Design of Geosynthetics for Unpaved Roads

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Outline of Presentation

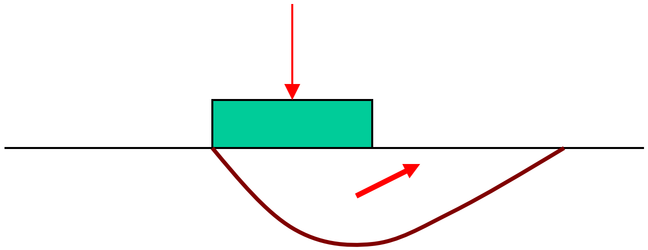
- Introduction
- Design of Planar Geosynthetics for Unpaved Roads
- Recent Research on 3D Geosynthetics for Unpaved Roads

Introduction

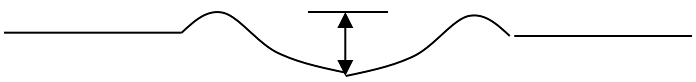
Problems with Unpaved Roads

Bearing failure - failure of subgrade due to its low strength as compared with traffic loading

Rutting - surface depression in the wheel paths



Bearing failure



Rutting

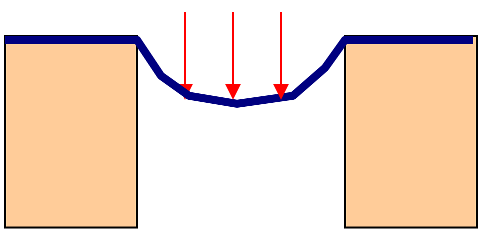
Geogrid-Reinforced Roads

Field Construction of Geocell

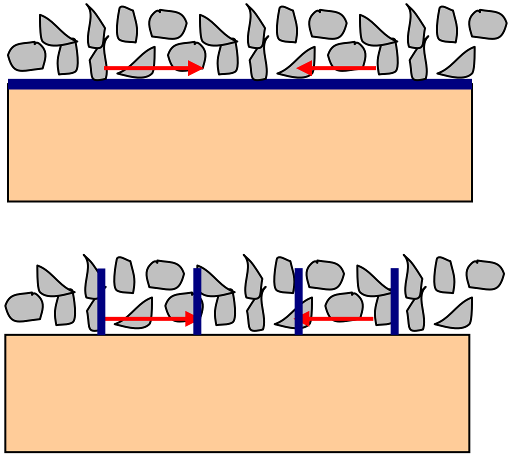



Reinforcement Function

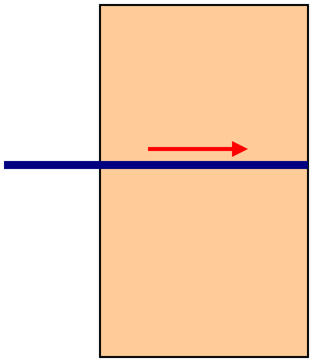
- Provide (tensile) strength necessary for soil
- Increase shear (interlocking or confinement) resistance
- Mechanisms: membrane, confinement, and anchorage types



Membrane

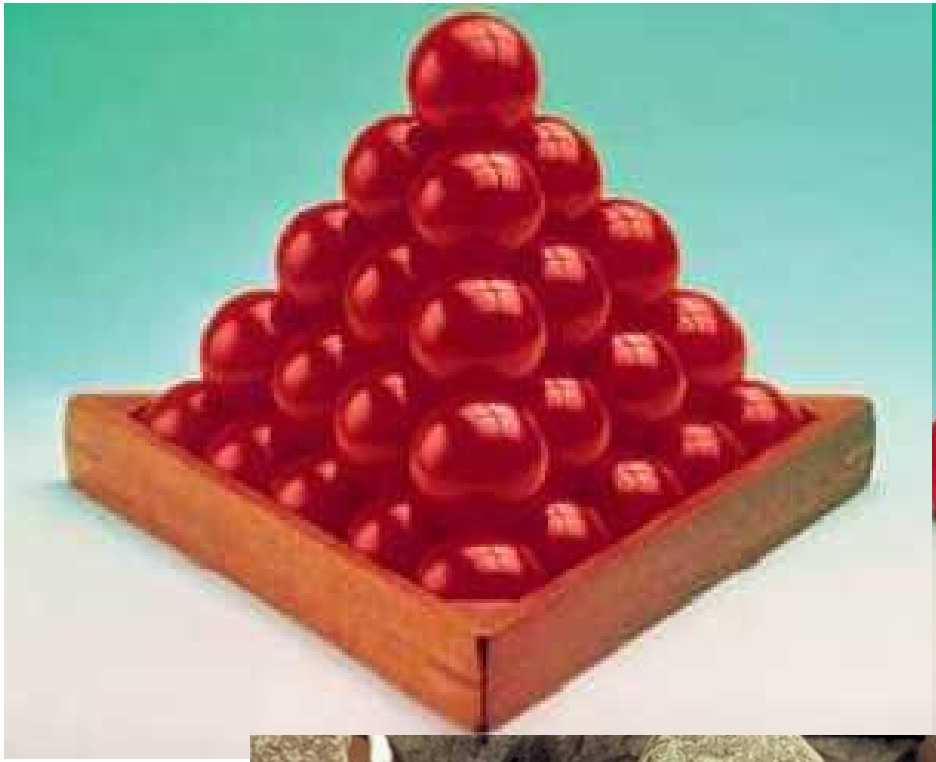


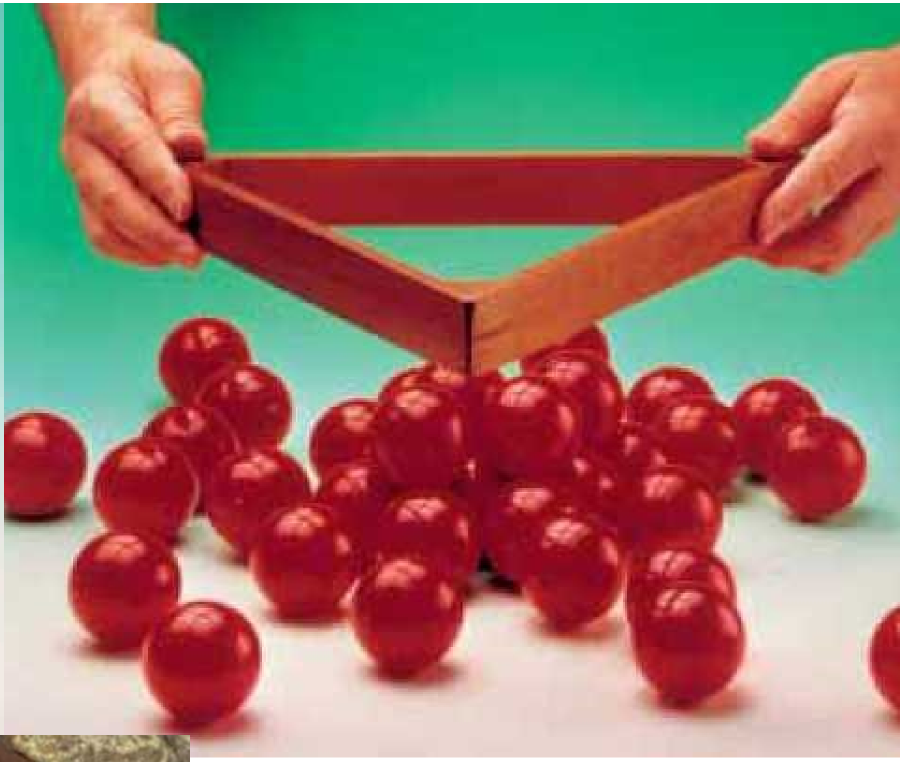
Confinement



Anchorage

Confinement and Interlocking





Interlocking

Effect of Confinement

- **Minimize lateral movement**
- **Less lateral movement, less upward movement**
- **Less lateral movement, less tensile stress in pavement**

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Lower rut depth and less chance of fatigue failure

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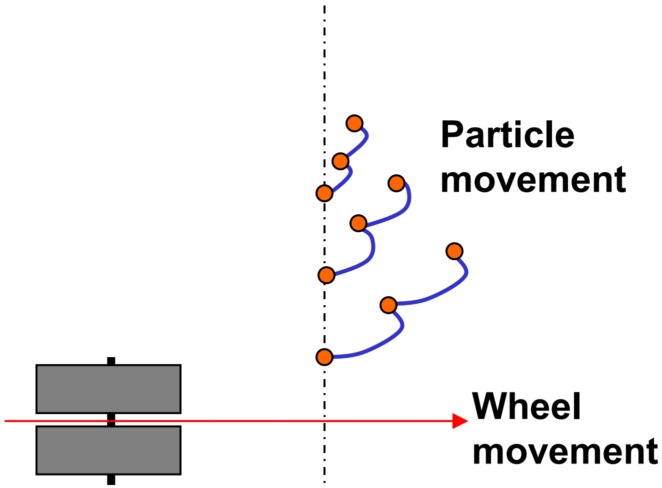
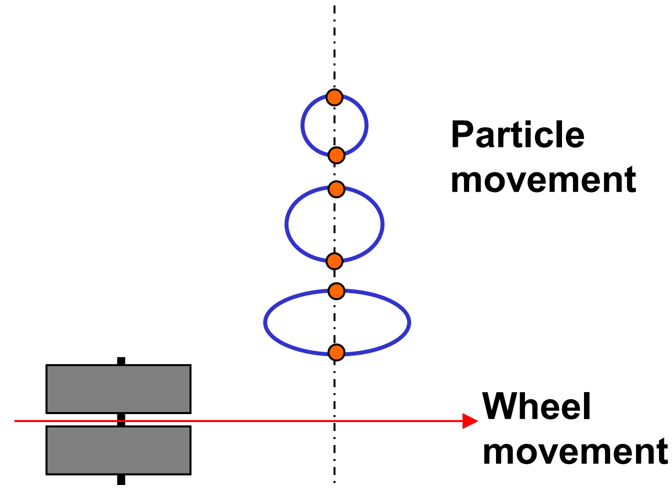
Longer pavement life

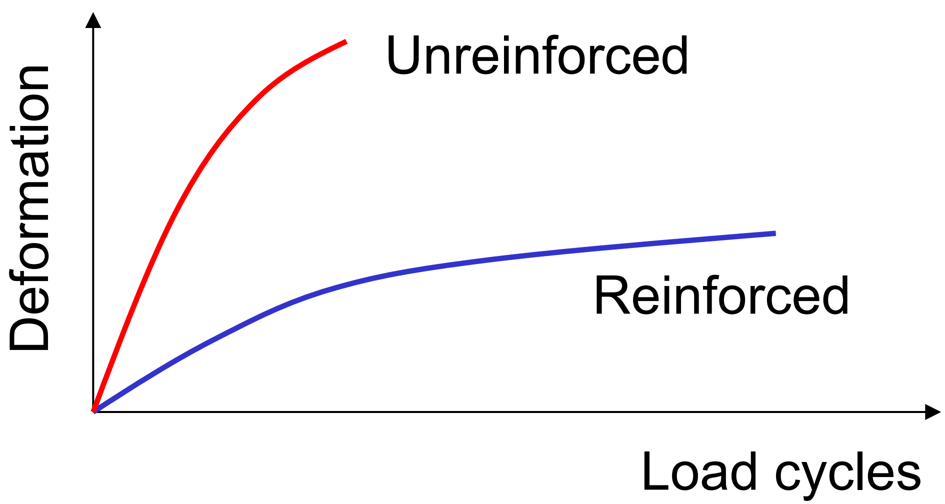
How Do We Know It Works?

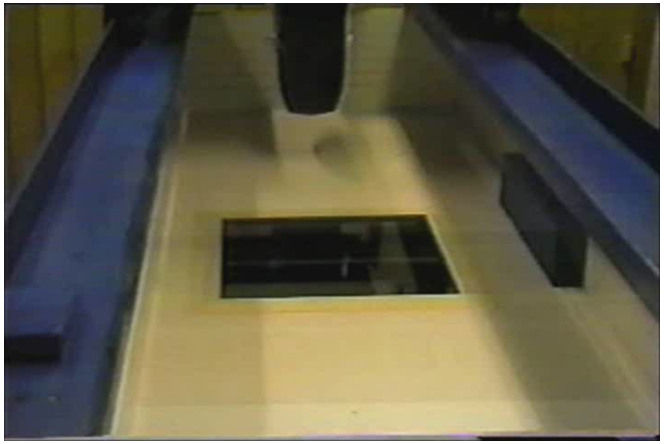


No Reinforcement



Geogrid Reinforcement





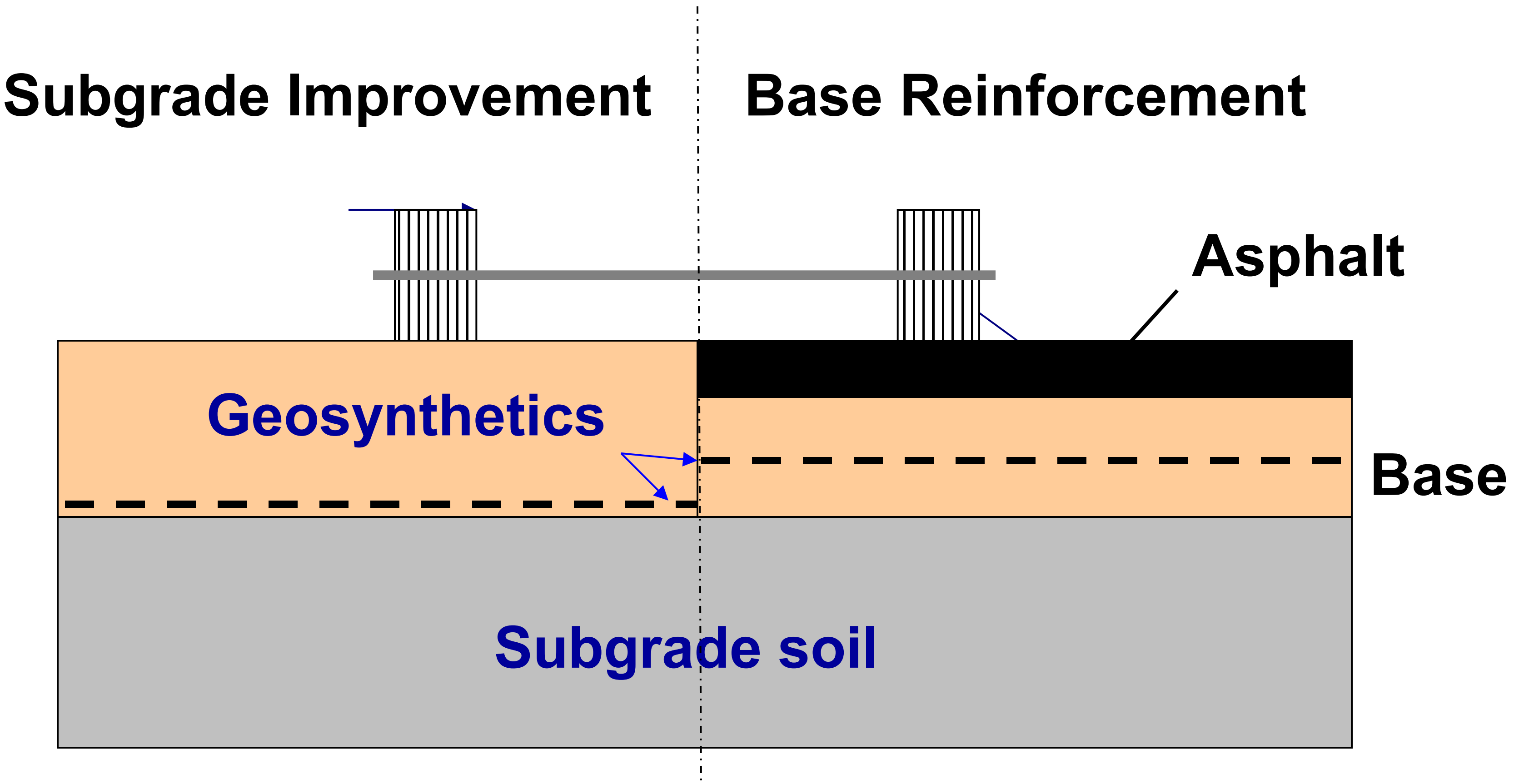
Courtesy of Kinney

Subgrade Improvement vs. Base Reinforcement

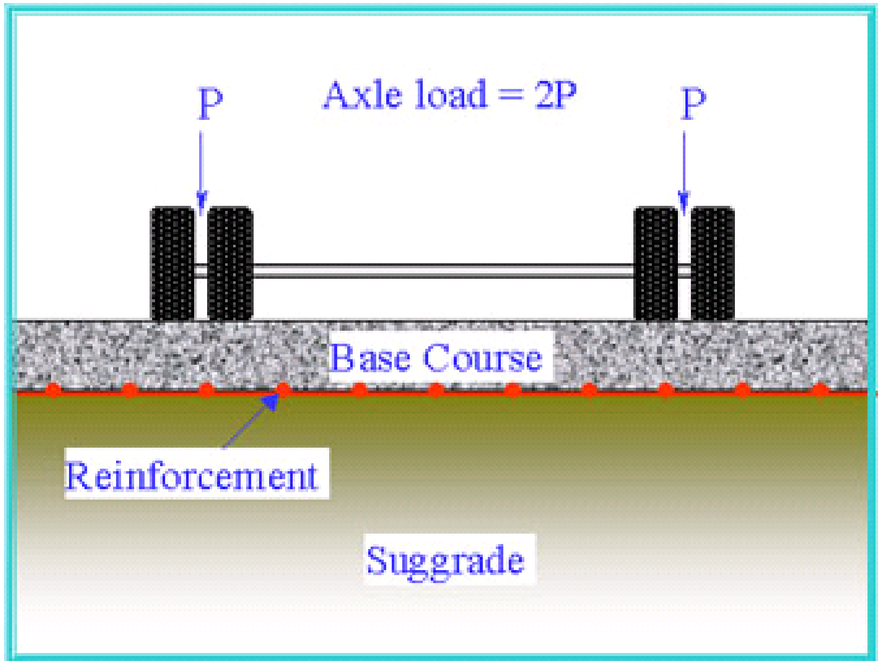
Subgrade improvement - increase bearing capacity of subgrade by placing a layer of geosynthetic reinforcement at the interface of subbase and subgrade

Base reinforcement - confine base course material to minimize its lateral movement under load; geosynthetic reinforcement can be placed within the base course or at the interface of base course and subbase/subgrade

Geosynthetic-Reinforced Unpaved and Paved Roads

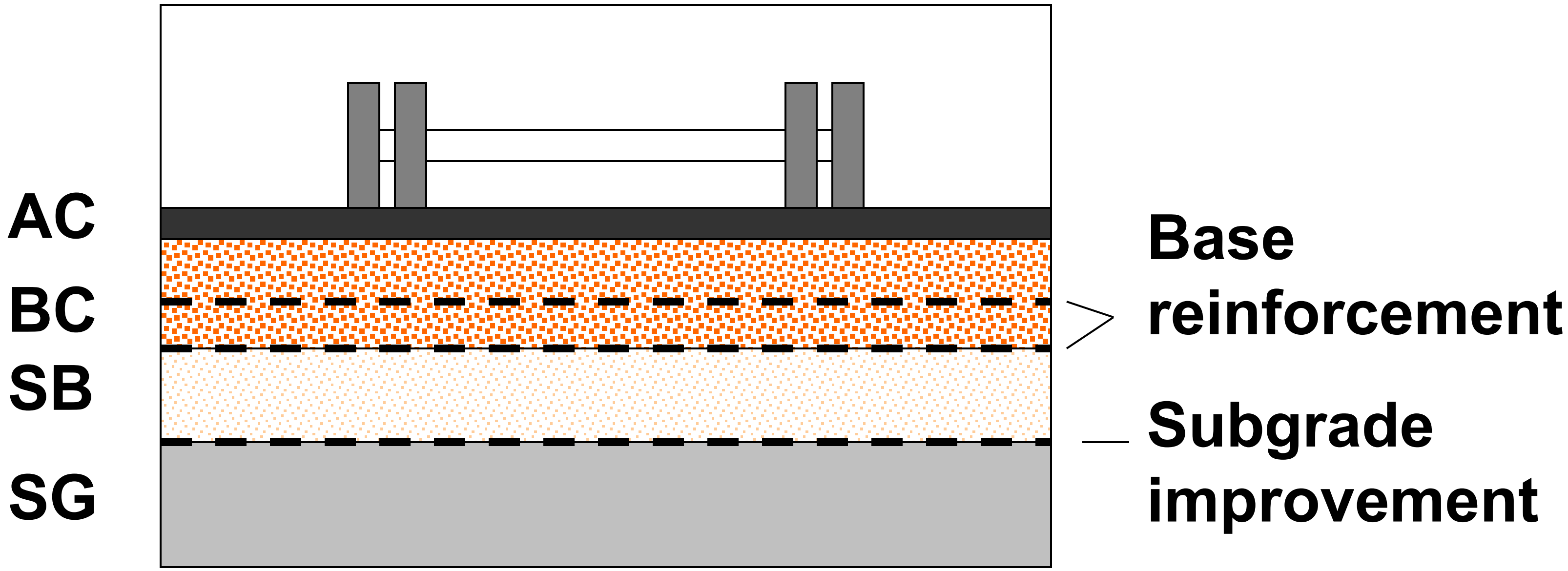


Subgrade Improvement



- Restrain lateral movement of base
- Reduce vertical stress on subgrade
- Increase bearing capacity of subgrade

