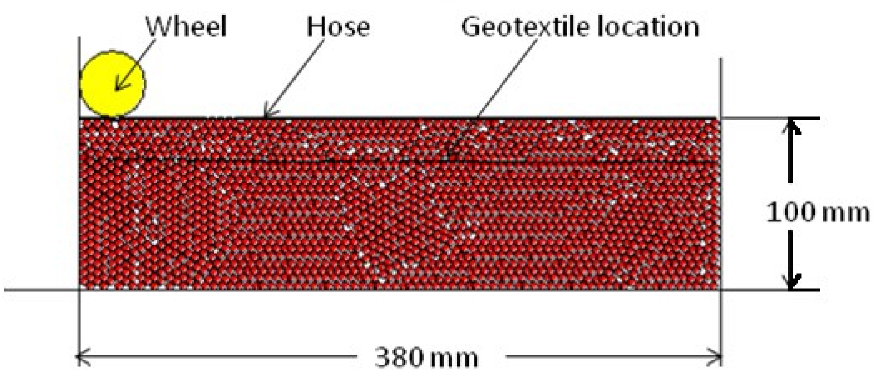
Traffic Benefit Ratio

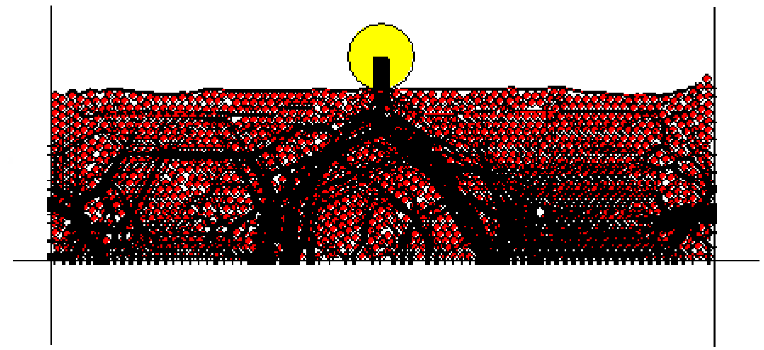


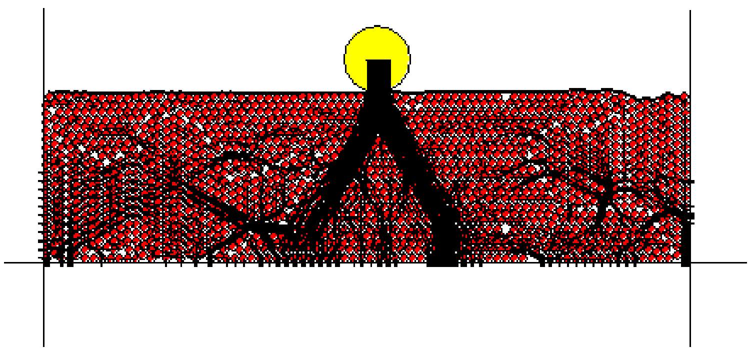
Calculated TBR Values

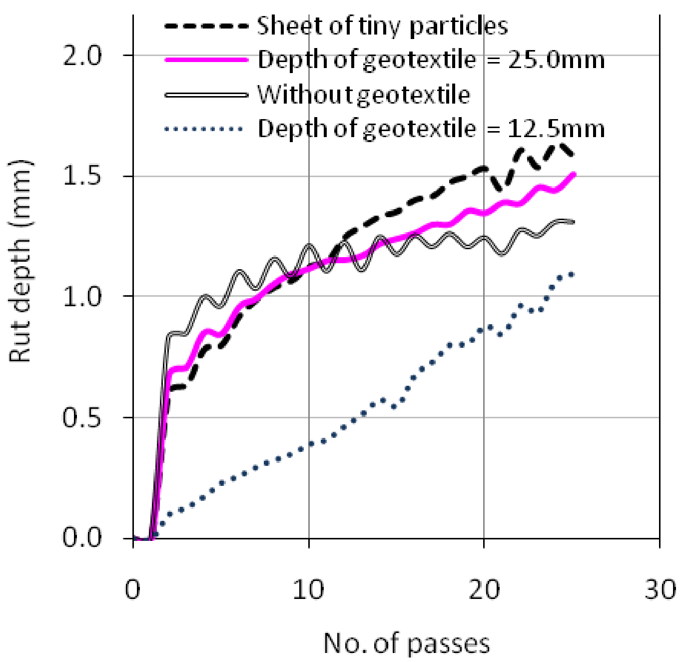
Base	Surcharge	Geosyn. Depth (mm)	TBR			
			GG1	GG2	GG3	GT1
Kansas River sand	No	25	0.7	1.0	2.1	2.7
		13	5.7	7.9	36.4	6.4
	Yes	25	4.6	0.4	0.4	0.4
		13	5.7	28.6	2.9	1.9
AB-3	No	25	0.5	1.1	2	0.6
		13	1	7.8	31	2.4