Base Reinforcement



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

Design of Planar Geosynthetics for Unpaved Roads

Use of Geosynthetics for Different Subgrade CBR Values

Function	CBR value		Geosynthetic product
	Unsoaked	Soaked	
Separation	≥ 8	≥ 3	NWV fabric
Reinforcement	8 - 3	3 - 1	Geogrid/WV fabric
Reinforcement & separation	≤ 3	≤ 1	Geogrid+NWV fabric /WV fabric

Reinforcement Benefits

Benefit	Subgrade condition		
	Low CBR < 3	Moderate $3 \le CBR \le 8$	Firmer CBR > 8
Reducing undercut	●	☾	○
Reducing aggregate thickness required to stabilize subgrade	●	☾	○
Reducing disturbance of subgrade during construction	●	☾	○
Reducing section by reinforcing subbase aggregate	●	☾	○
Reducing section by reinforcing base aggregate	☾	●	☾
Increasing design life by reinforcing subbase aggregate	☾	☾	☾
Increasing design life by reinforcing base aggregate	●	●	☾

● usually a benefit ☾ A known benefit in certain conditions

○ usually not a benefit

Required Thickness for Unreinforced Unpaved Roads

U.S. Army Corps Method

$$h = (3.24 \log N + 2.21)\,(P/(36.0\ CBR)-A/2030)^{1/2}$$

h = base thickness (mm)

N = traffic in terms of passes

P = equivalent single wheel load (N)

A = tire contact area (mm)

Rut depth = 75mm

Required Thickness for Unreinforced Unpaved Roads

Giroud & Noiray Method

$$h = 0.19 \log N / (CBR)^{0.63}$$

h = base thickness (m)

N = traffic in terms of passes

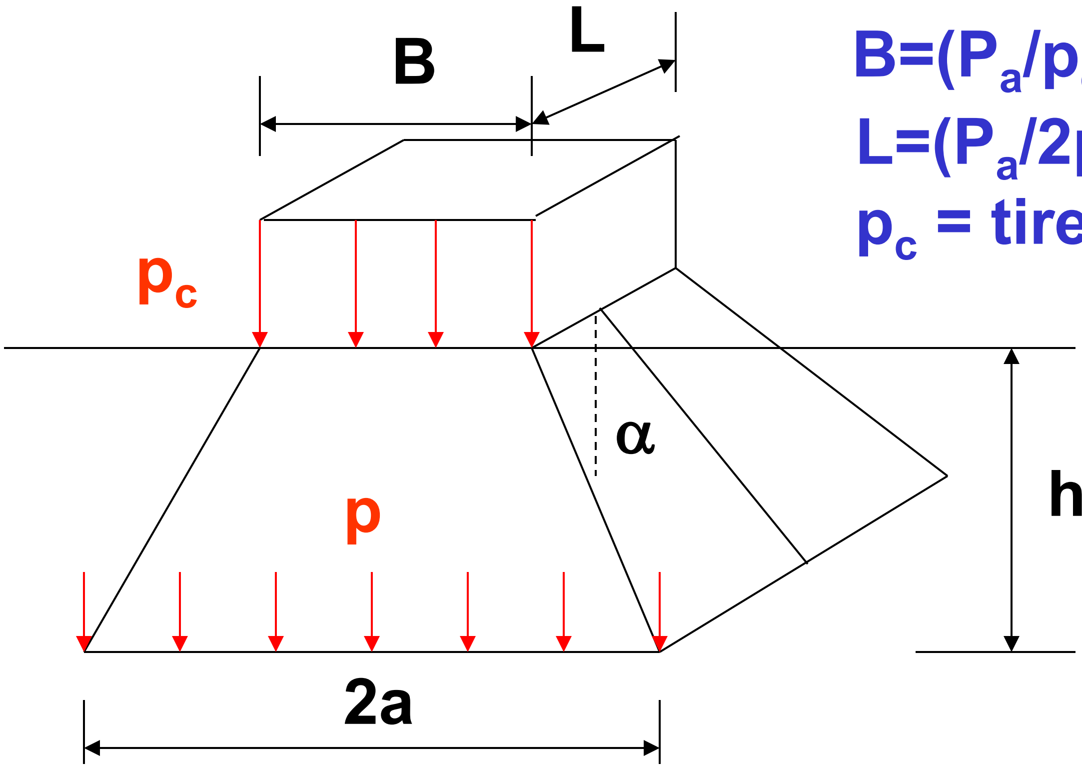
Rut depth = 75mm.

Other factors

$N' = N (P_a/P_s)^{3.95}$ P_a = axle load P_s = 80kN (18kips)

$\log N' = \log N - 2.34 (s - 75mm)$ s = rut depth

Stress Distribution



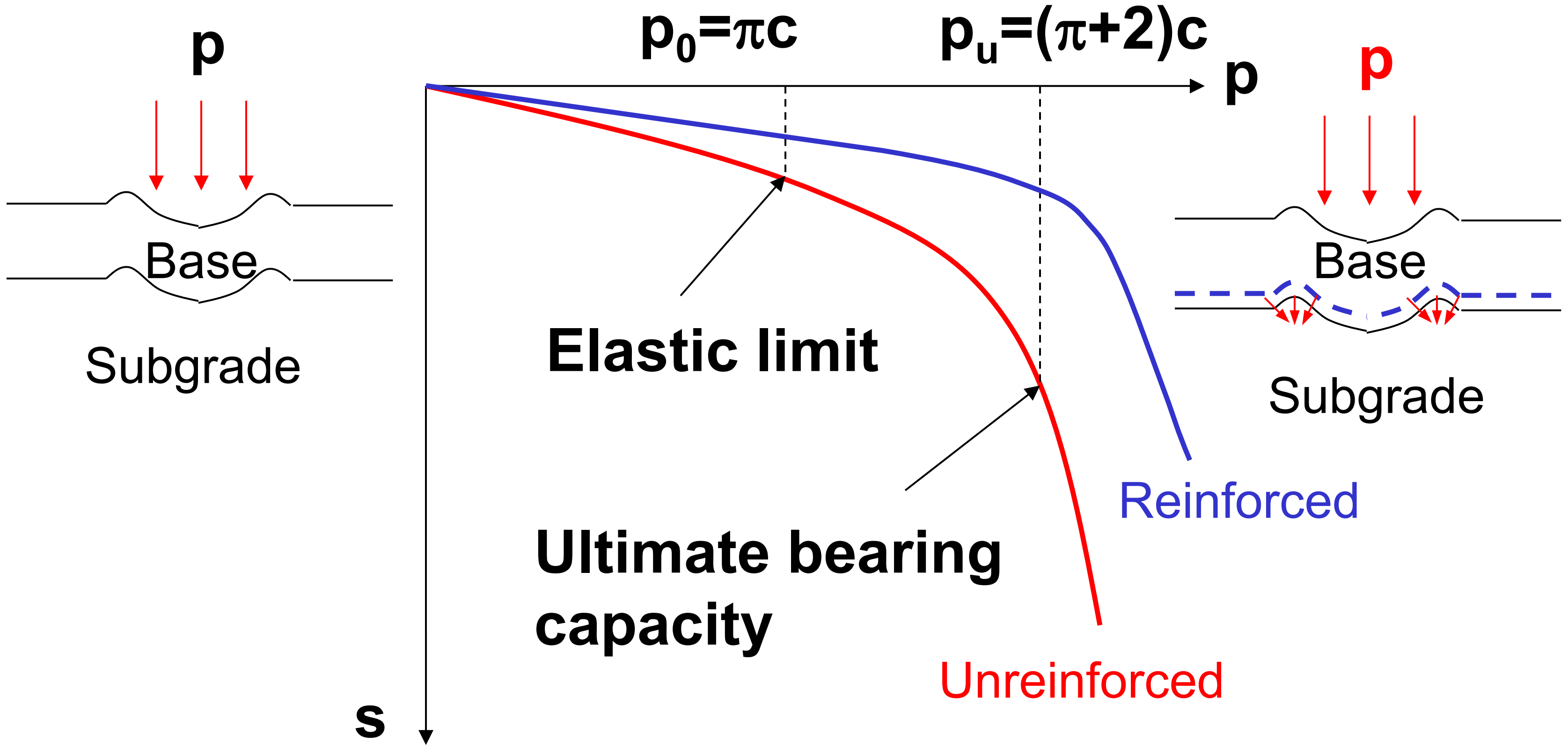
$B=(P_a/p_c)^{1/2}$

$L=(P_a/2p_c)^{1/2}$

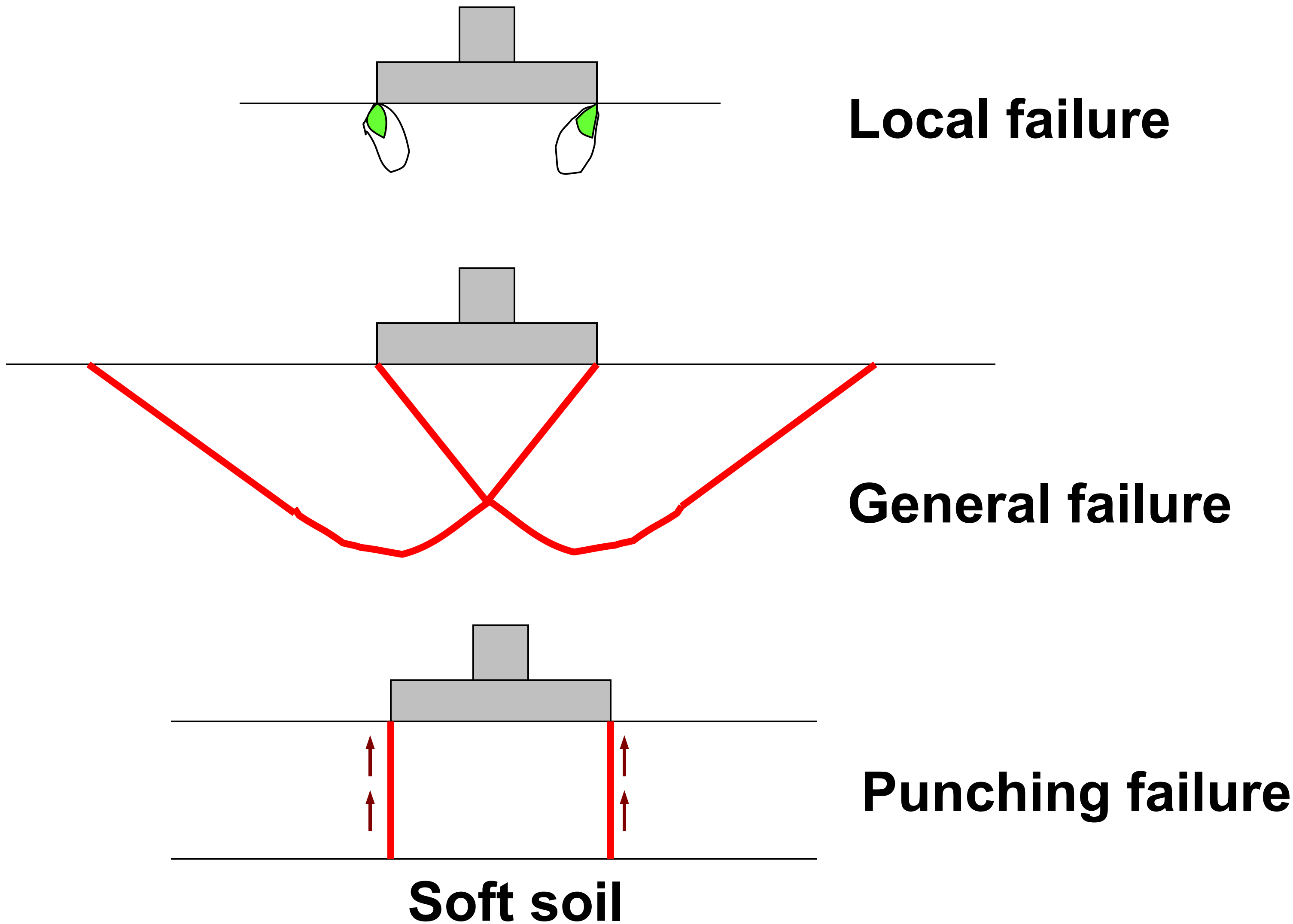
p_c = tire pressure

$$p = \frac{P_a}{2(B + 2h \tan\alpha)(L + 2h \tan\alpha)} + \gamma h$$

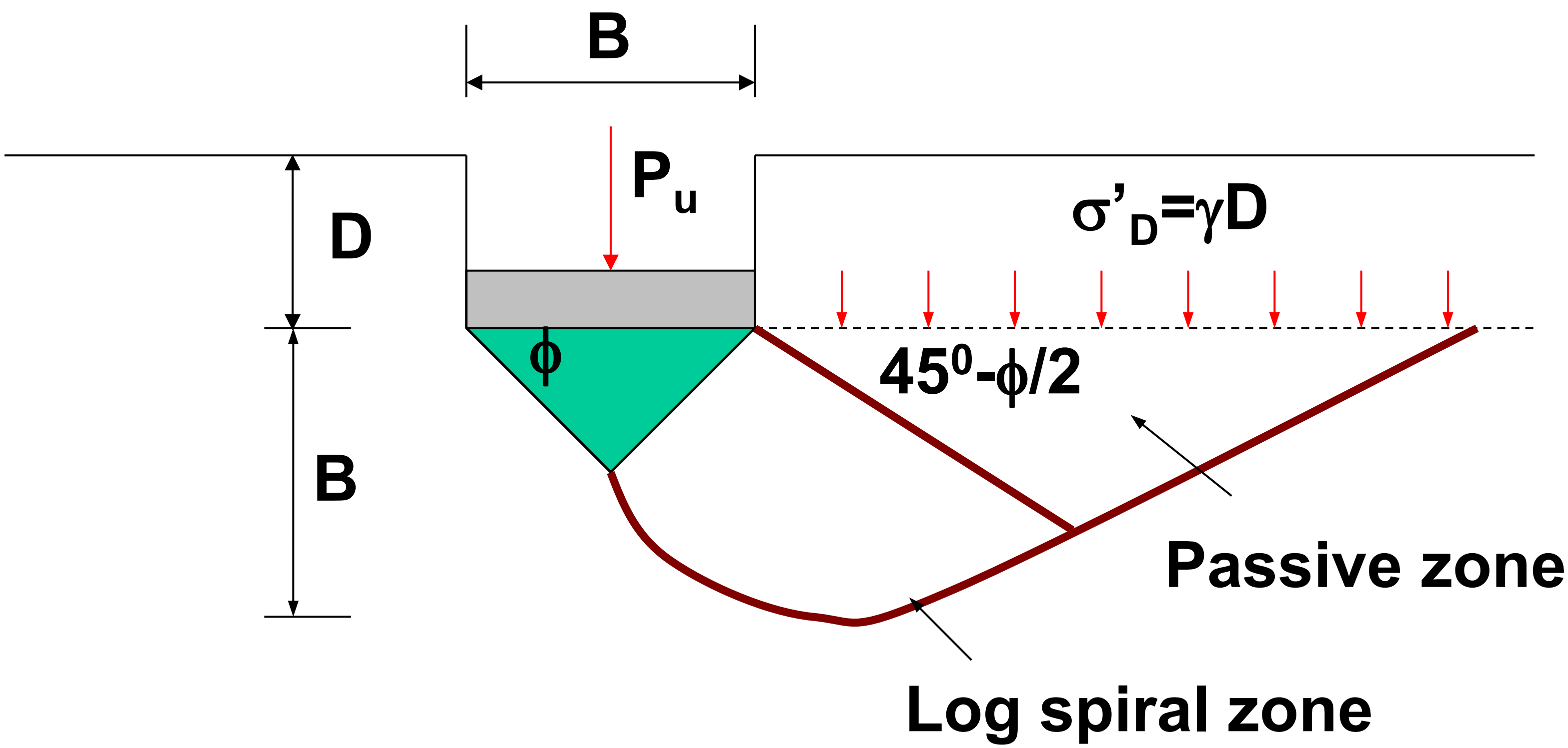
Bearing Capacities for Unreinforced and Reinforced Cases



Possible Foundation Failure Modes



Terzaghi Bearing Capacity Formula



Ultimate bearing capacity of a strip footing

$$q_{ult} = cN_c + \sigma'_D N_q + 0.5\gamma' BN_\gamma$$

Applied Pressure vs. Bearing Capacity for Unreinforced Case

$$p_0 = \pi c_u + \gamma h$$

$$\frac{P_a}{2(B + 2h_0 \tan\alpha)(L + 2h_0 \tan\alpha)} = \pi c_u$$

$$\tan\alpha = 0.6$$

Solve for h_0

Applied Pressure vs. Bearing Capacity for Reinforced Case

$$p_r - p_g = (\pi+2)c_u + \gamma h$$

$$\frac{P_a}{2(B + 2h_r \tan\alpha)(L + 2h_r \tan\alpha)} - \frac{E_g \varepsilon_g}{a(1+(a/2s)^2)^{1/2}} = (\pi+2)c_u$$

$\tan\alpha = 0.6$ $\quad$ s = rut depth

Under low rut depth (< 4in.), the effect $E_g\varepsilon_g$ is minimal

Solve for h_r

Required Subbase Thickness for Reinforced Case

Base thickness reduction

$$\Delta h = h_0 - h_r$$

Required base thickness

$$h' = h - \Delta h$$

h = base thickness of unreinforced case, calculated from U.S. Army Corps

Giroud and Noiray Method

Step 1: Determine the required base thickness for an unreinforced case under traffic in terms of passes using U.S. Army Corps Method (h)

Step 2: Determine the required base thickness for the unreinforced and reinforced case under a static load (h_0 and h_r)

Step 3: Determine the reduction of base thickness ($\Delta h = h_0 - h_r$)

Step 4: Determine the required base thickness for the reinforced case ($h' = h - \Delta h$)