Discrete Element Modeling

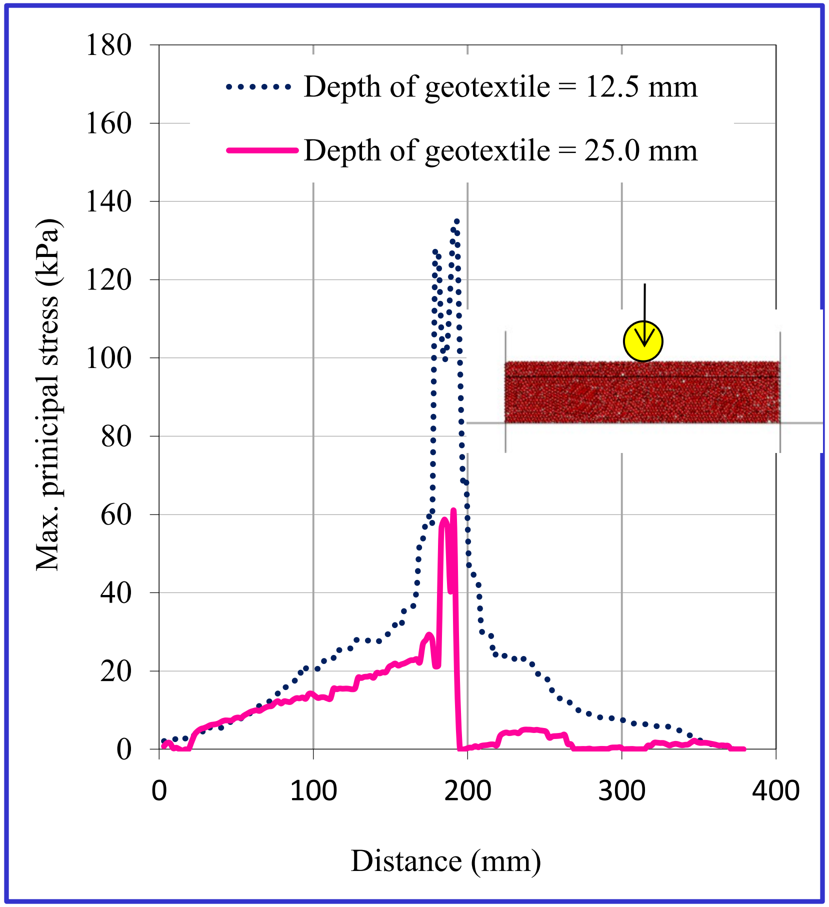


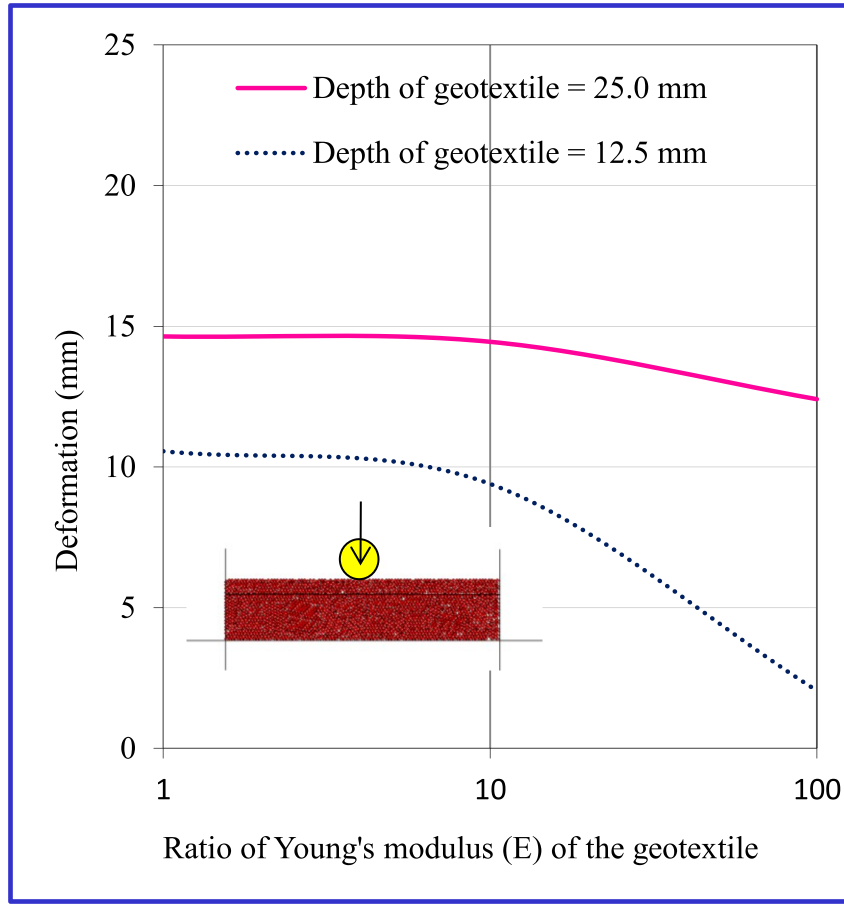






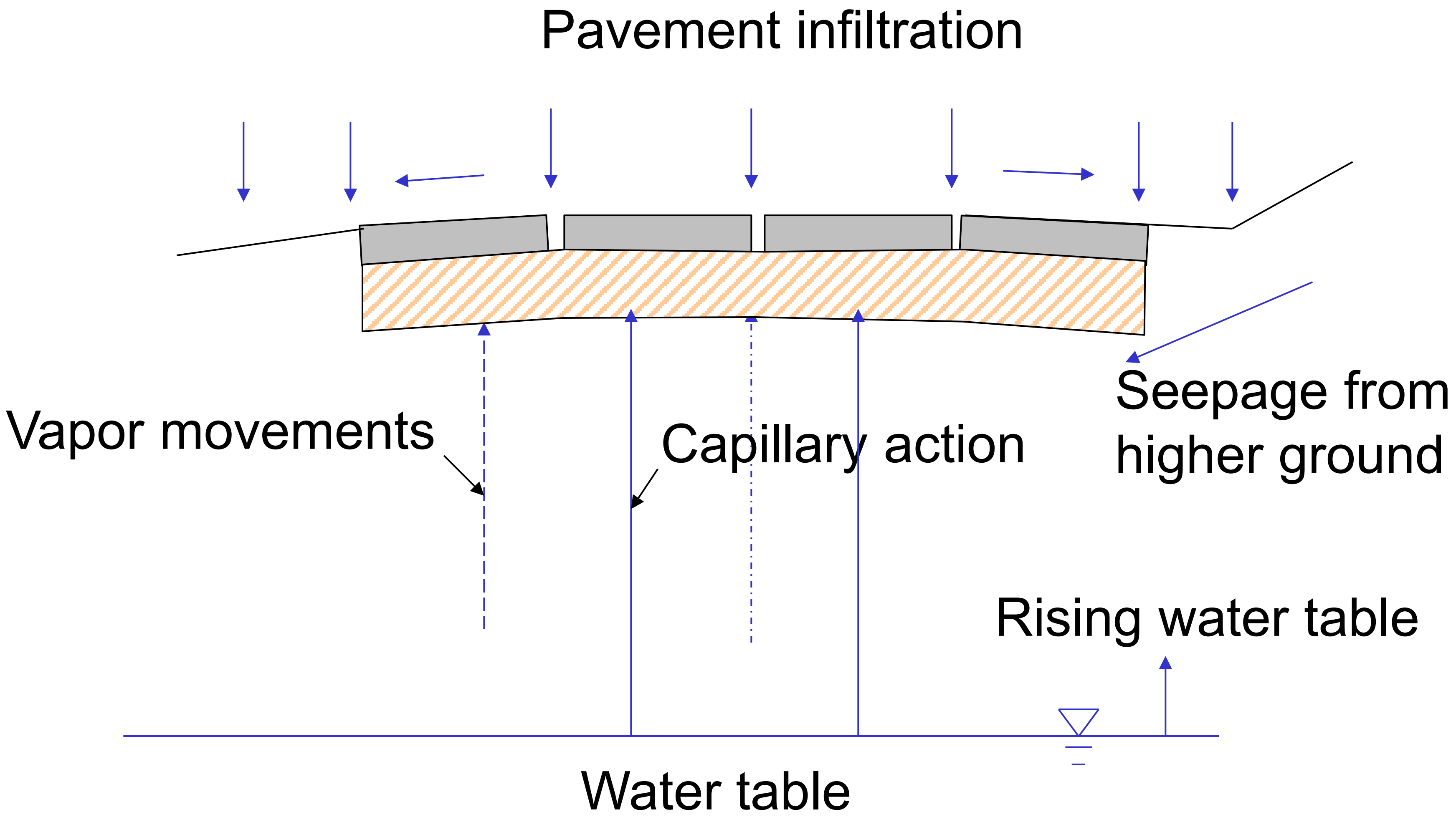