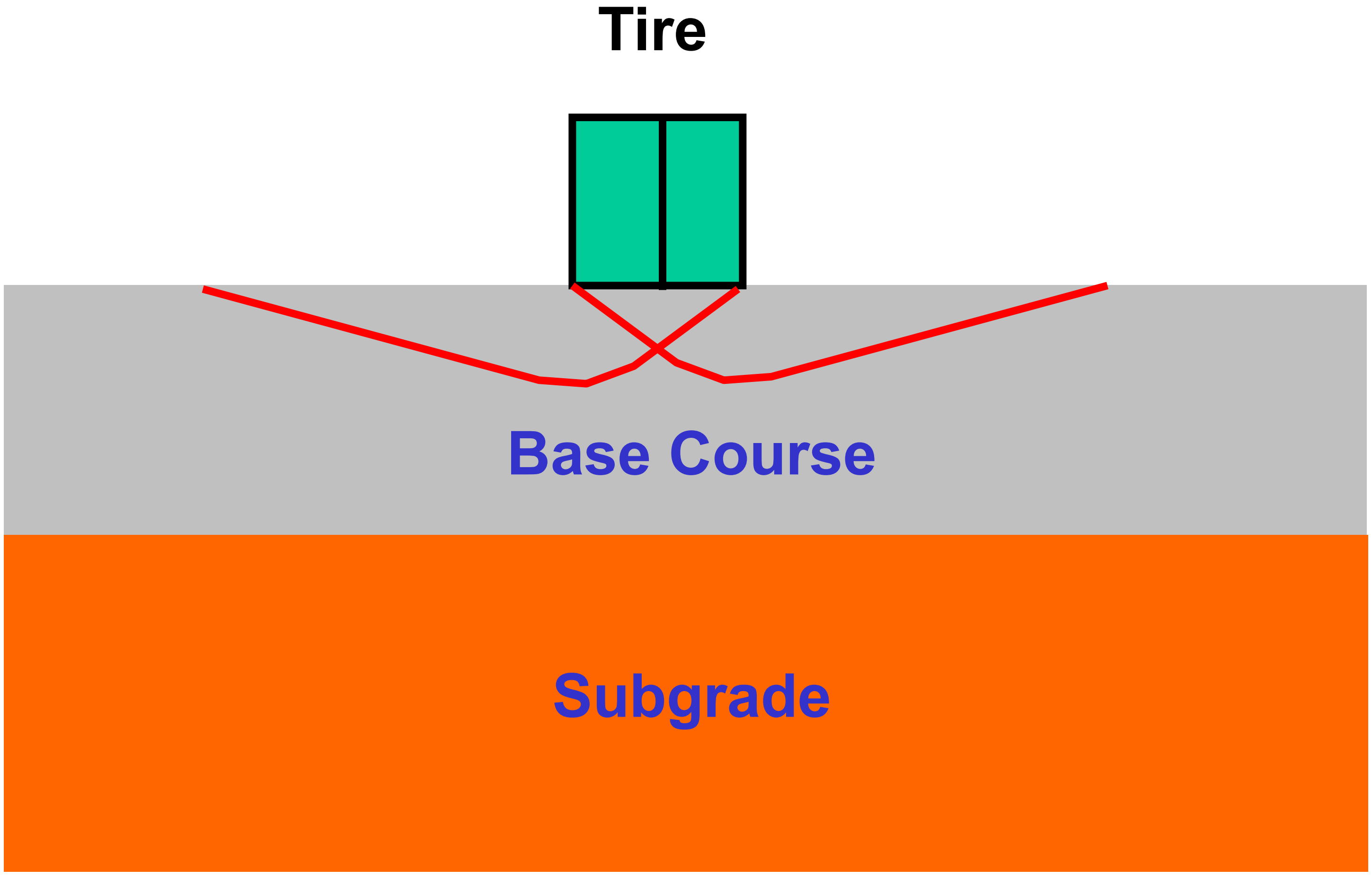
Limitations of Giroud and Noiray Method

- No consideration of base quality
- Fixed stress distribution angle
- Base thickness reduction based on static loading rather than cyclic loading
- No difference among all geosynthetic materials
- Influence of rut depth based on the empirical relationship for paved roads
- Not well verified

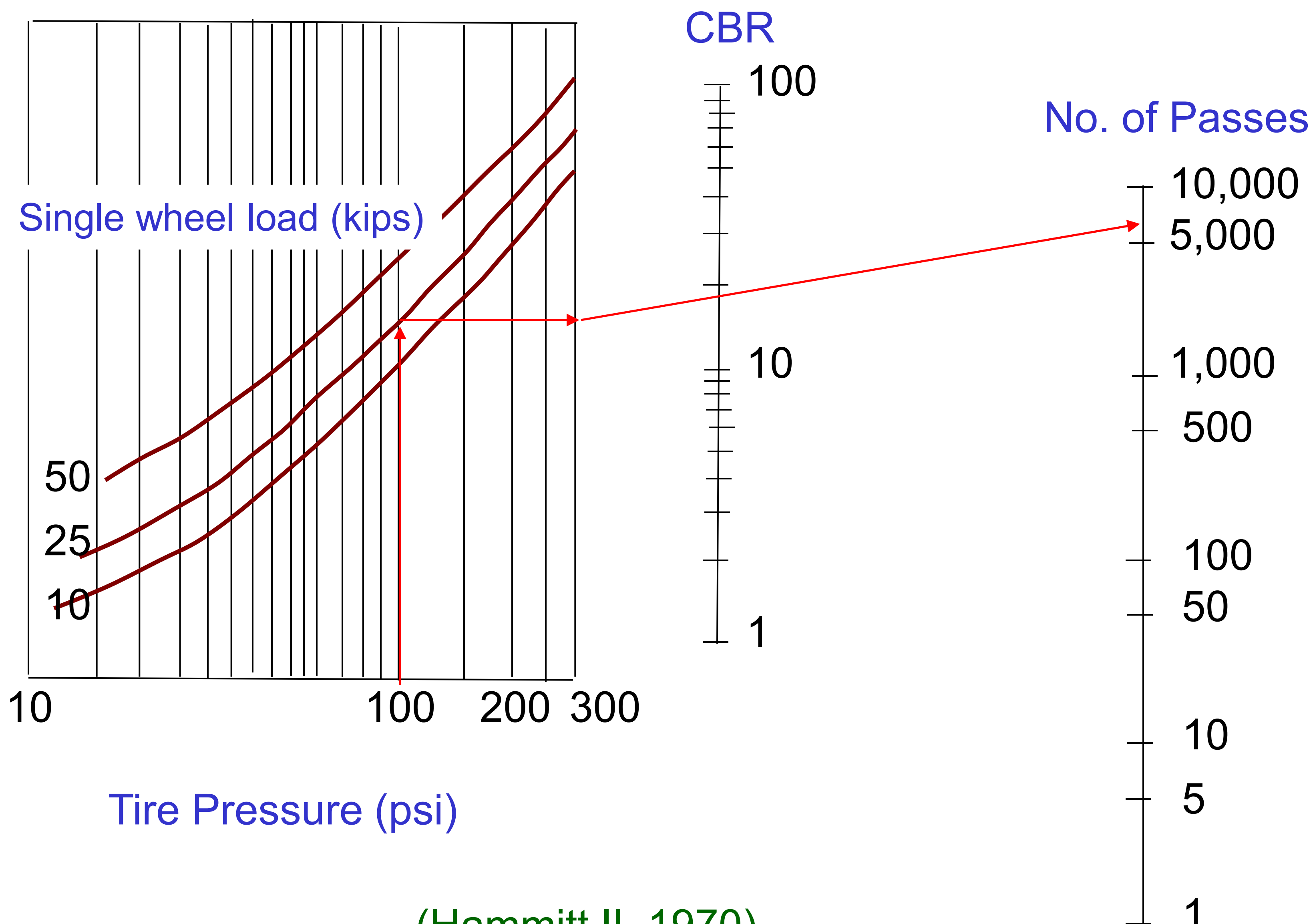
The Improved Method (Giroud and Han, 2004)

- Consideration of base quality
- Stress distribution angle varying with traffic passes
- Base thickness reduction based on cyclic loading
- Differentiation among all geosynthetic materials
- Influence of rut depth based on the stress-strain relationship
- Calibrated and verified by field data

Failure of Base Course

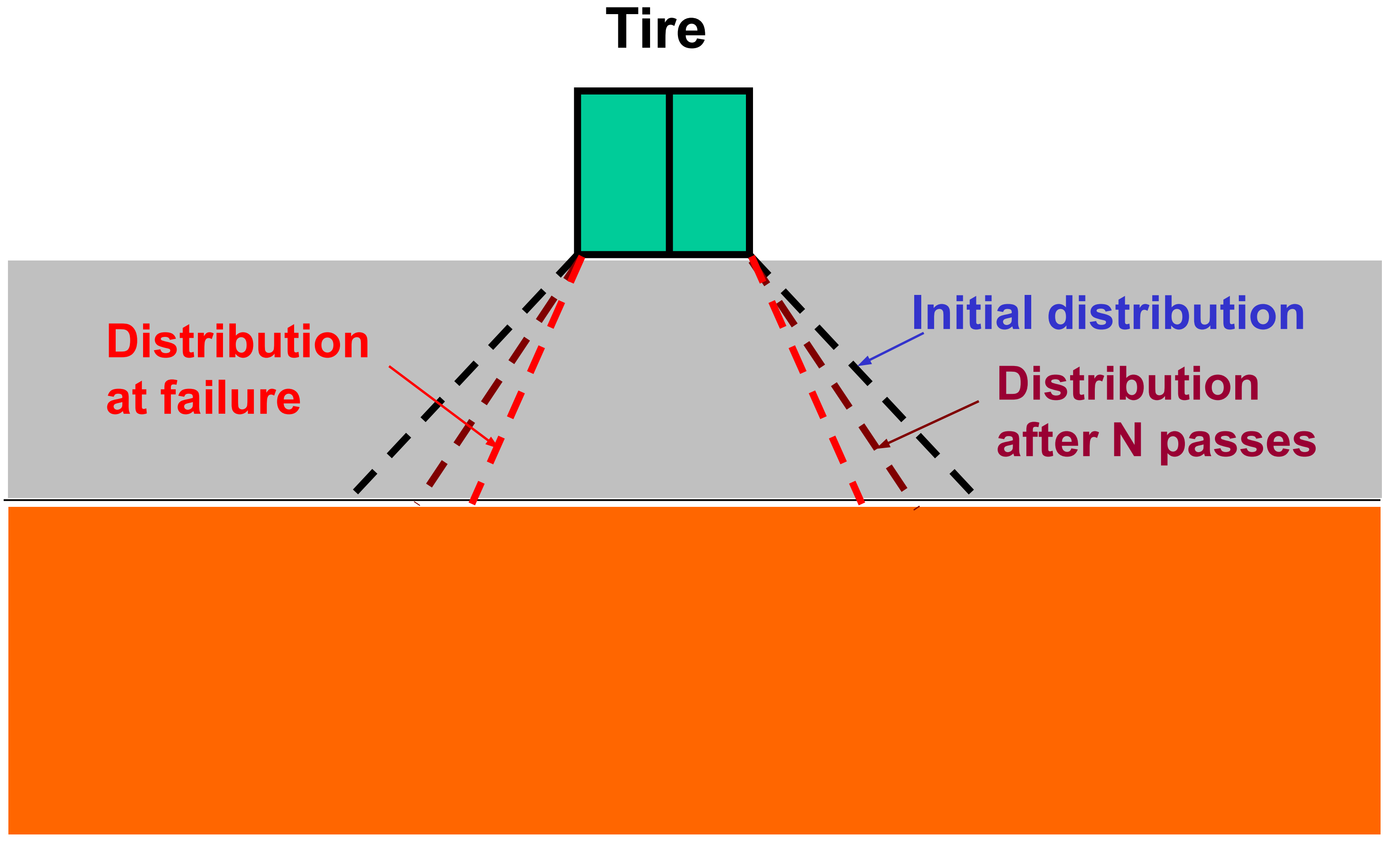


CBR Required for Traffic on Base Course

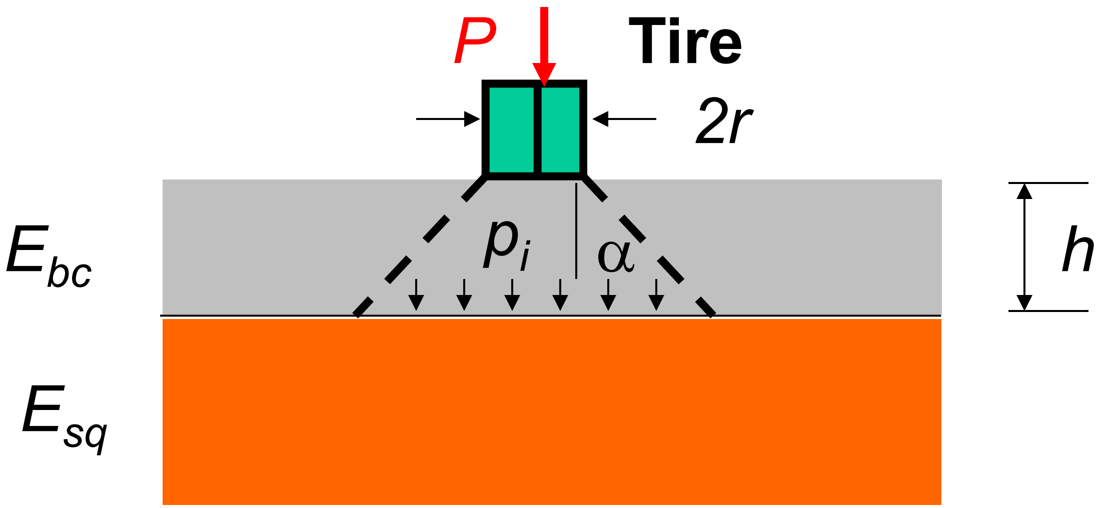


(Hammitt II, 1970)

Failure of Subgrade



Stresses on Subgrade Soil



$$r = \sqrt{\frac{P}{\pi p}}$$

$$p_i = \frac{P}{\pi (r + h \tan \alpha)^2} \quad \Rightarrow \quad h = \frac{r}{\tan \alpha}\left(\sqrt{\frac{P}{\pi r^2 p_i}} - 1\right)$$

$$p_i \leq m \; N_c \, c_u$$

m = bearing capacity mobilization factor

Bearing Capacity Factor

Unreinforced unpaved roads

$N_c = 3.14$ Elastic limit

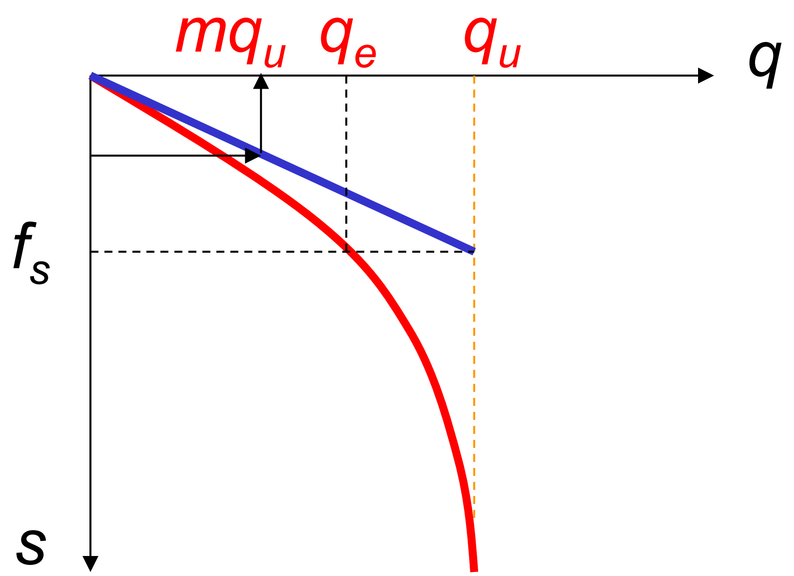
Geotextile reinforced unpaved roads

$N_c = 5.14$ Ultimate bearing capacity with smooth geotextile-subgarde interface

Geogrid reinforced unpaved roads

$N_c = 5.71$ Ultimate bearing capacity with rough geogrid-subgarde interface

Bearing Capacity Mobilization Factor



$$m = \left(\frac{s}{f_S}\right)\left[1 - \xi \exp\left(-\omega\left(\frac{r}{h}\right)^n\right)\right]$$

f_s = surface rut depth of 75mm, serviceability failure

s = surface rut depth

Stress Distribution Angle

Influence of number of cycles

$$\frac{1}{\tan\alpha} = \frac{1 + k \log N}{\tan\alpha_1} = \frac{1}{\tan\alpha_1} + \lambda \log N$$ from Gabr (2001)

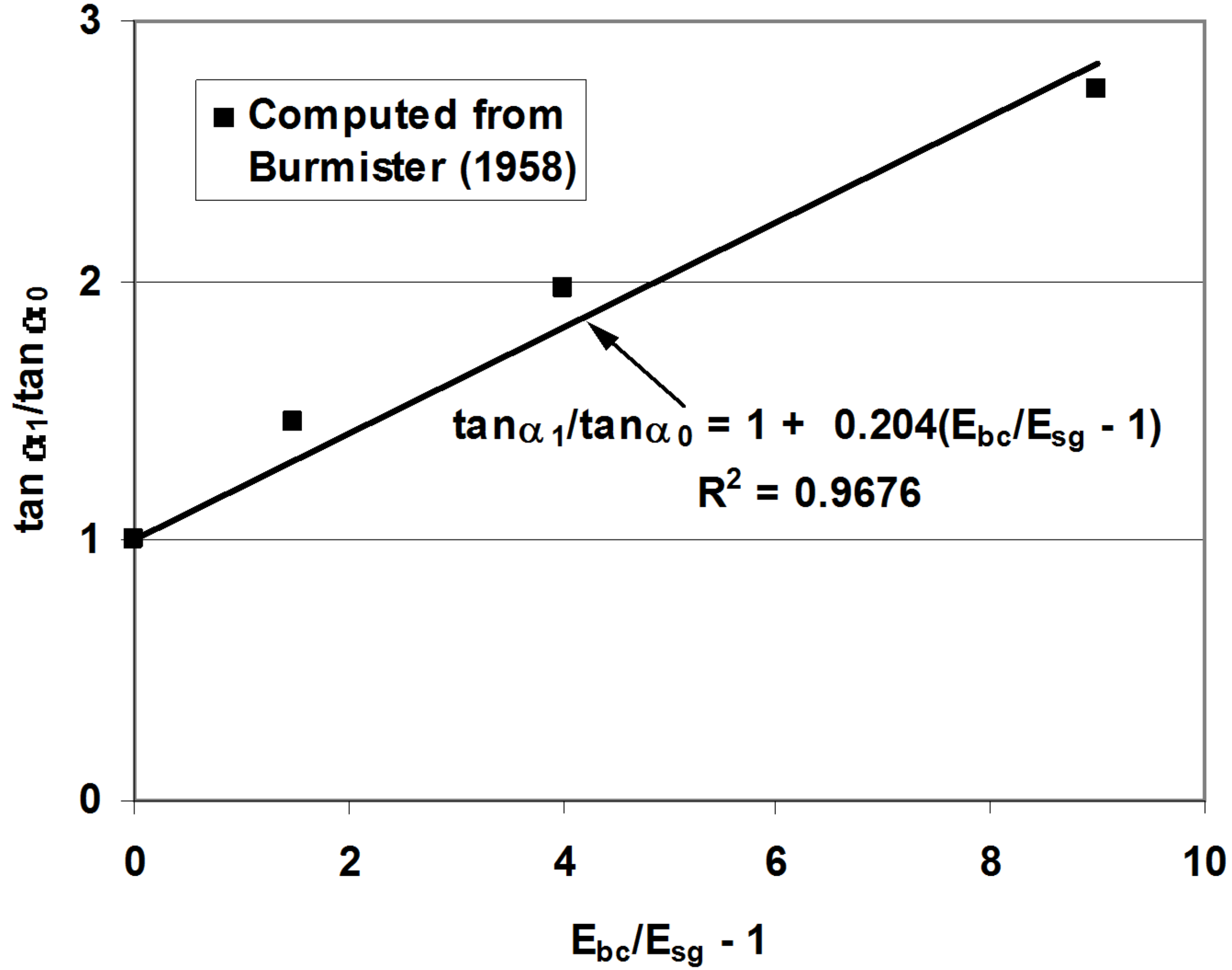
α_1 = initial distribution angle for the case where the number of pass is one