Tensile Stress and Deformation



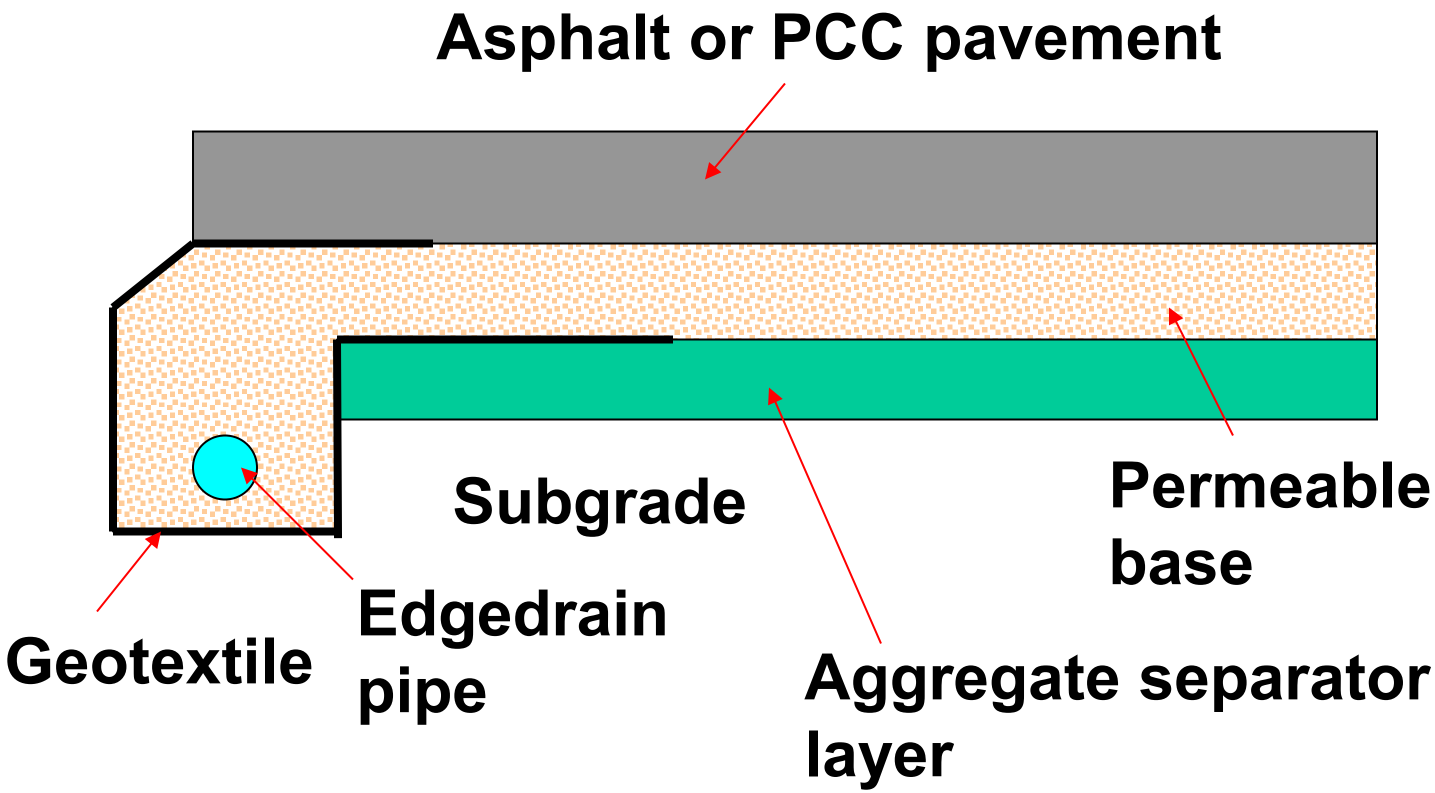


Drainage Design

Sources of Water

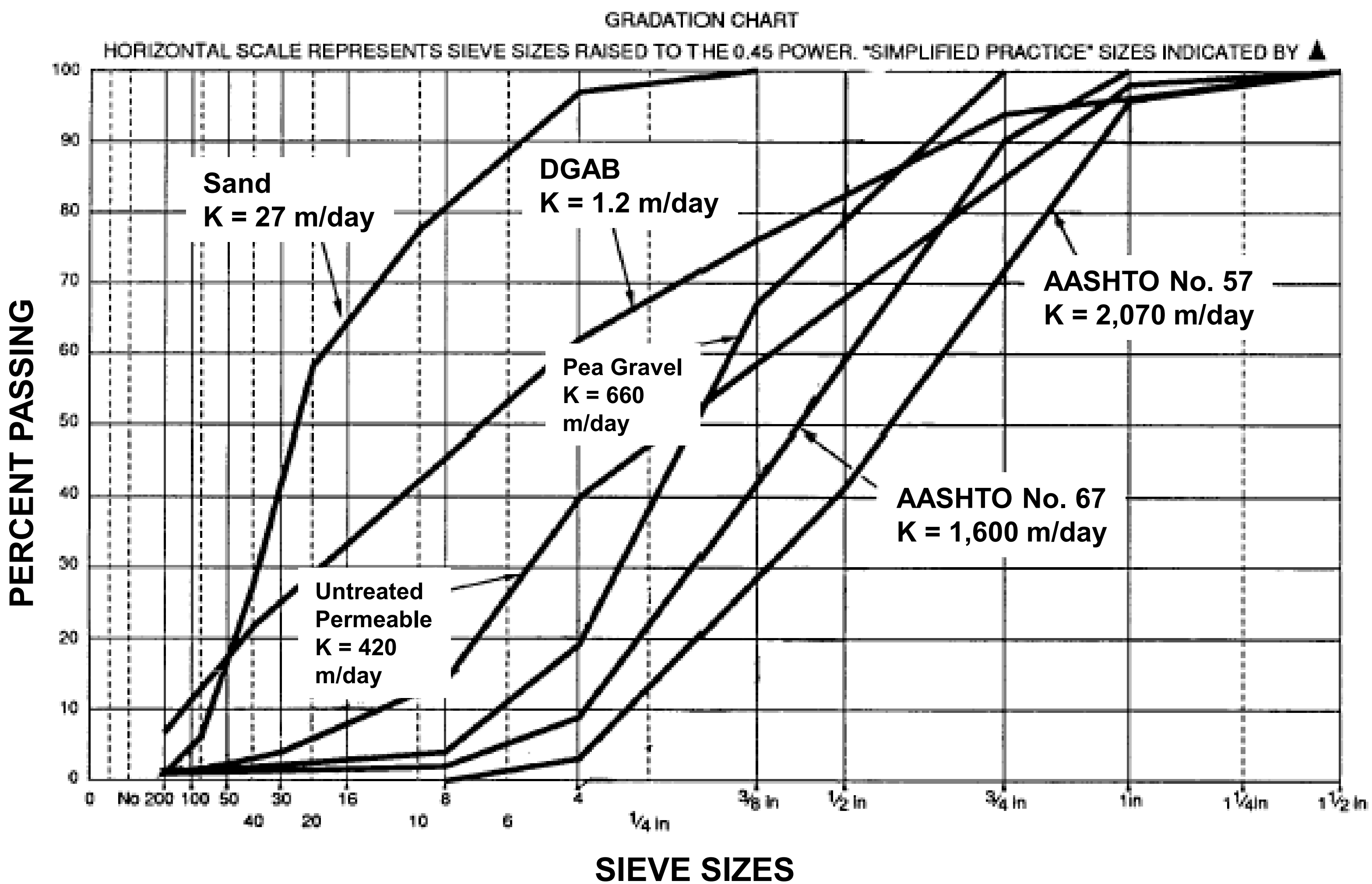