Initial distribution angle

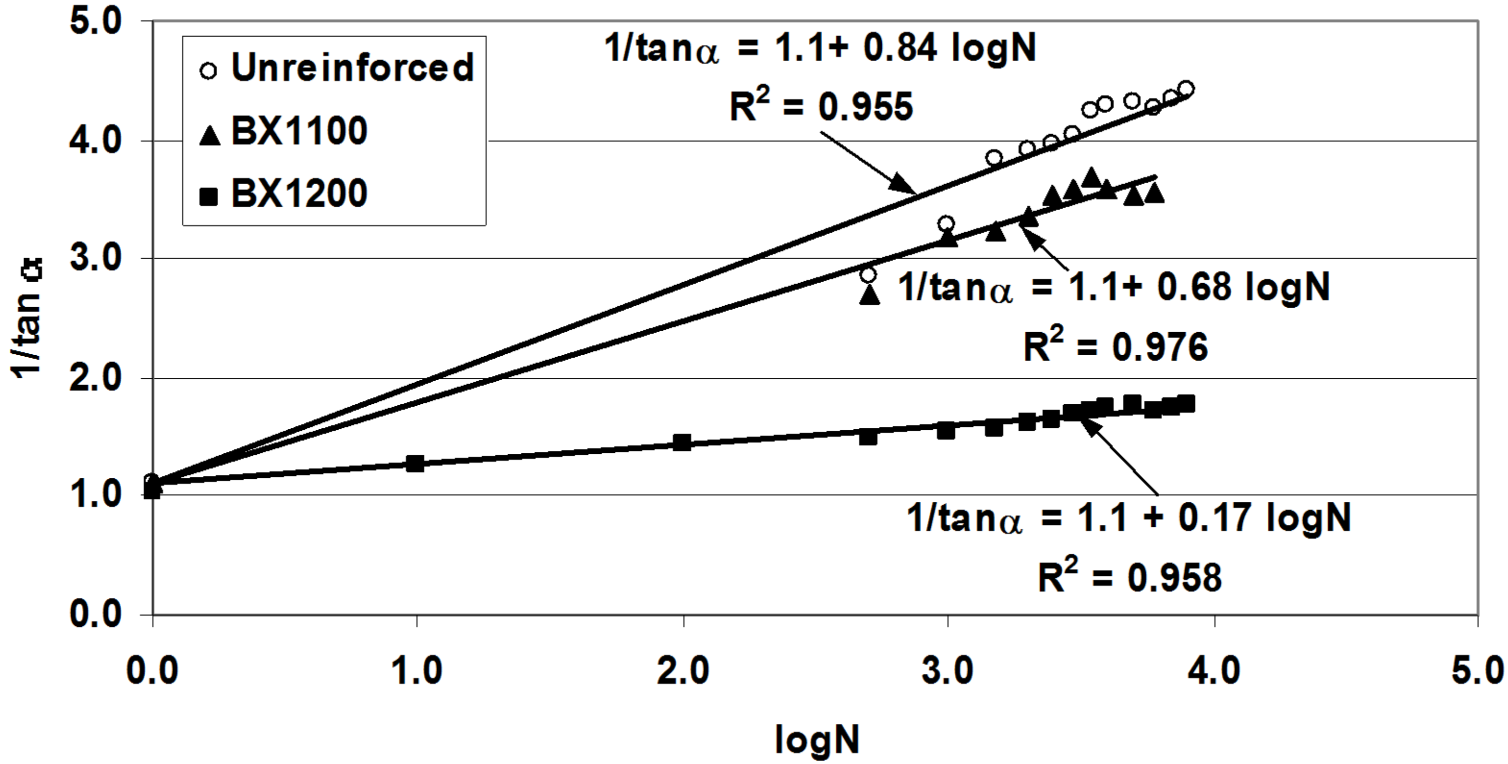
$$\tan\alpha_1 = \tan\alpha_0 \left[1 + 0.204 \left(\frac{E_{bc}}{E_{sg}} - 1 \right) \right]$$

α_0 = distribution angle for a reference uniform medium

Distribution Angle Ratio

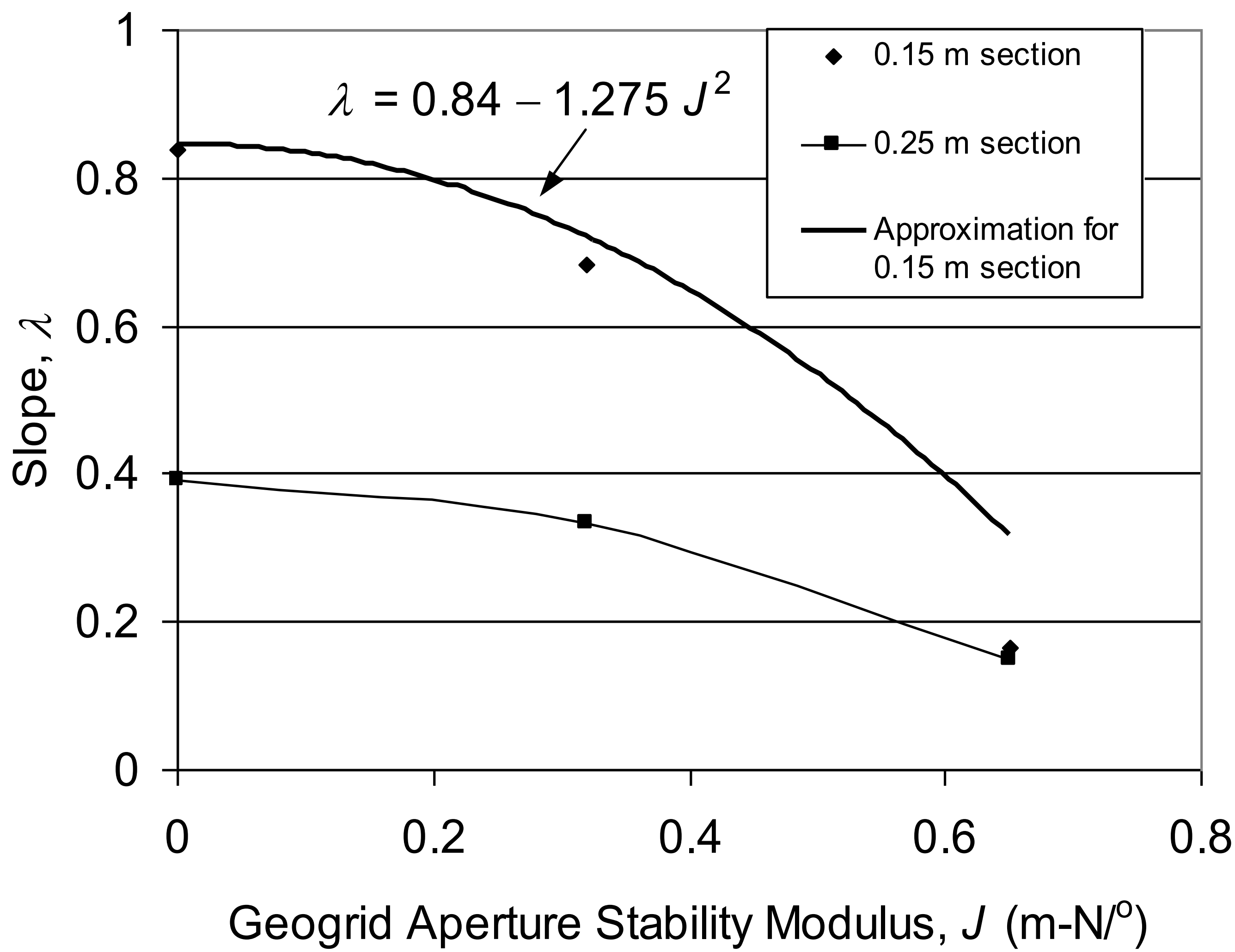


Distribution Angle vs. Number of Cycles



Cyclic Plate Loading Test

Determination of Slope λ



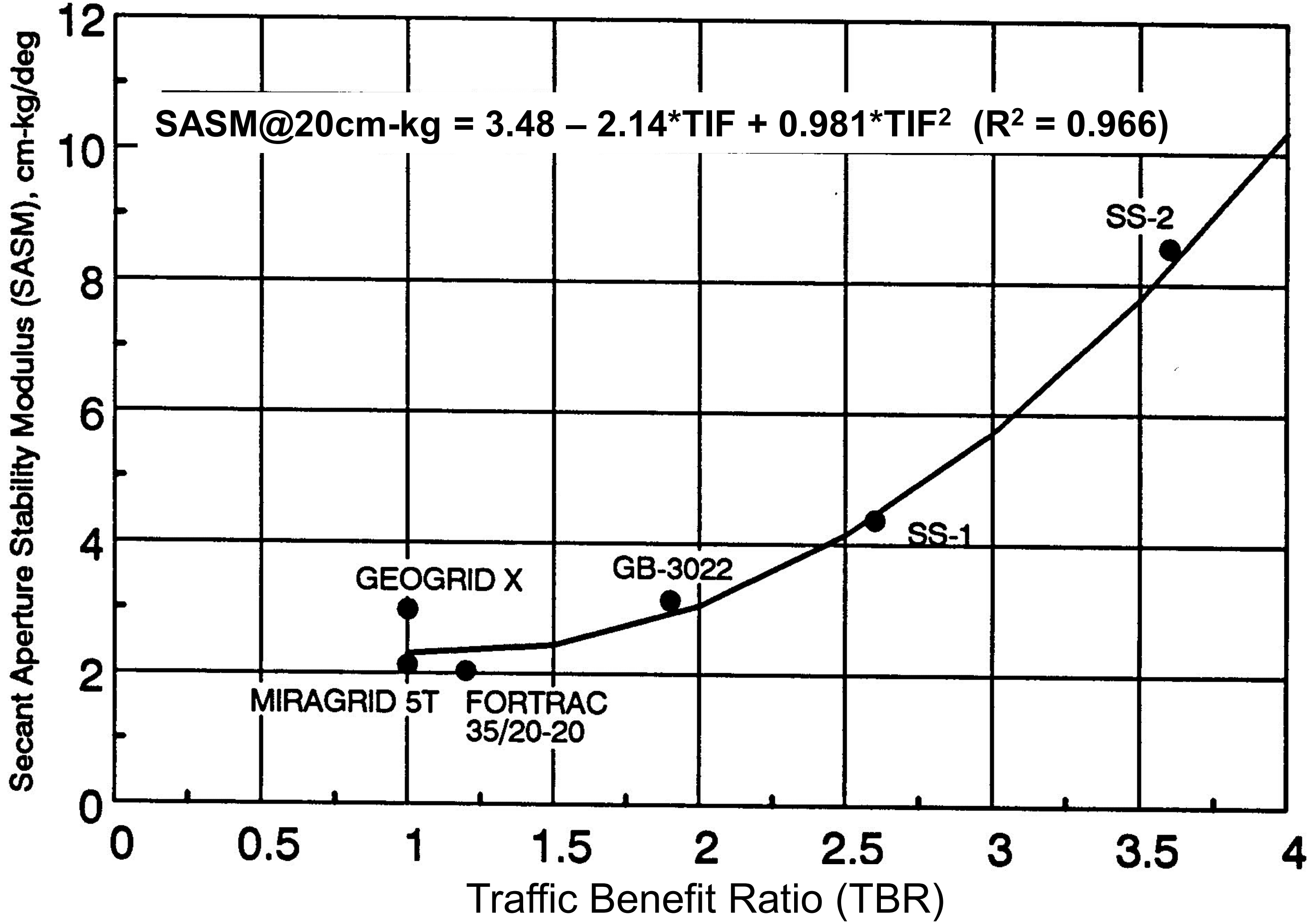
Aperture Stability Modulus Test

Tensar Geogrid Products

Geogrid aperture stability modulus

BX1100	0.32m-N/^{o}
BX1200	0.65m-N/^{o}

Why Was the Aperture Stability Modulus Selected?



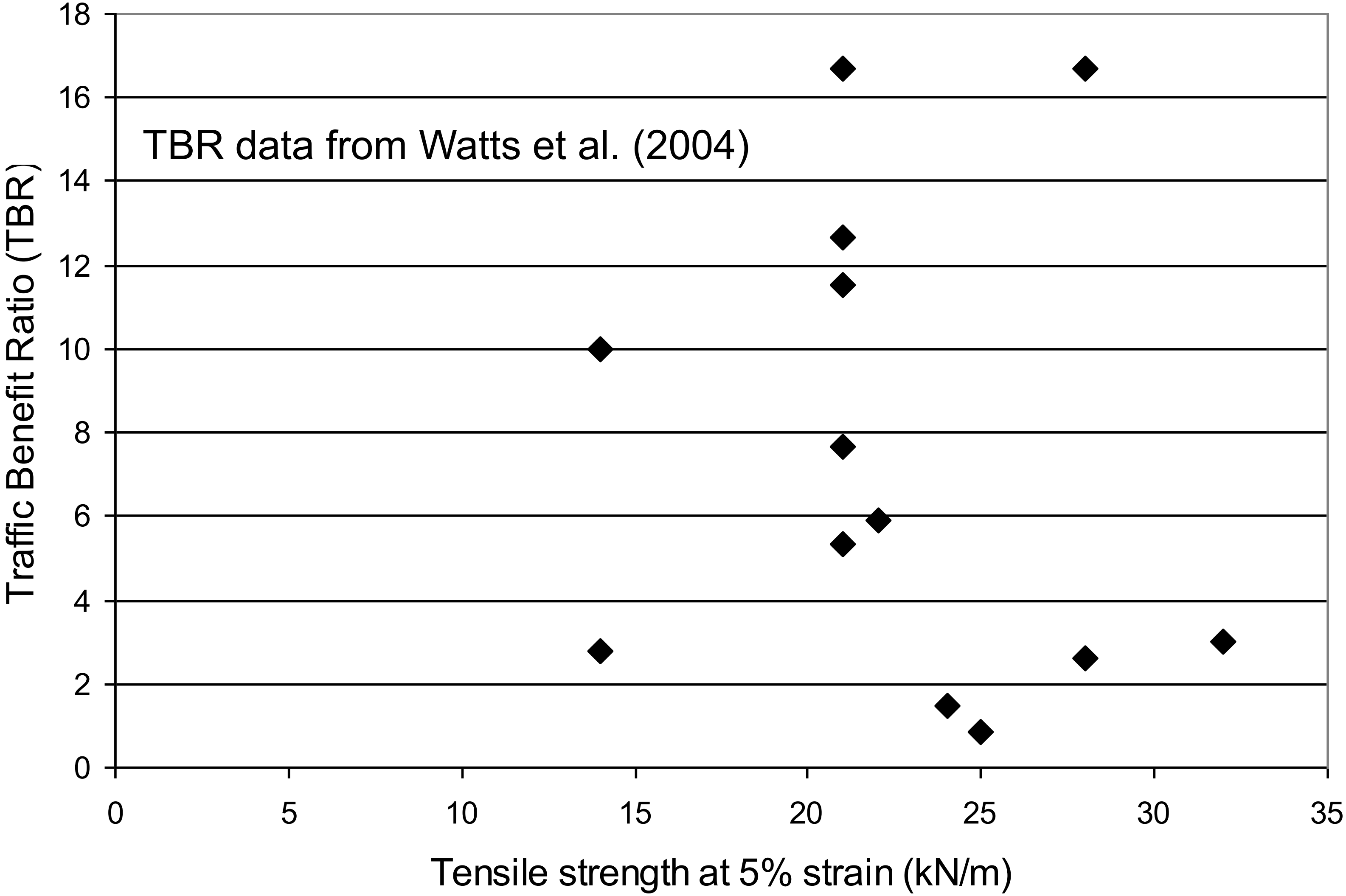
Webster (1992)

Traffic Benefit Ratio

- Traffic benefit ratio (TBR) is defined as the ratio of the number of cycles to reach *a certain rut depth* when reinforced to the number of cycles to reach the same rutting depth when unreinforced.

$$TBR = \frac{N_{reinforced}}{N_{unreinforced}}$$

Why Not Use $T_{5\%}$?



Required Base Course Thickness

$$h = \frac{a + (b - dJ^2)\left(\frac{r}{h}\right)^{1.5} \log N}{1 + 0.204(R_E - 1)} \left[\sqrt{\frac{P}{\pi r^2 \left(\frac{s}{f_s}\right)\left[1 - \xi\left(-\omega\left(\frac{r}{h}\right)^n\right)\right] N_c c_u}} - 1 \right] r$$

a, b, d, ξ*,* ω*, and n factors* are calibrated using field data from Hammitt (1970) for unreinforced cases

$$h = \frac{0.868 + \left(0.661 - 1.006J^2\right)\left(\frac{r}{h}\right)^{1.5} \log N}{1 + 0.204\left[R_E - 1\right]} \left[\sqrt{\frac{\frac{P}{\pi r^2}}{\left(\frac{s}{f_S}\right)\left[1 - 0.9\exp\left(-\left(\frac{r}{h}\right)^2\right)\right] N_c\, f_C\, CBR_{sg}}} - 1 \right] r$$

Required Base Course Thickness

$$h = \frac{0.868 + (0.661 - 1.006J^2)\left(\frac{r}{h}\right)^{1.5} \log N}{f_E} \left[\sqrt{\frac{P}{\pi r^2 m N_c c_u}} - 1 \right] r$$

$$f_E = 1 + 0.204(R_E - 1)$$

$$m = \left(\frac{s}{f_s}\right)\left\{1 - 0.9\exp\left[-\left(\frac{r}{h}\right)^2\right]\right\}$$