Drainable Pavement Systems



Drainable Pavement Systems

FHWA(1987) recommend a minimum k of 300m/day

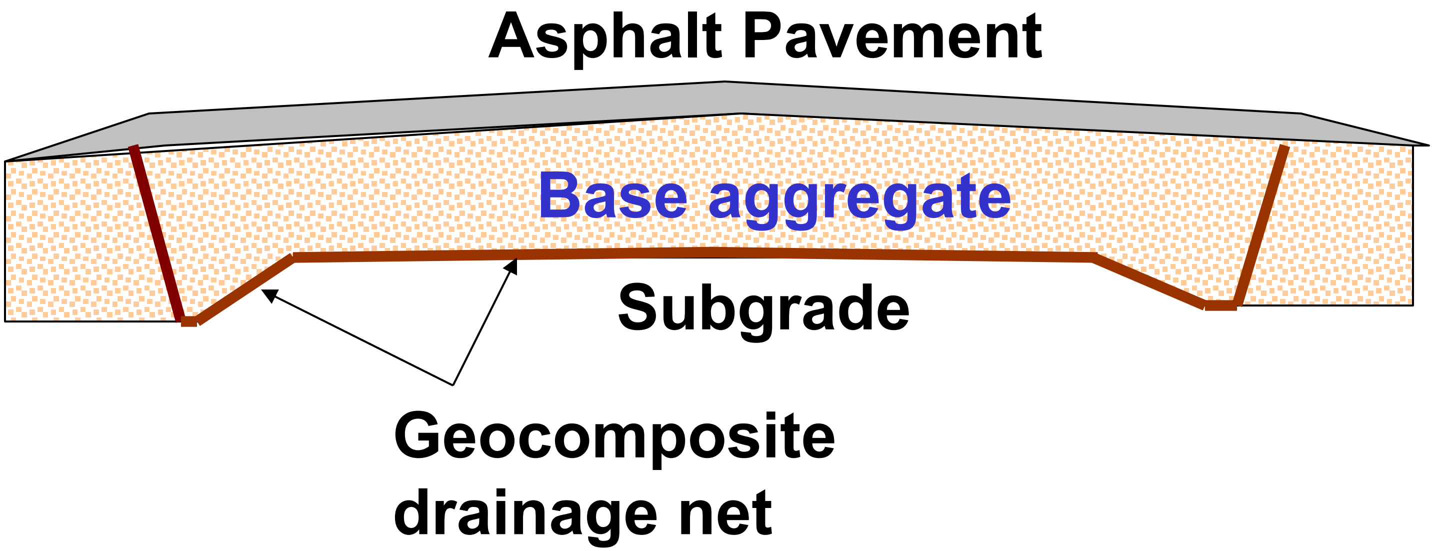


Drainage Quality