Undrained Shear Strength of Subgrade

$$c_u = 30\ CBR_{sg} \qquad kPa$$

CBRsg = subgrade CBR

Modulus Ratio of Base Course to Subgrade

$$R_E = \frac{E_{bc}}{E_{sg}} = \frac{3.48 CBR_{bc}^{0.3}}{CBR_{sg}} \leq 5.0$$

CBR_{bc} = base course CBR

Need for Base Course

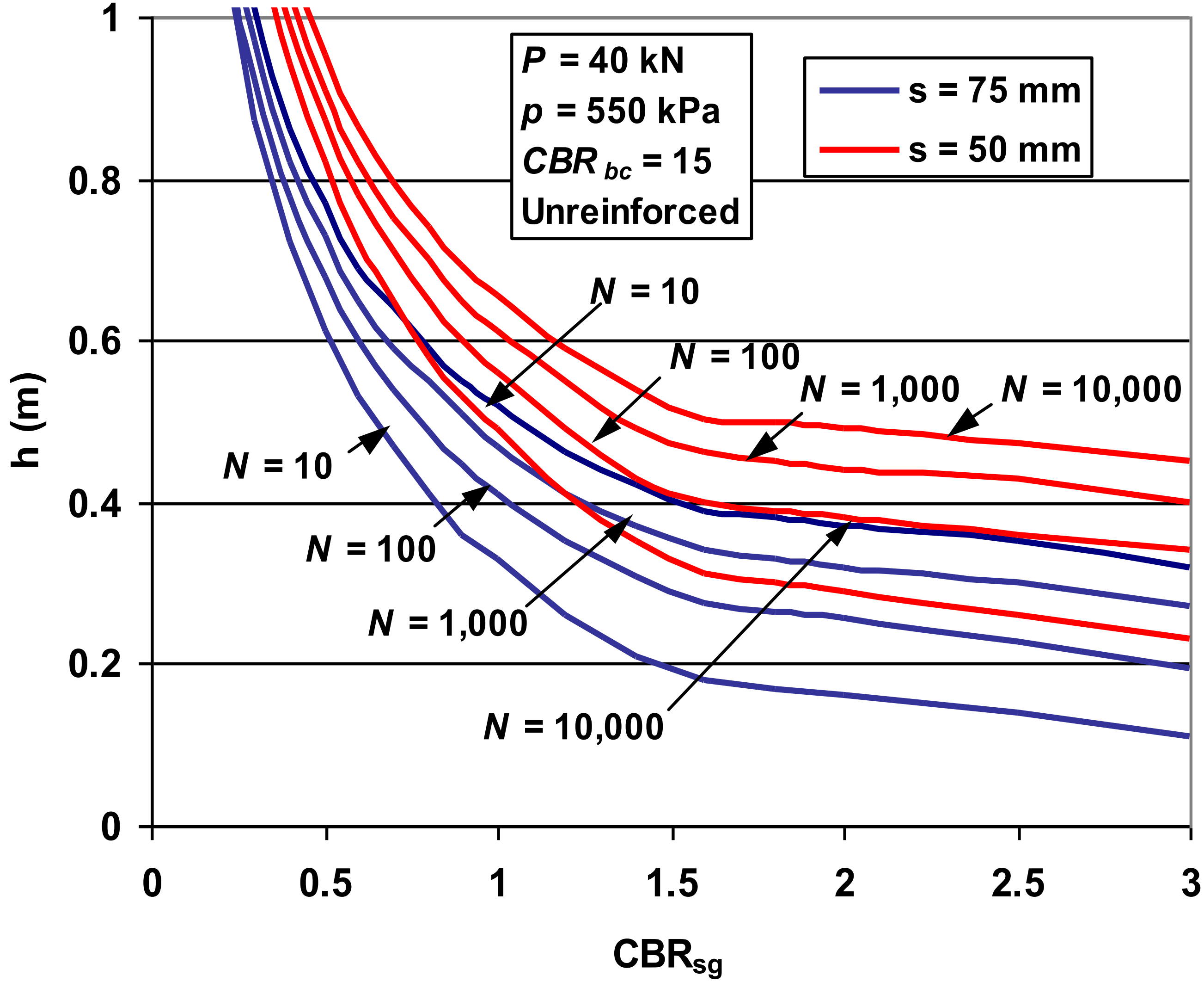
Bearing load without base course

$$P_{h=0} = \left(\frac{s}{f_s}\right)\pi r^2 N_c c_u$$

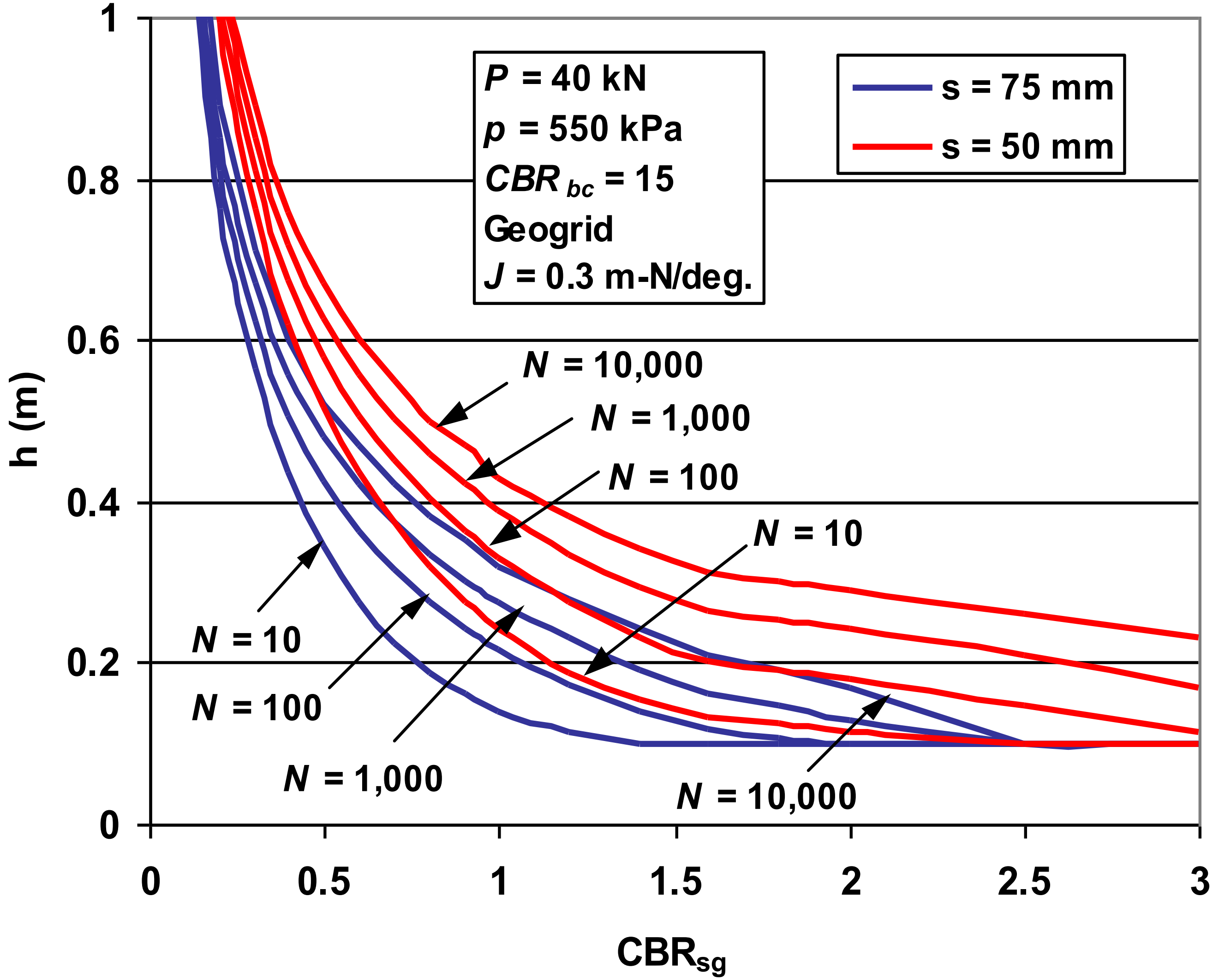
If $P > P_{h=0}$ and $N_c = 3.14$, base course is needed

Otherwise, minimal base thickness of 100mm is needed

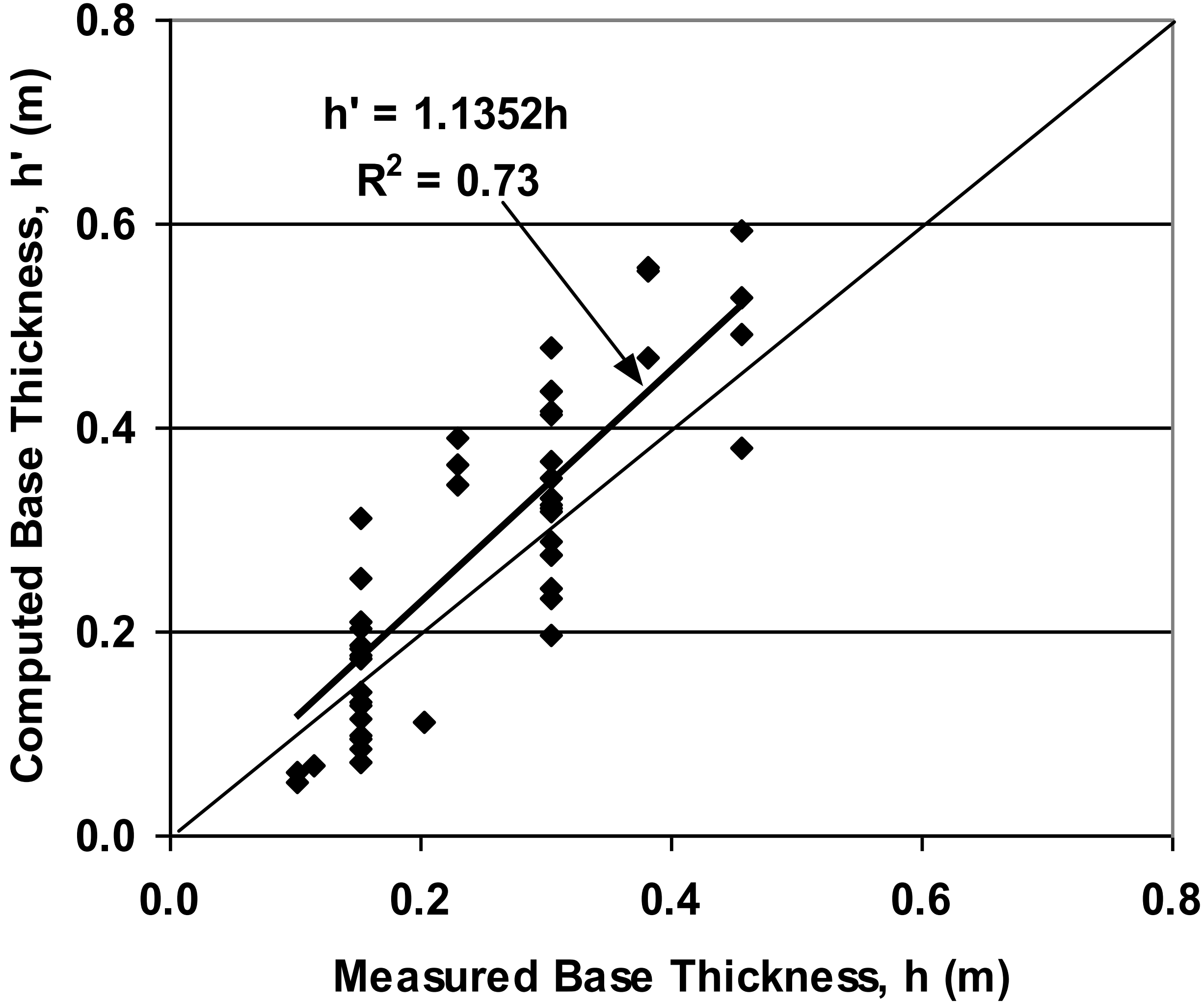
Base Thickness - Unreinforced



Base Thickness - Reinforced



Computed vs. Measured for Unreinforced Cases



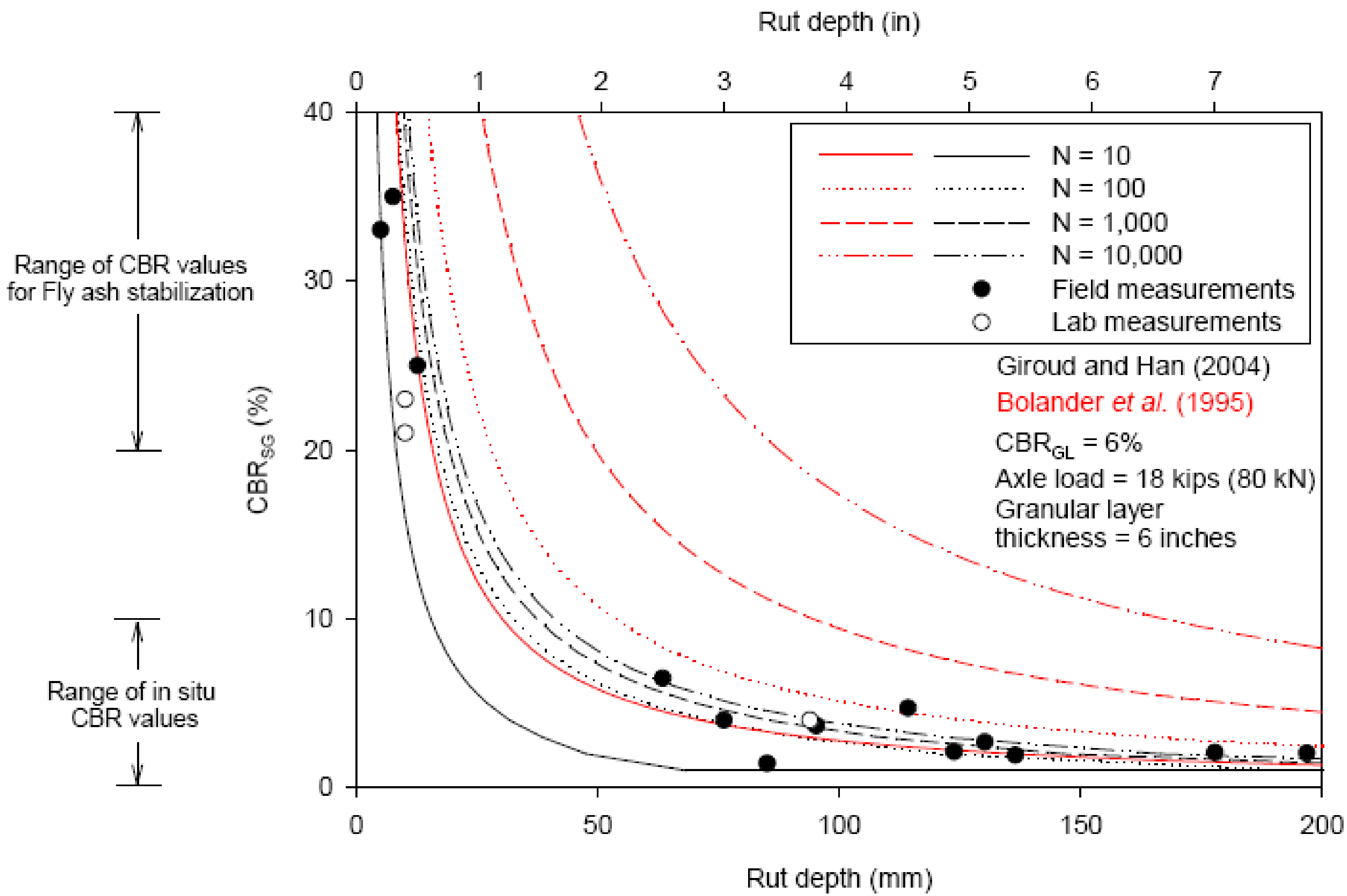
Comparison –
Tingle & Webster Study (2003)

Road section	*h (m)* Measured	*h (m)* Calculated This study
Unreinforced	0.51	0.59
Reinforced with nonwoven geotextile	0.38	0.43
Reinforced with woven geotextile	0.38	0.43
Reinforced with BX1200 geogrid on geotextile	0.25	0.25

Comparison – Knapton & Austin Study (1996)

Number of passes	Road section	Rut depth (mm)	
		Measured	Calculated
14,500	Unreinforced	98	>75
	Reinforced with geogrid BX1200	50	50
52,000	Unreinforced	104	>75
	Reinforced with geogrid BX1200	53	52

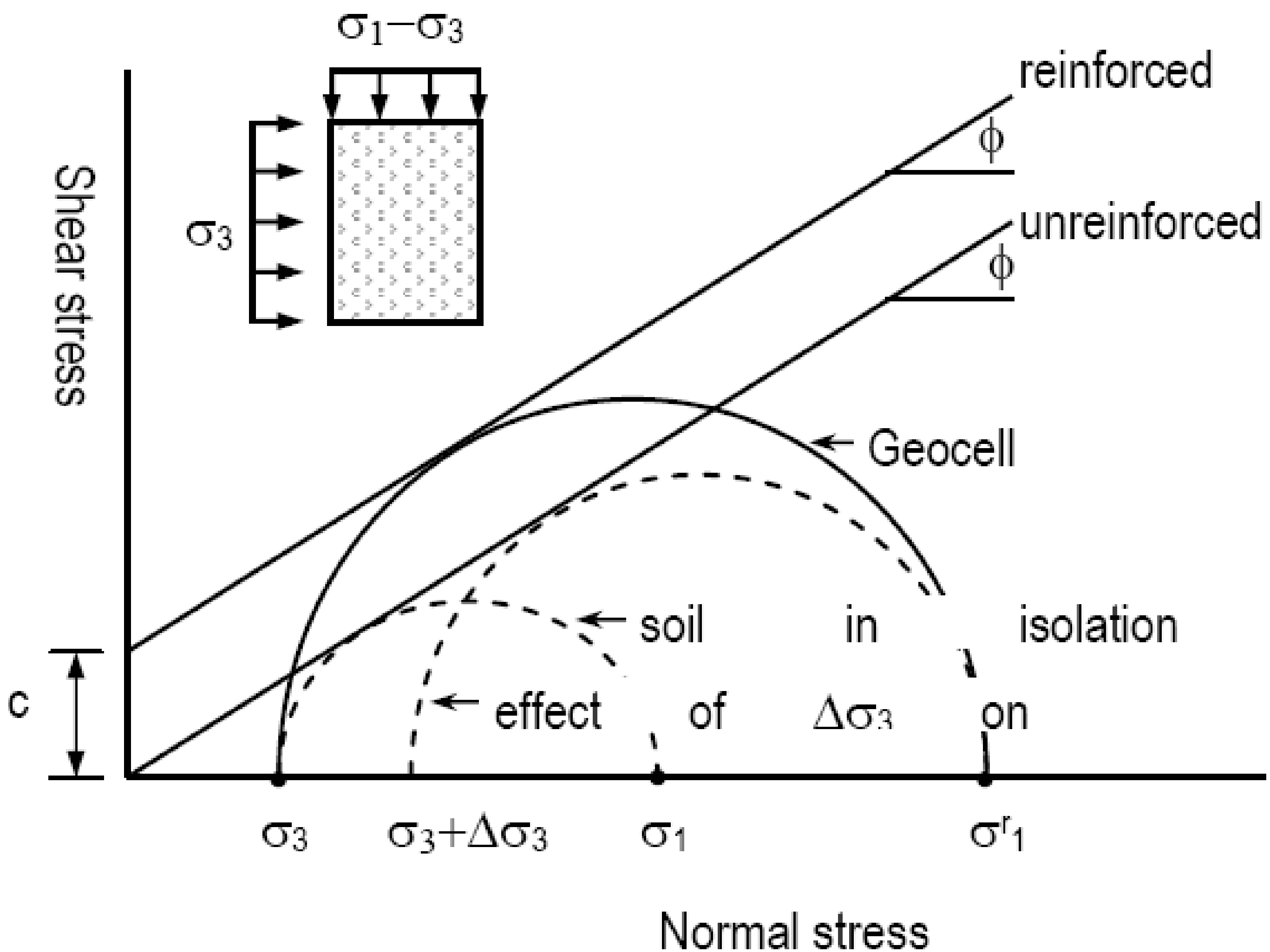
Rut Depth versus CBR of Subgrade



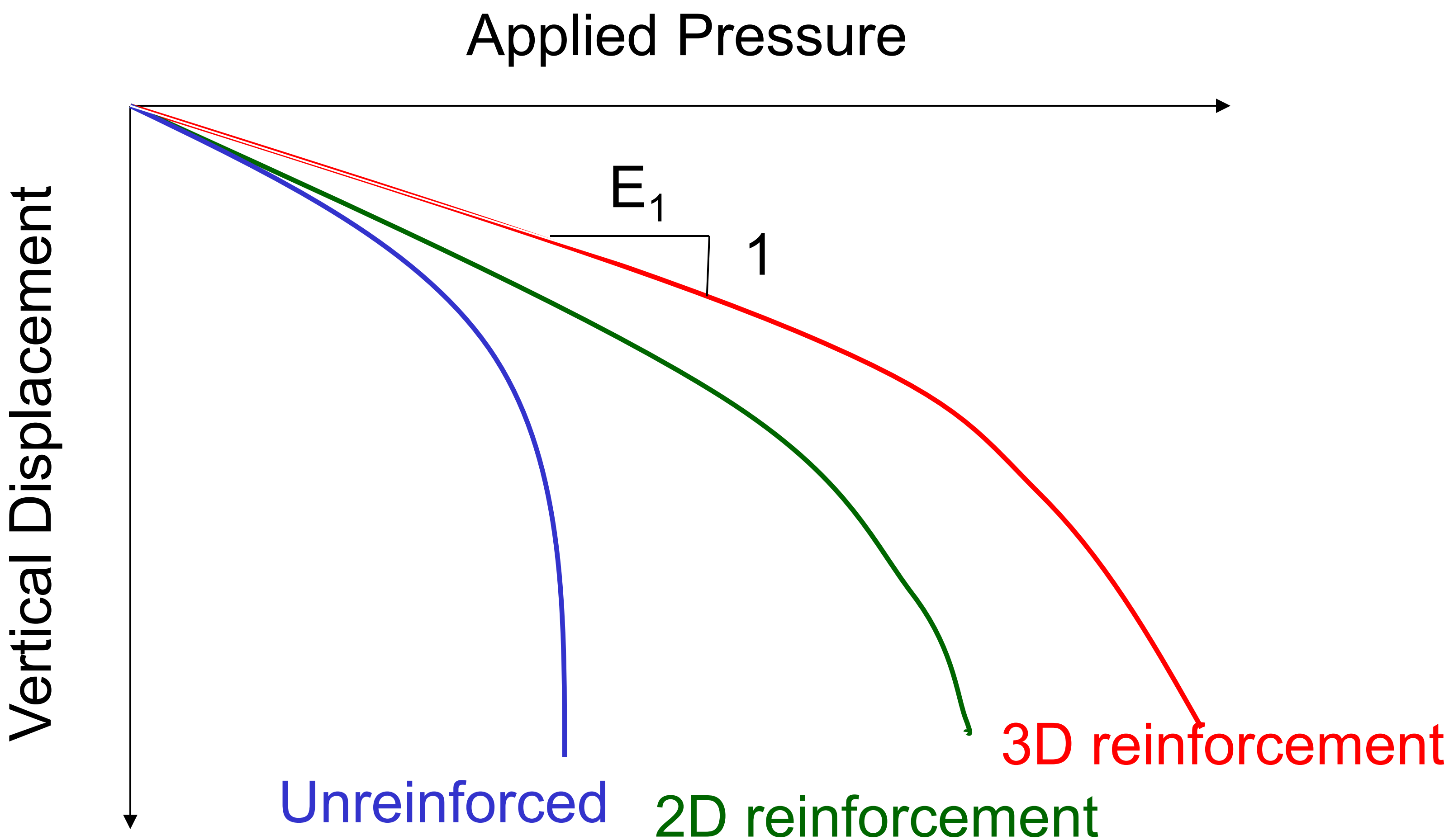
White et al. (2007)

Recent Research on 3D Geosynthetics for Unpaved Roads

Effect of Confinement - Strength



Effect of Confinement - Modulus



Original Research by US Army Corps of Engineers - 1979

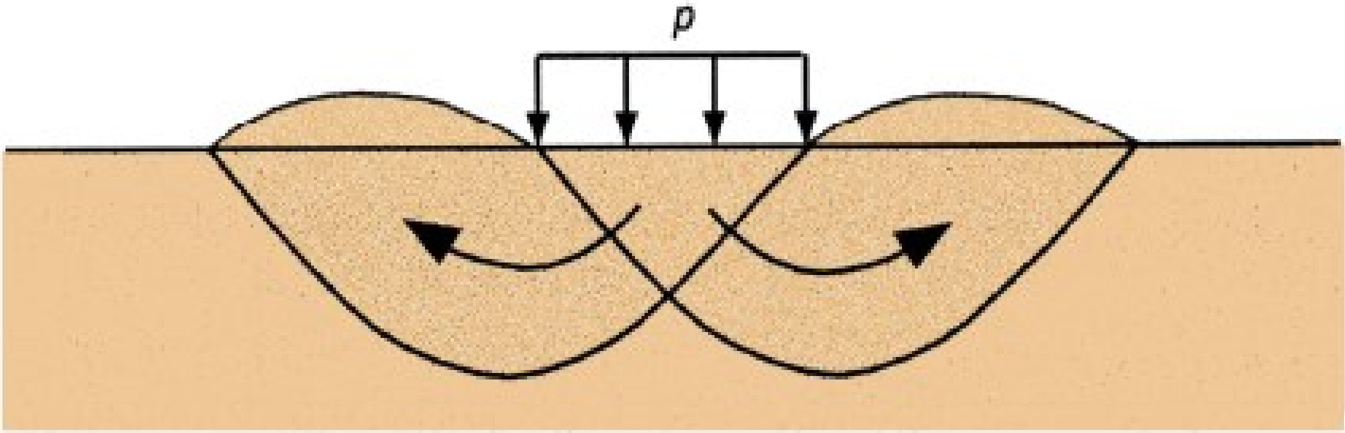
Beach Landing Tests - Virginia, USA - 1984

Wheels Sink into Sand

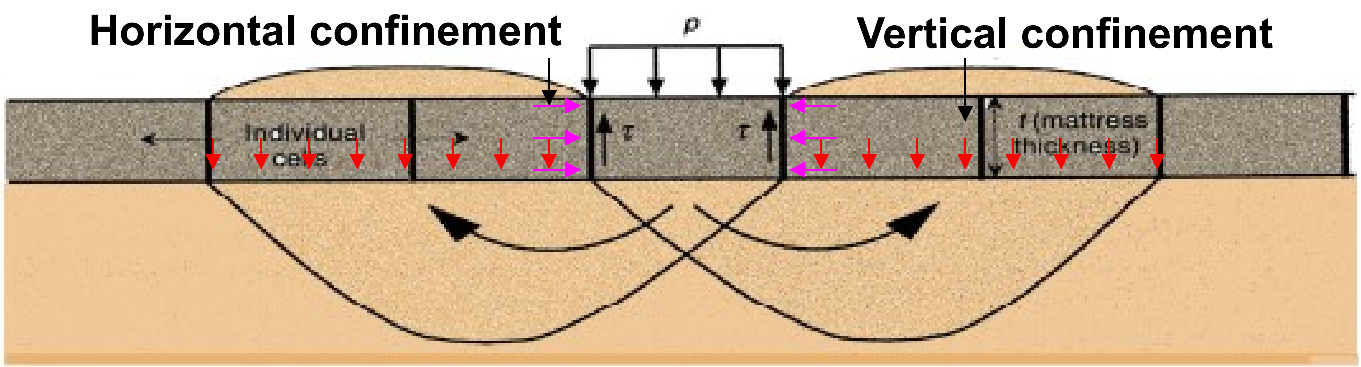
Support of Wheels on Geoweb Confined Sand

Geocell Products

Failure Mechanisms

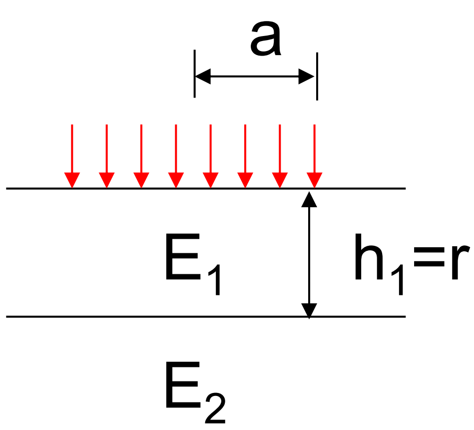


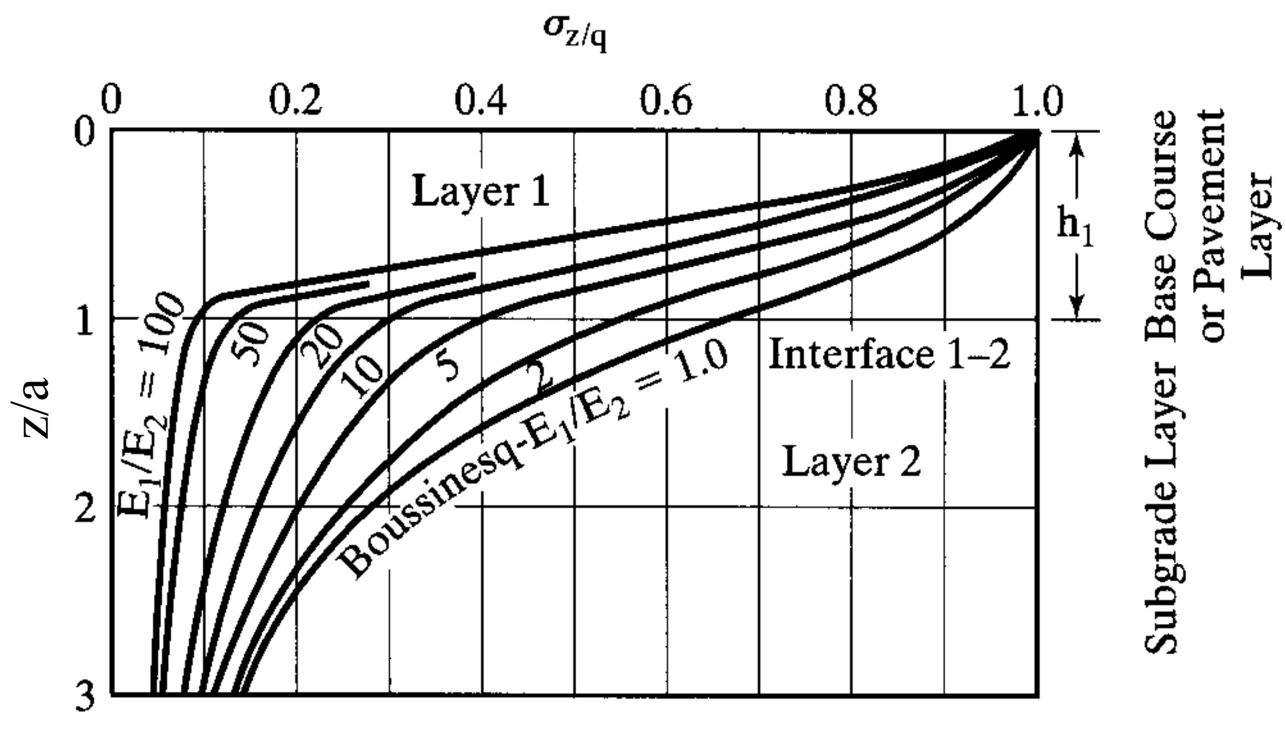
Unreinforced



Geocell-Reinforced

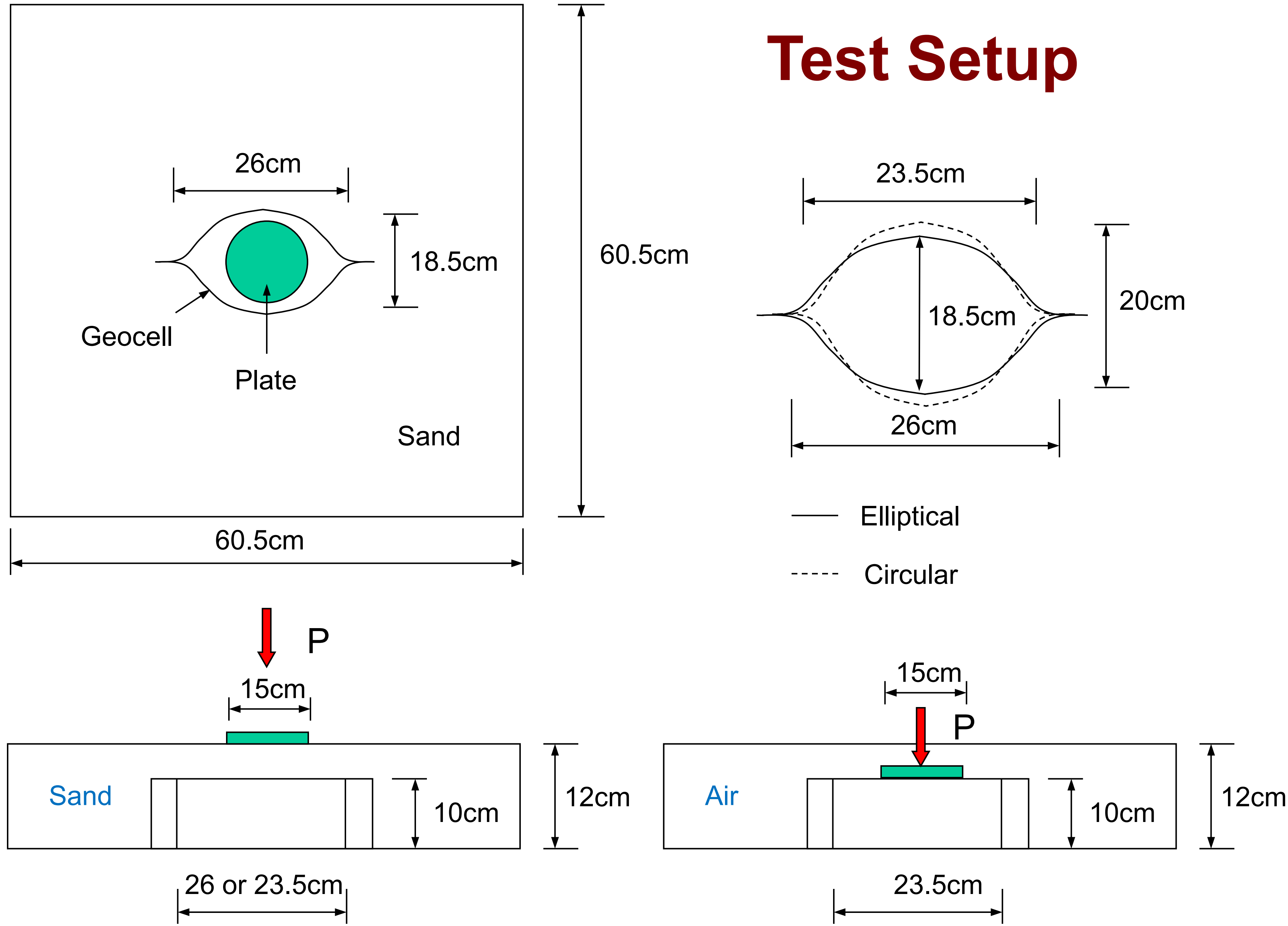
Vertical Stress Distribution in Two-Layer System





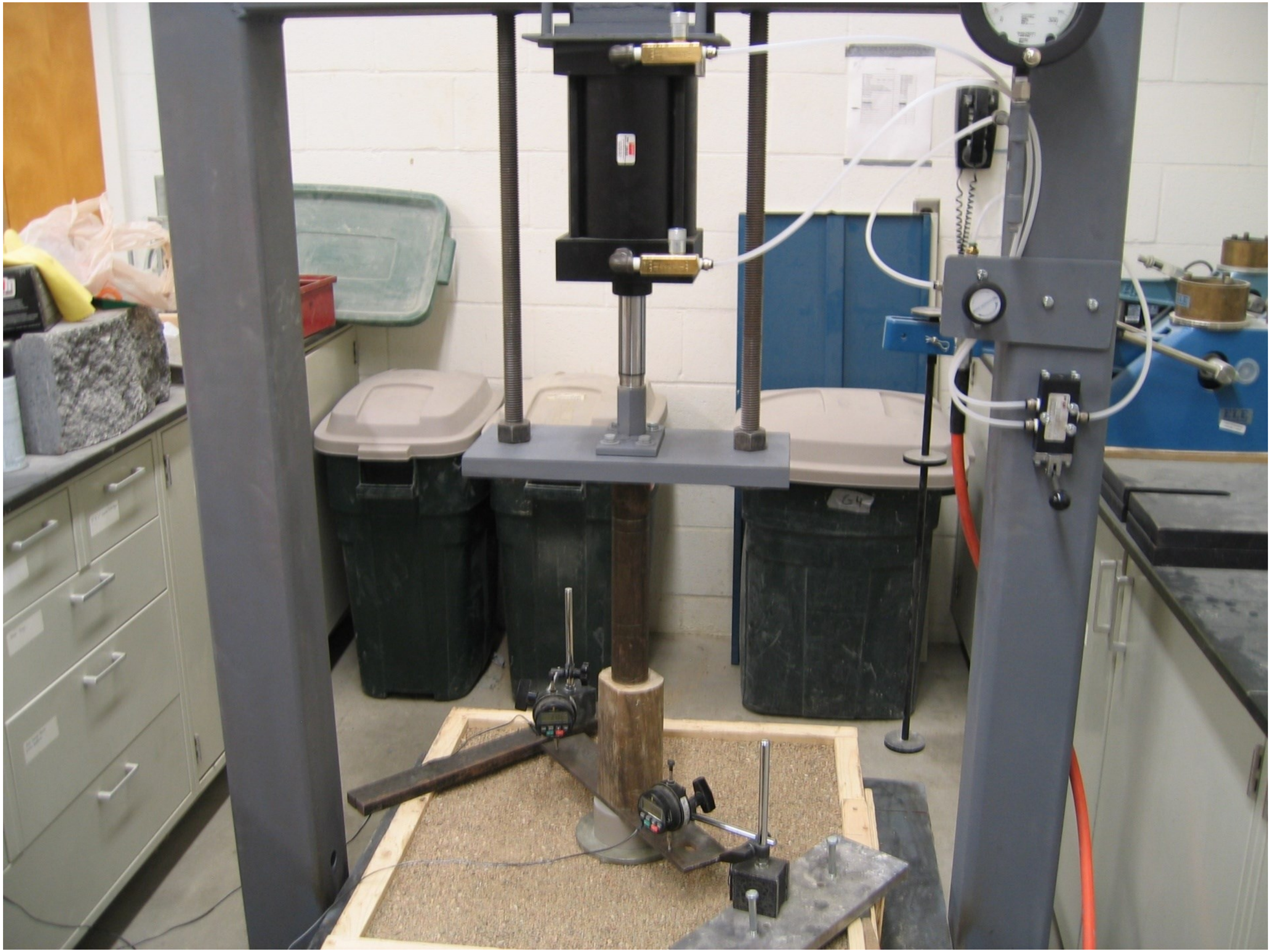
Burmister (1958)

Test Setup

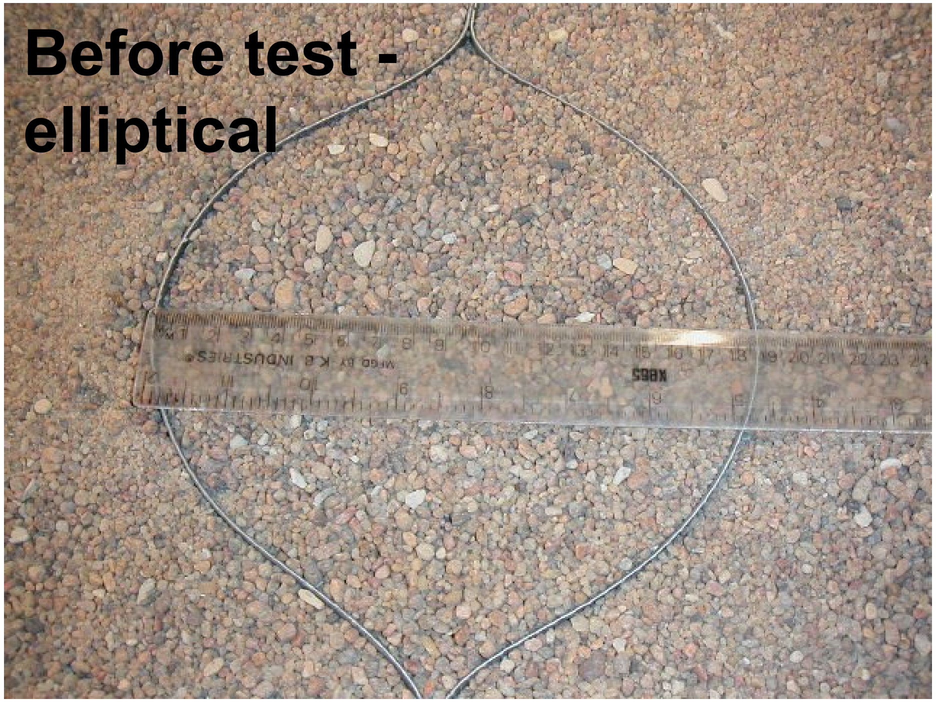


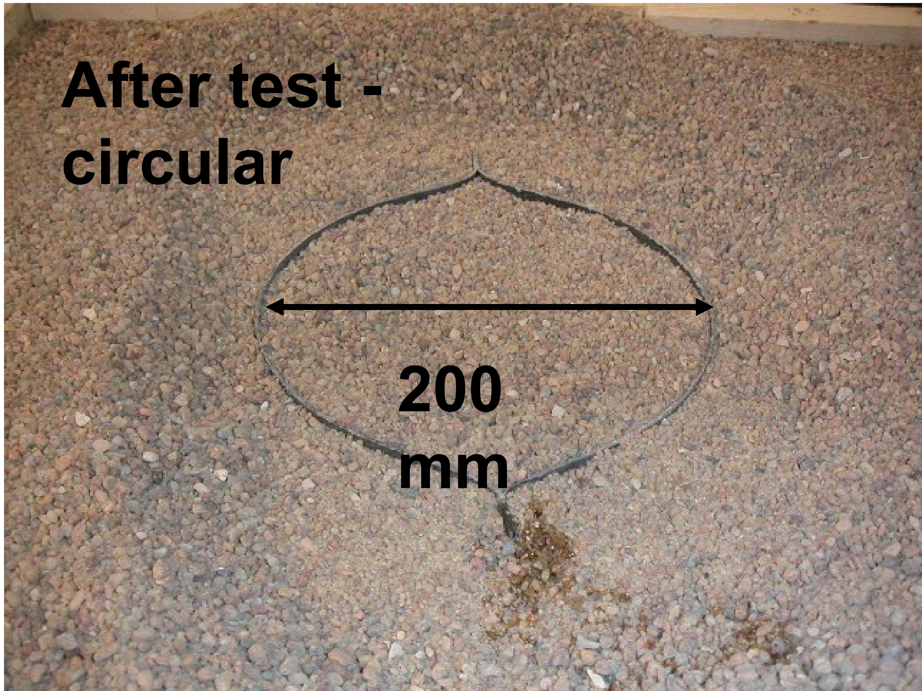
26cm
18.5cm
60.5cm
Geocell
Plate
Sand
60.5cm
23.5cm
20cm
18.5cm
26cm
Elliptical
Circular
P
15cm
Sand
10cm
12cm
26 or 23.5cm
15cm
P
Air
10cm
12cm
23.5cm