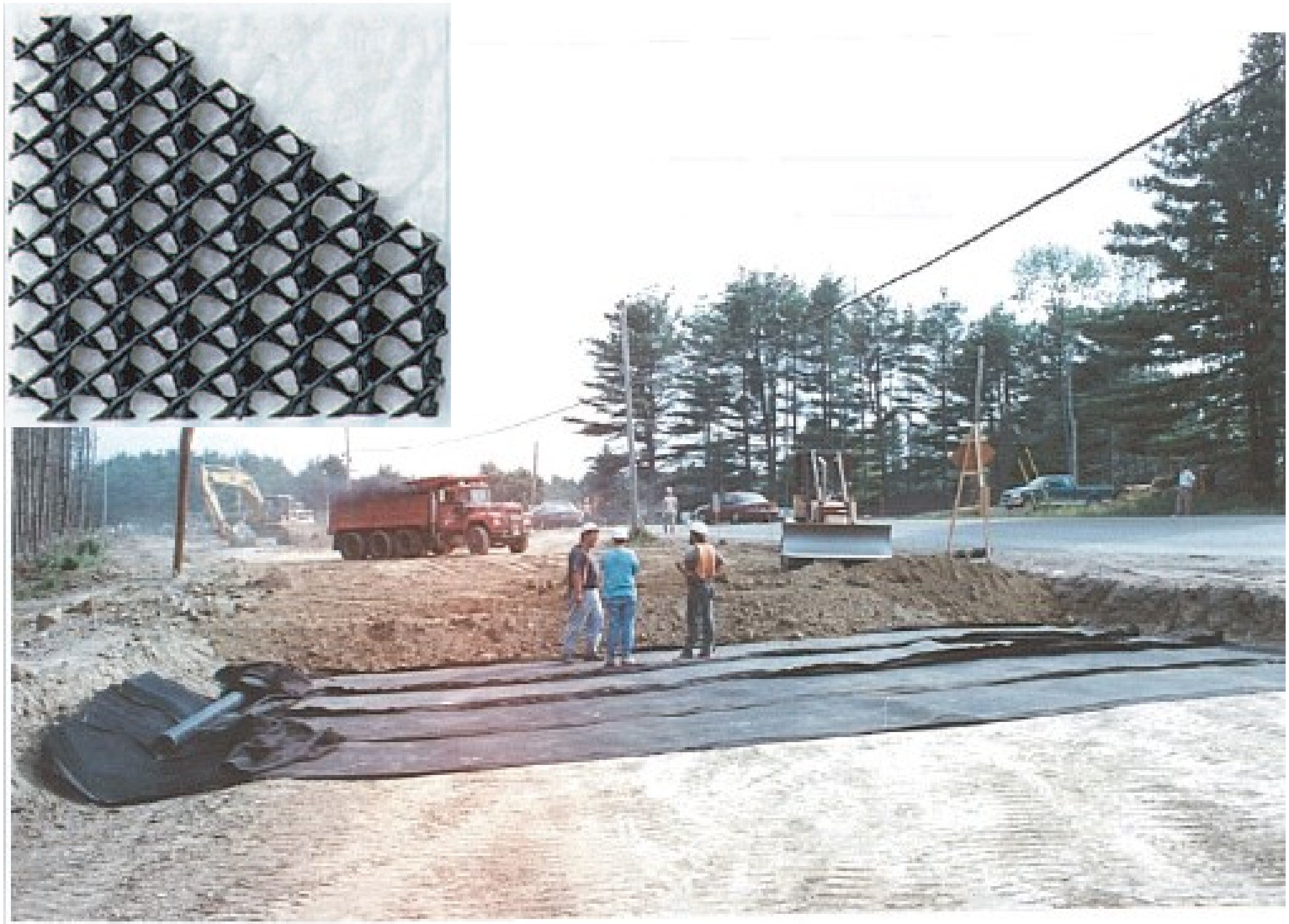
Quality of Drainage	Water Removed Within
Excellent	2 hours
Good	1 day
Fair	1 week
Poor	1 month
Very poor	(water will not drain)

Note: the drainage conditions at the AASHO Road Test are considered to be fair

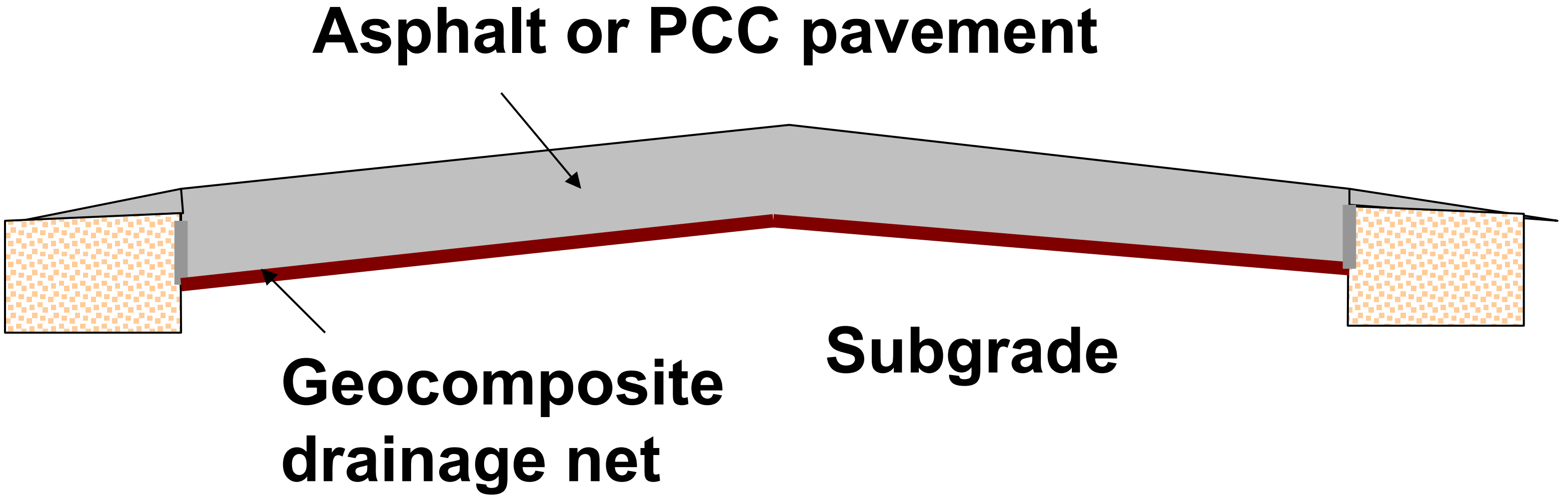
Geocomposite Drainage of Base



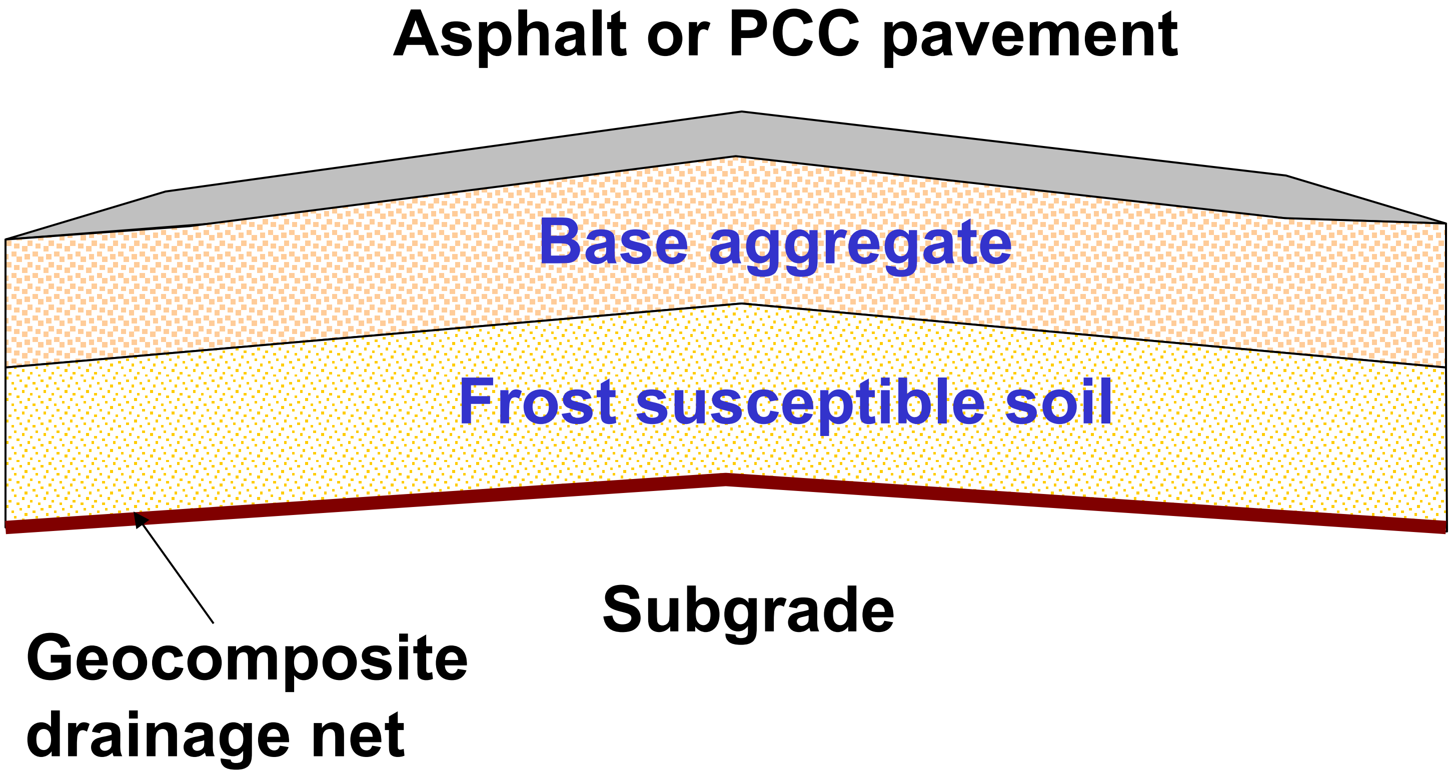
Geocomposite Drainage of Base



Geocomposite Drainage of Surface Asphalt or Concrete Pavement



Geocomposite Drainage of Subgrade



Time to 50% Drain

The time to drain is determined by:

$$t = T \times m \times 24$$

t = time to drain in hours

T = time factor, determined from the relationship with S_I

$$S_I = (L_R\ S_R)/H$$

L_R = drain distance

S_R = resultant slope

H = drainage layer thickness

$$m = N_0 L_R^2/(kH) = N_0 L_R^2/\psi$$

N_0 = effective porosity of the drainage layer

ψ = transmissivity of the drainage layer

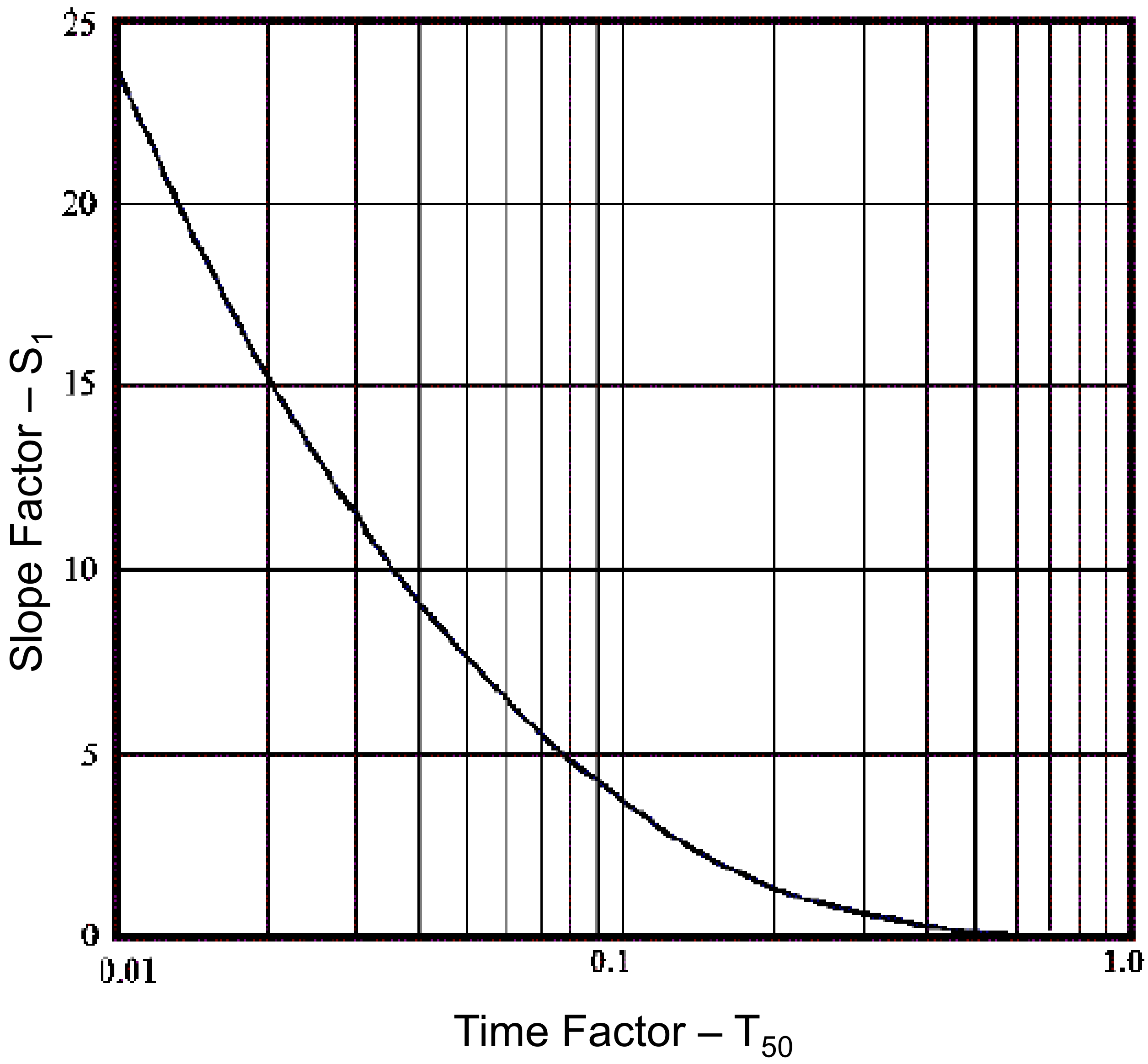
Recommended Time to Drain

1 hour: for the highest class roads with the greatest amount of traffic

2 hours: for most other high use roadways

1 day: for secondary roads