Test Device

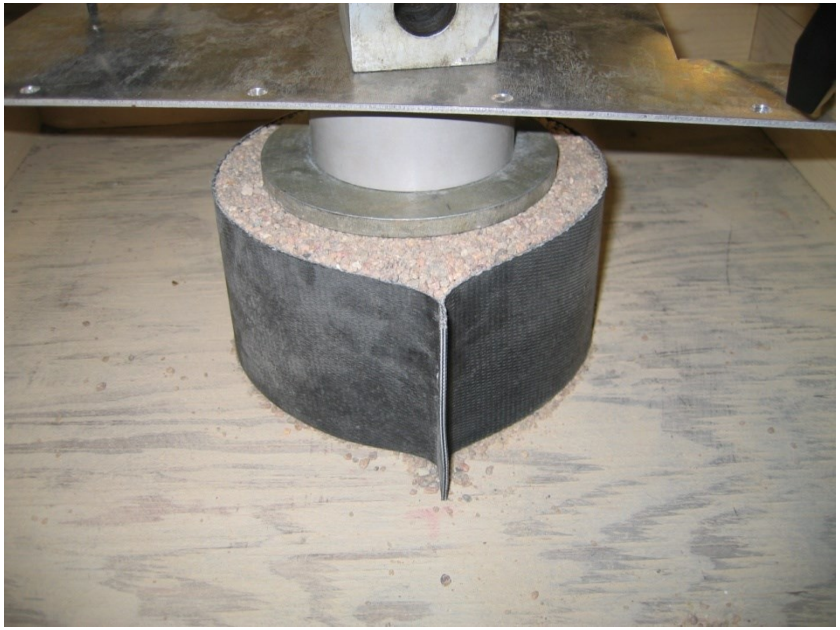


Shape Change

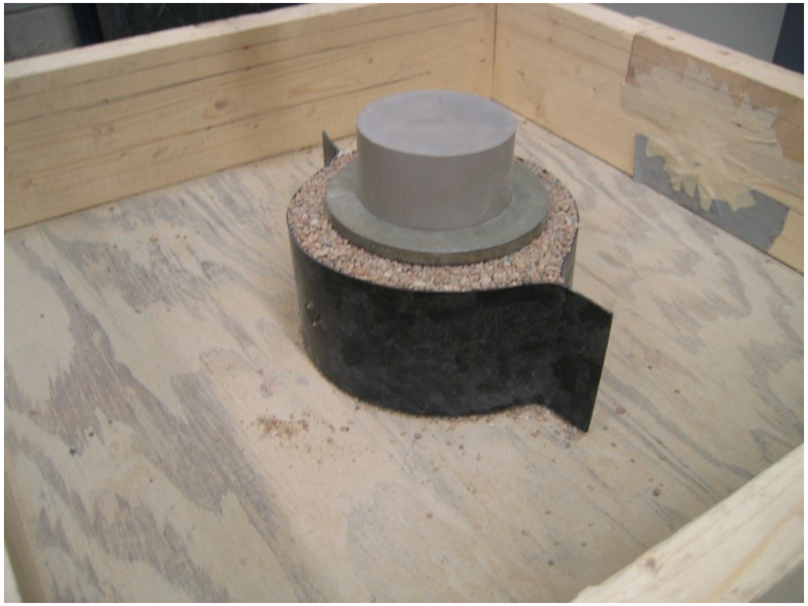




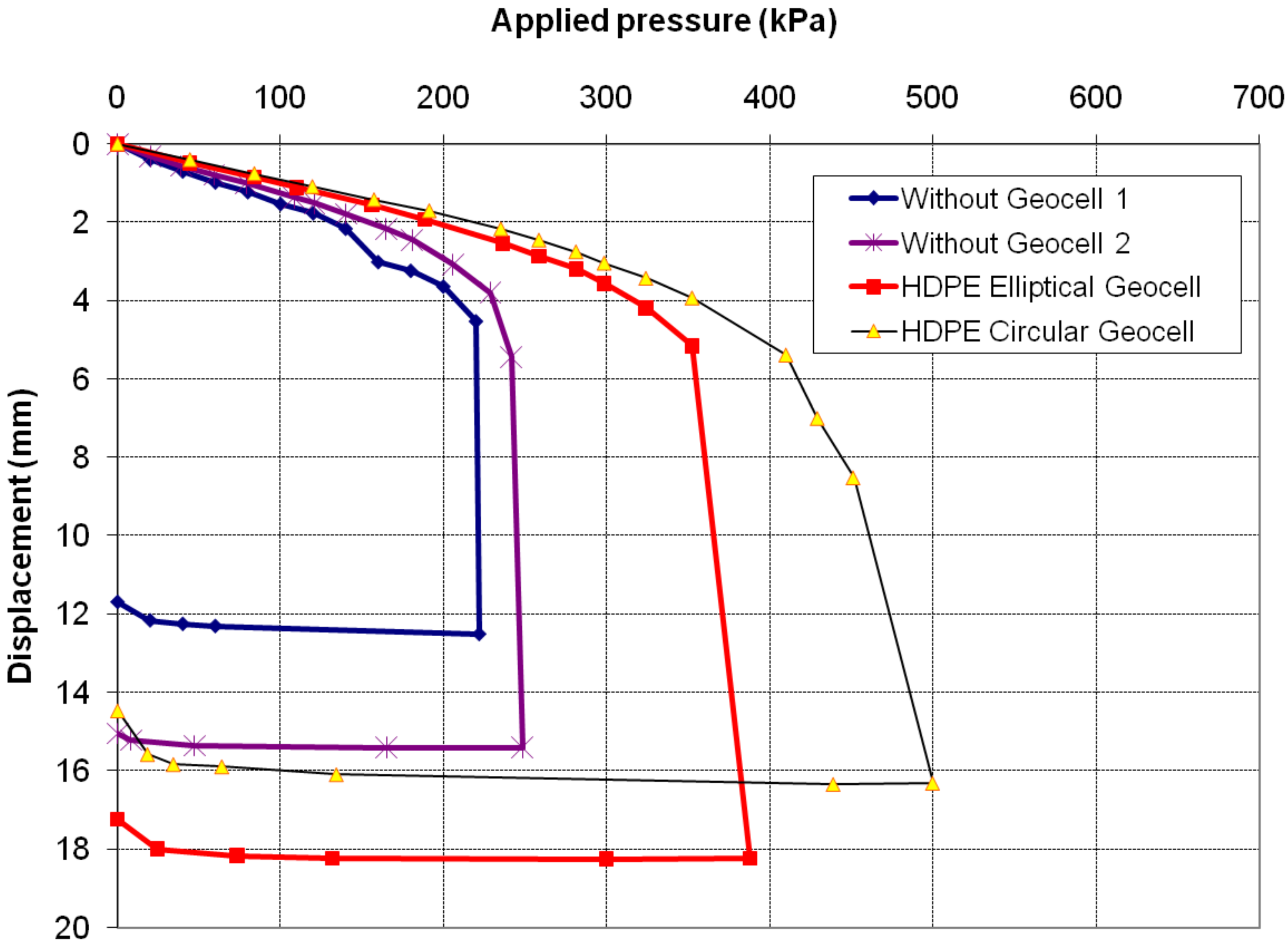
Axial Load Test with Single Geocell



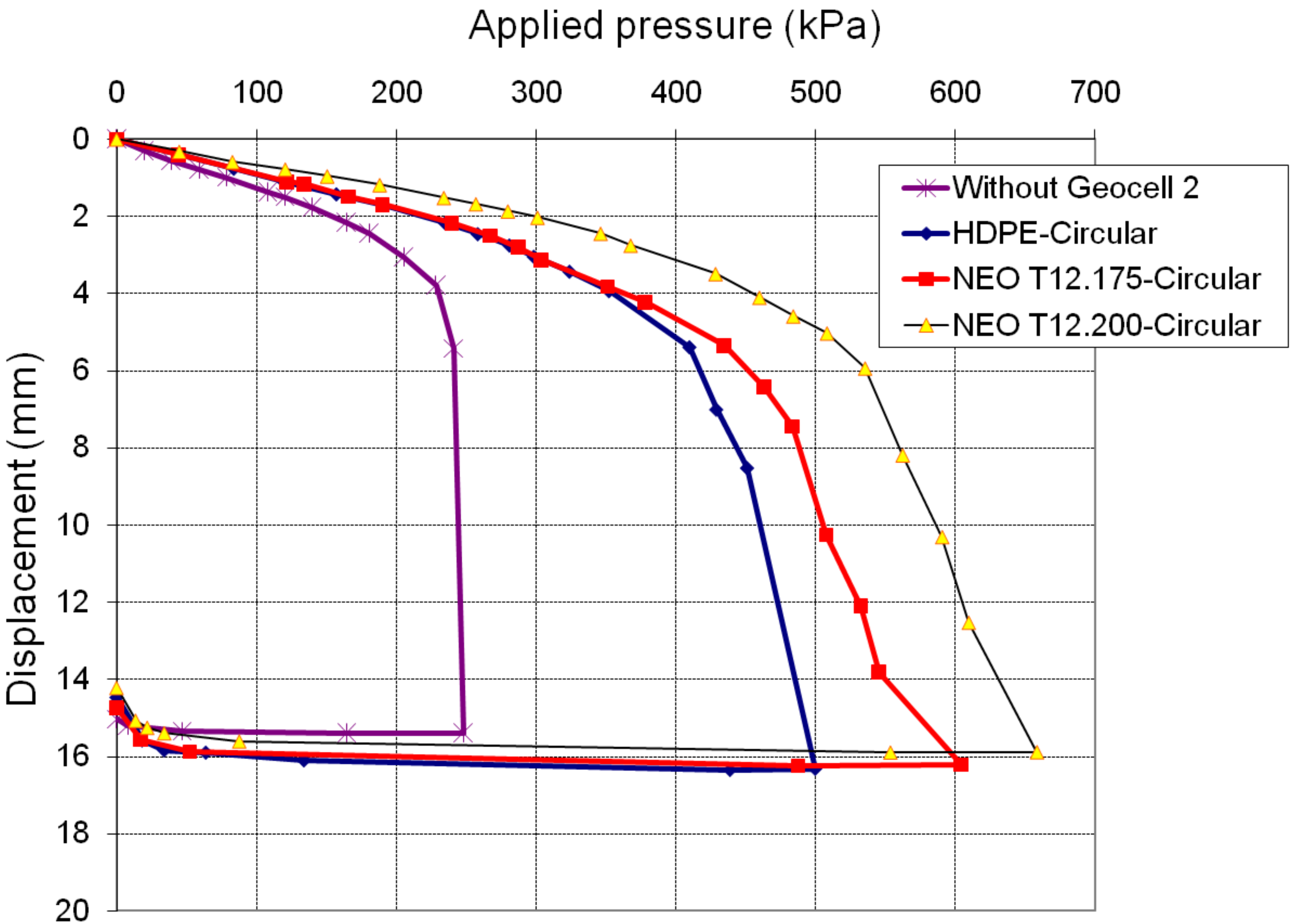
Unconfined Cell Failures



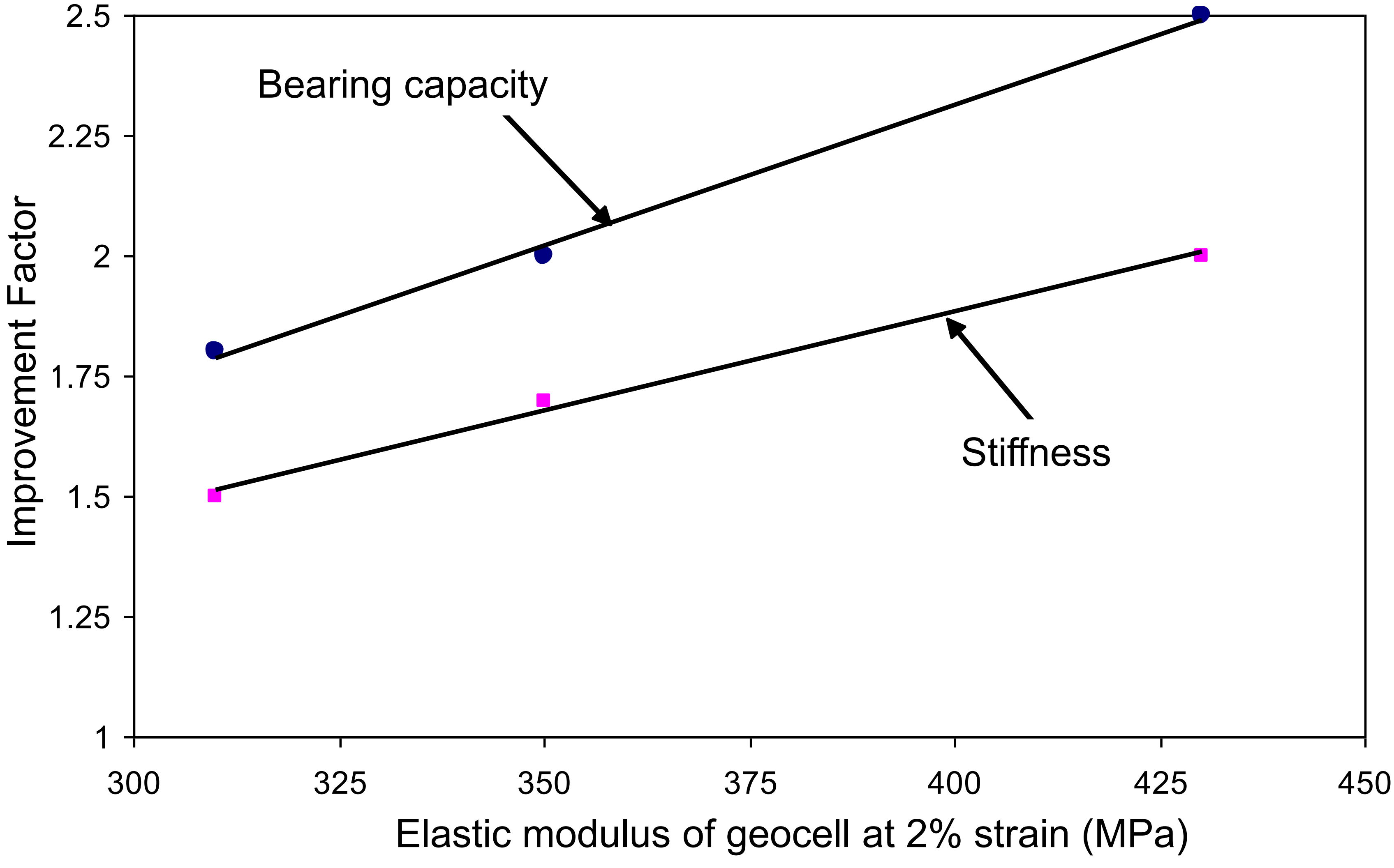
Effect of Geocell Shape



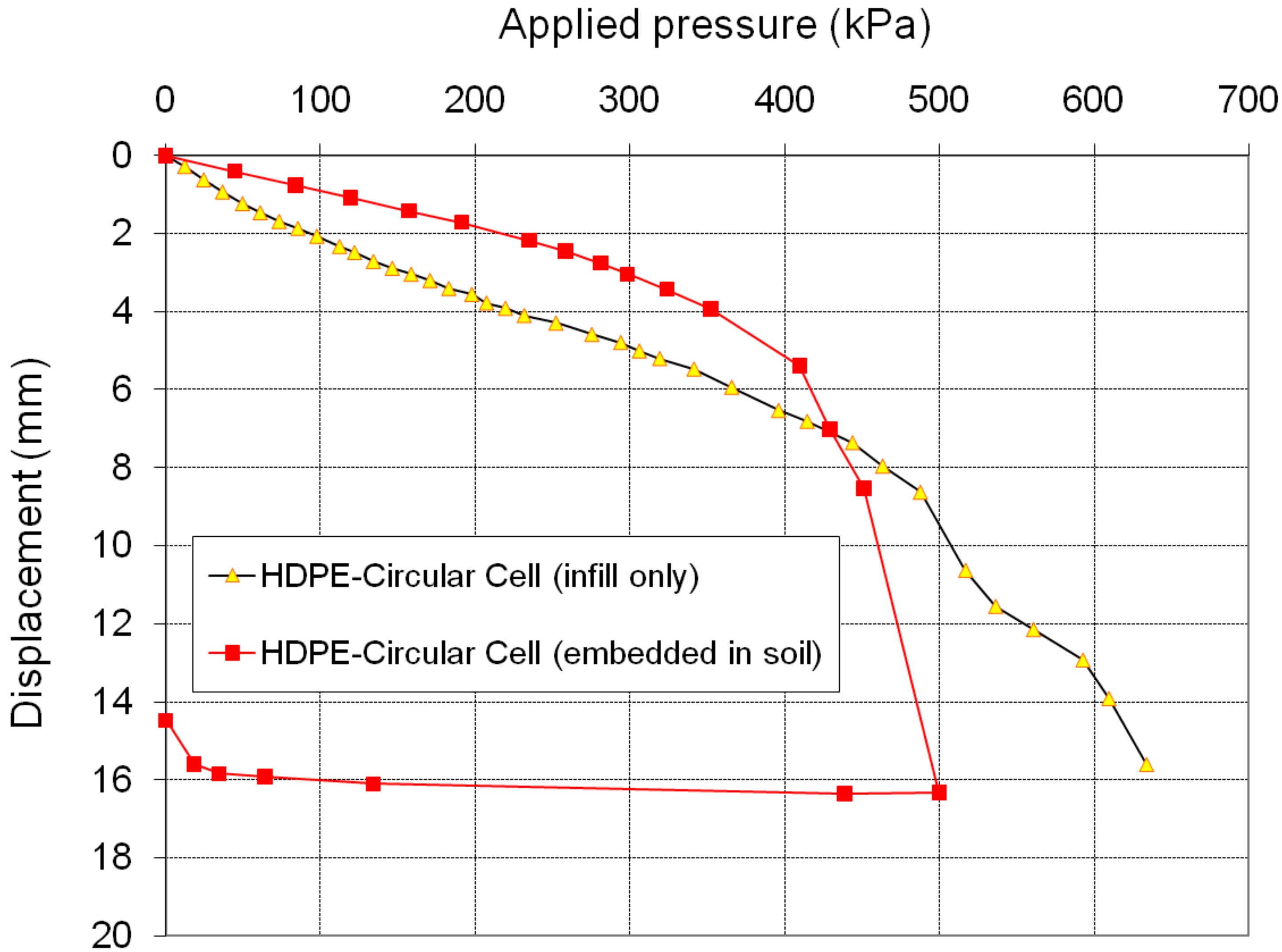
Effect of Different Geocell Products



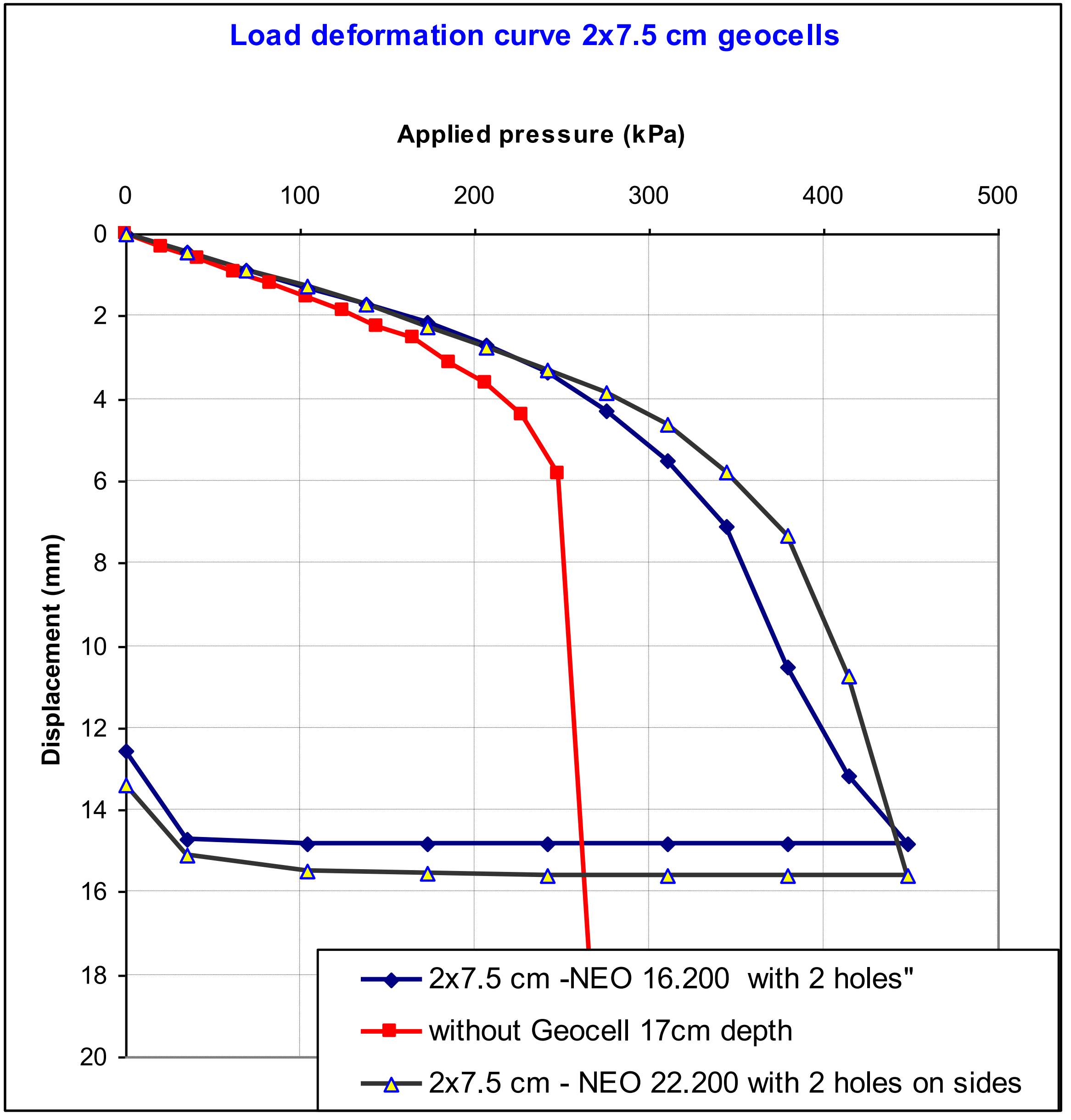
Effect of Modulus



Effect of Geocell Embedment

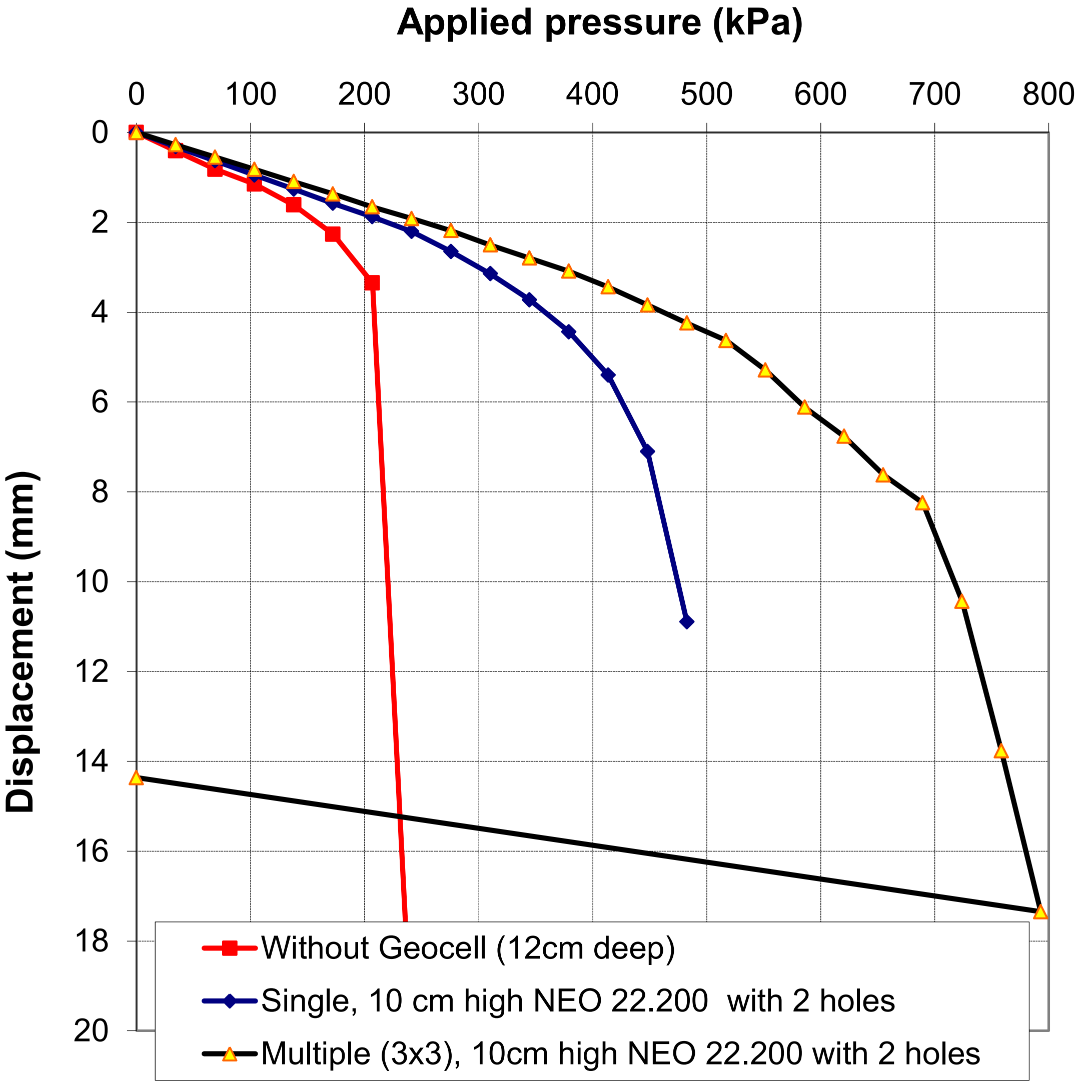


Two Layers of Geocells

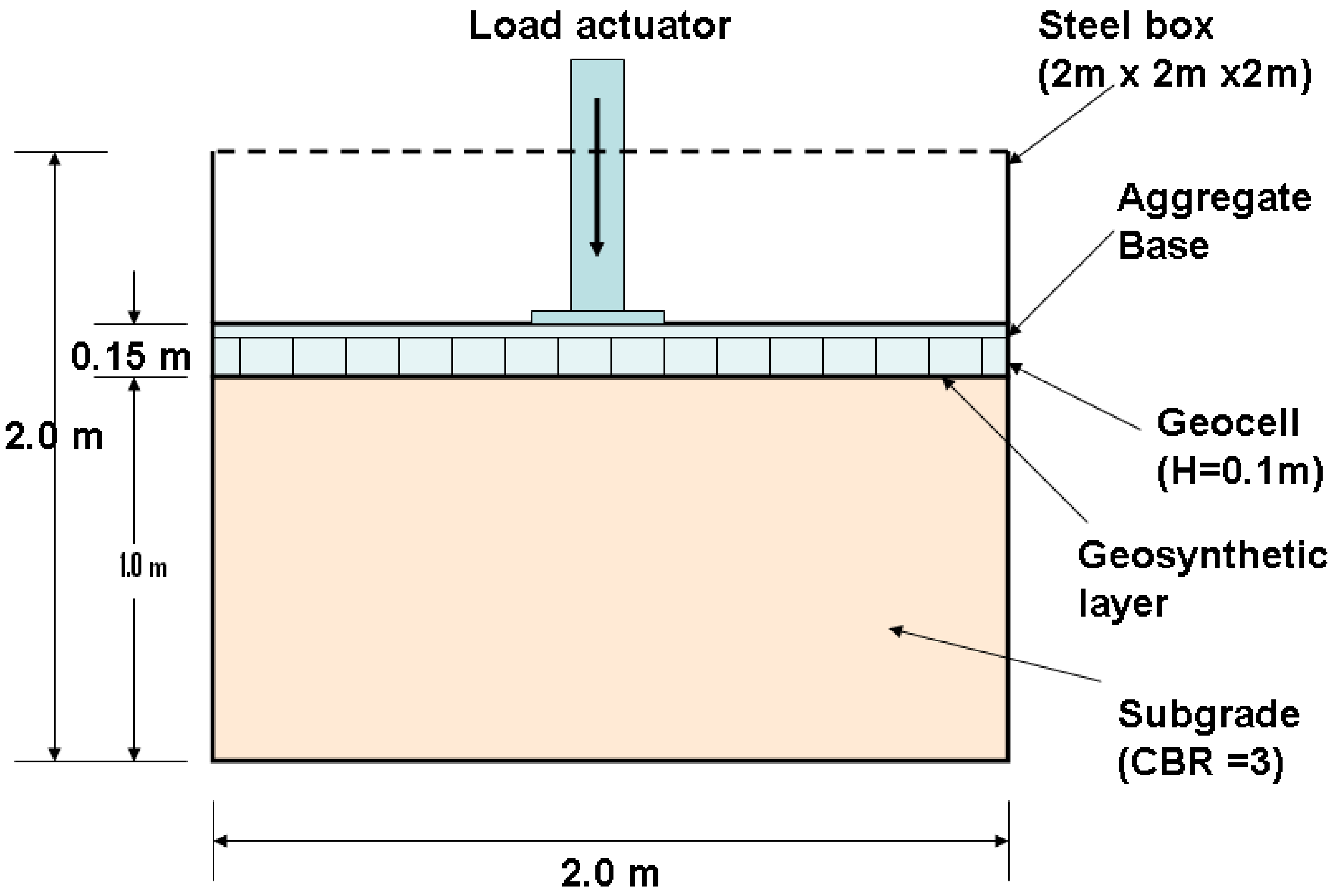