Time Factor for 50% Drainage



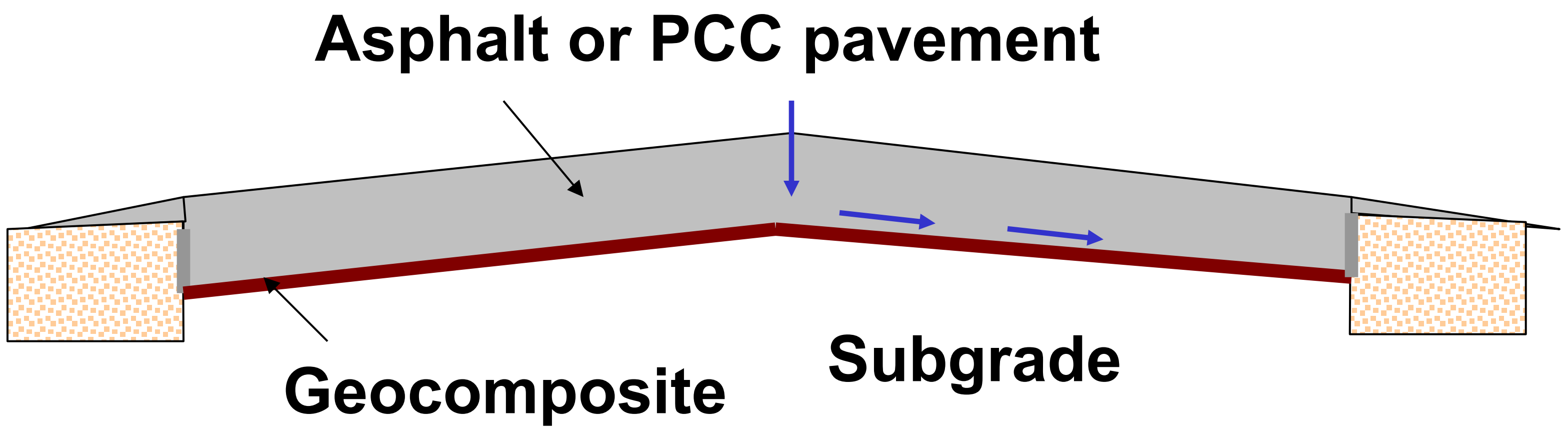
Effective Porosity of Geosynthetics

- **The ratio of the volume of drained water to the total volume of the sample**

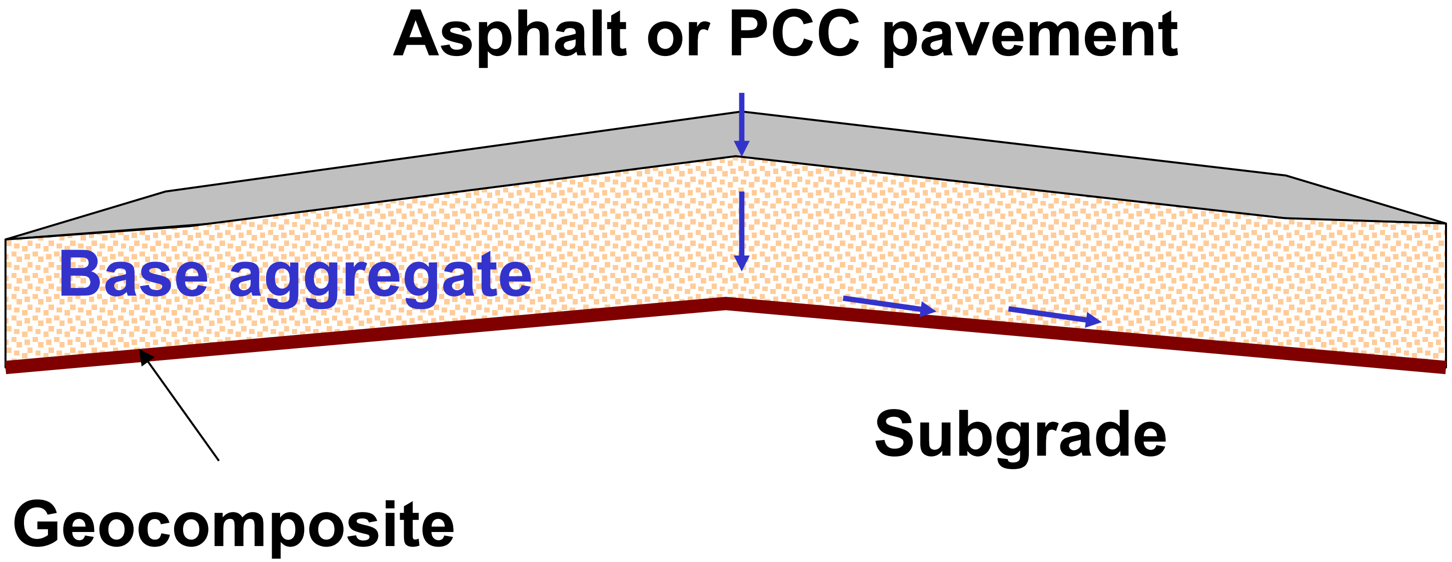
For example:

Effective porosity of Tendrain 100-2 = 0.69
Porosity of the material = 0.74

Geocomposite Directly underneath Pavement



Geocomposite Directly underneath Base Course



Geotextile Filtration Design

Proper geotextile should be selected outside the geonet to allow the flow of water into the geonet and prevent soil from washing into the system