Multi-Geocell Test

Effect of Multi-Geocell



Box Test

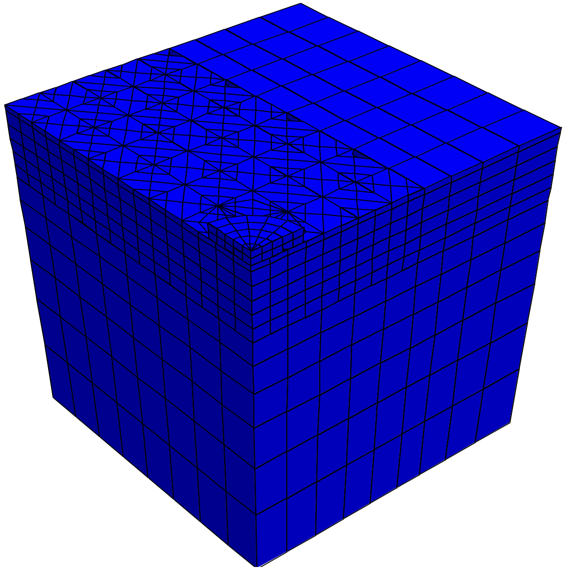

Load actuator
Steel box
(2m x 2m x2m)
Aggregate
Base
0.15 m
2.0 m
1.0 m
Geocell
(H=0.1m)
Geosynthetic
layer
Subgrade
(CBR =3)
2.0 m

Moving Wheel Test

Numerical Simulation of Model Test

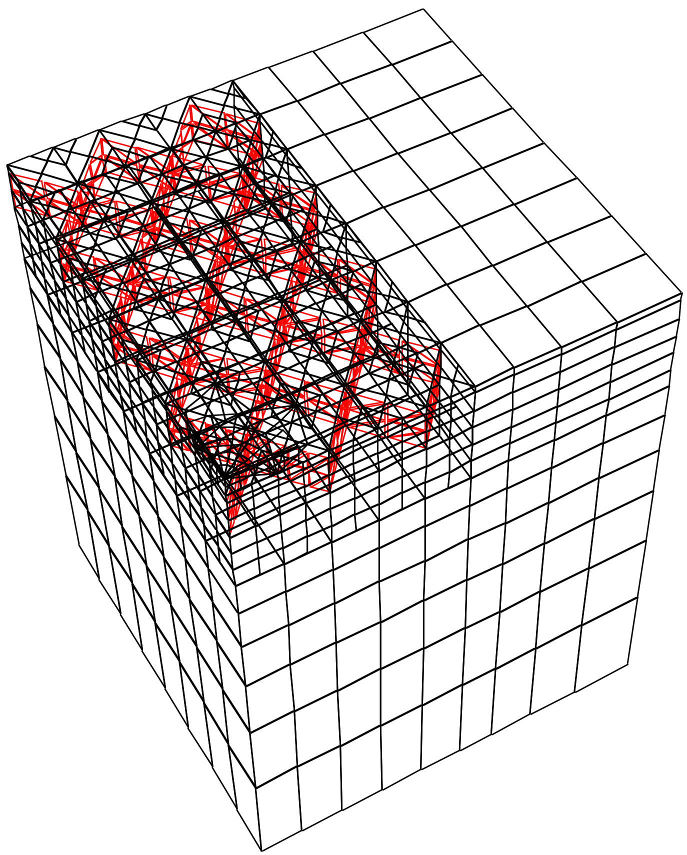
- To simulate the behavior of geocell reinforced Mattress using FLAC^{3D}

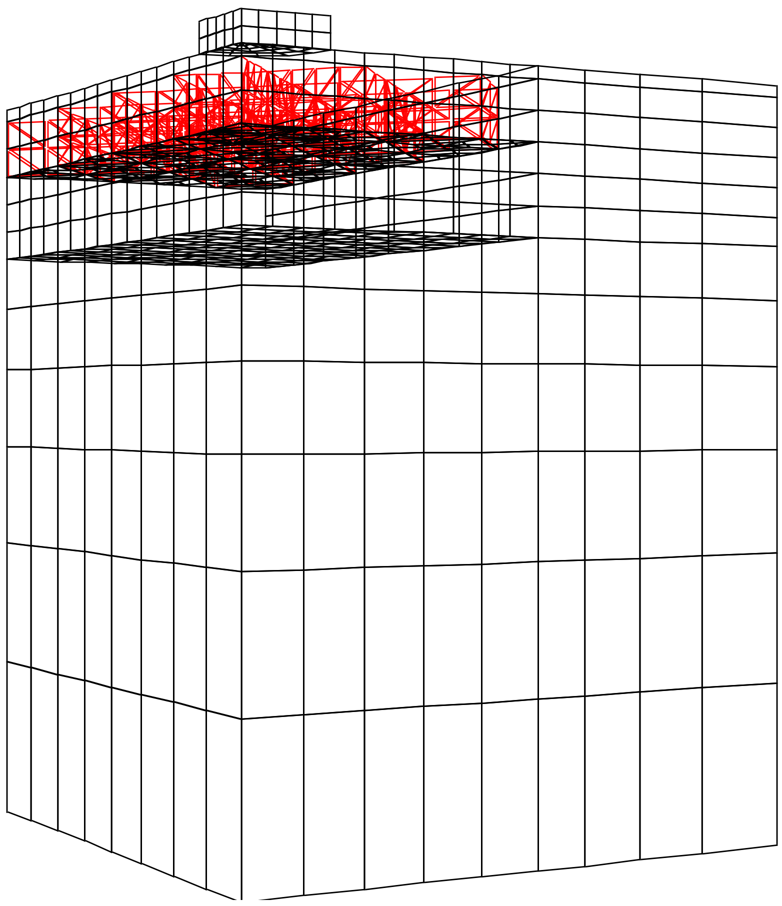
Lab Load Test by Prof. Meyer at TU Clausthal (in Germany)



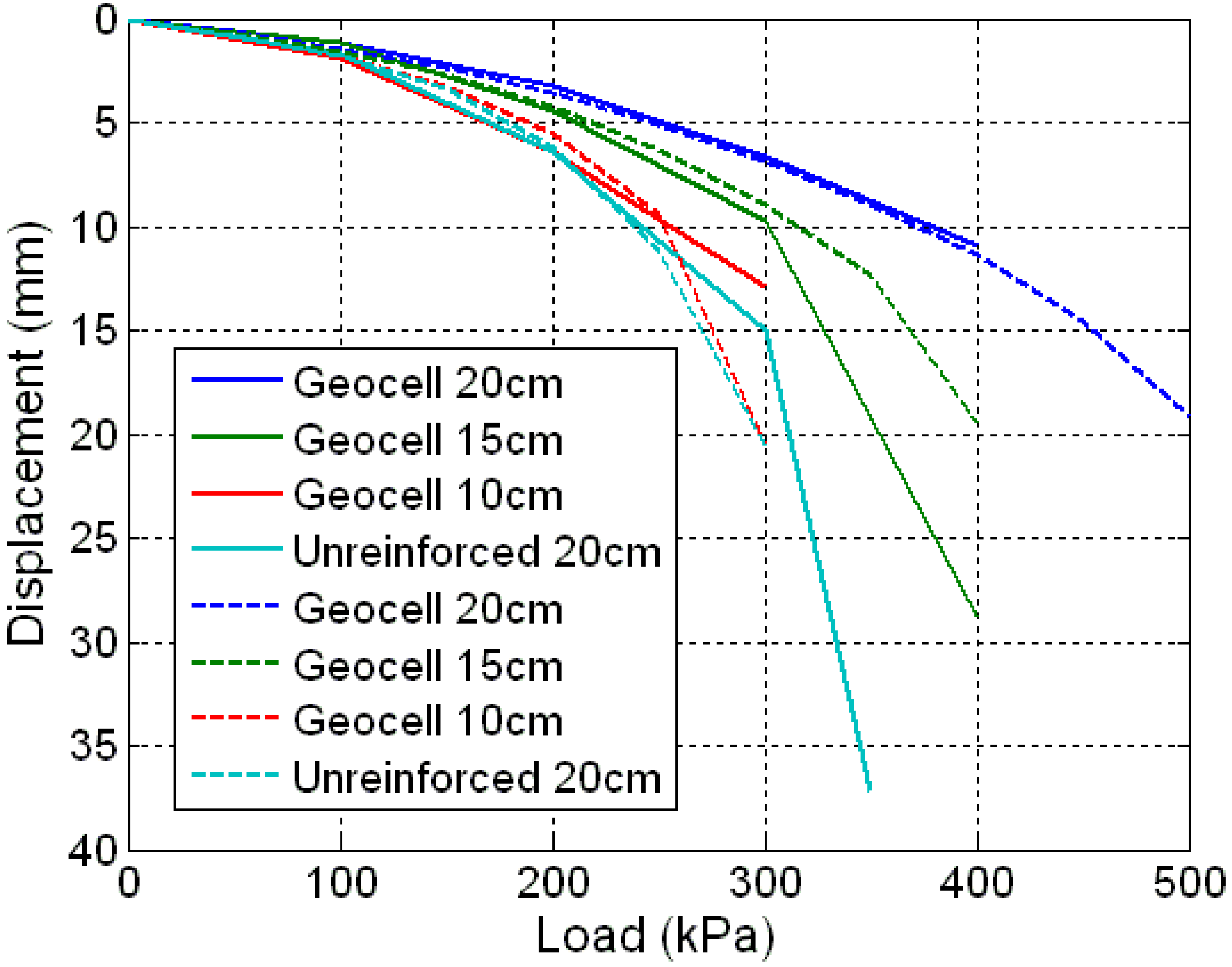
FLAC3D Model at KU

Numerical Modeling

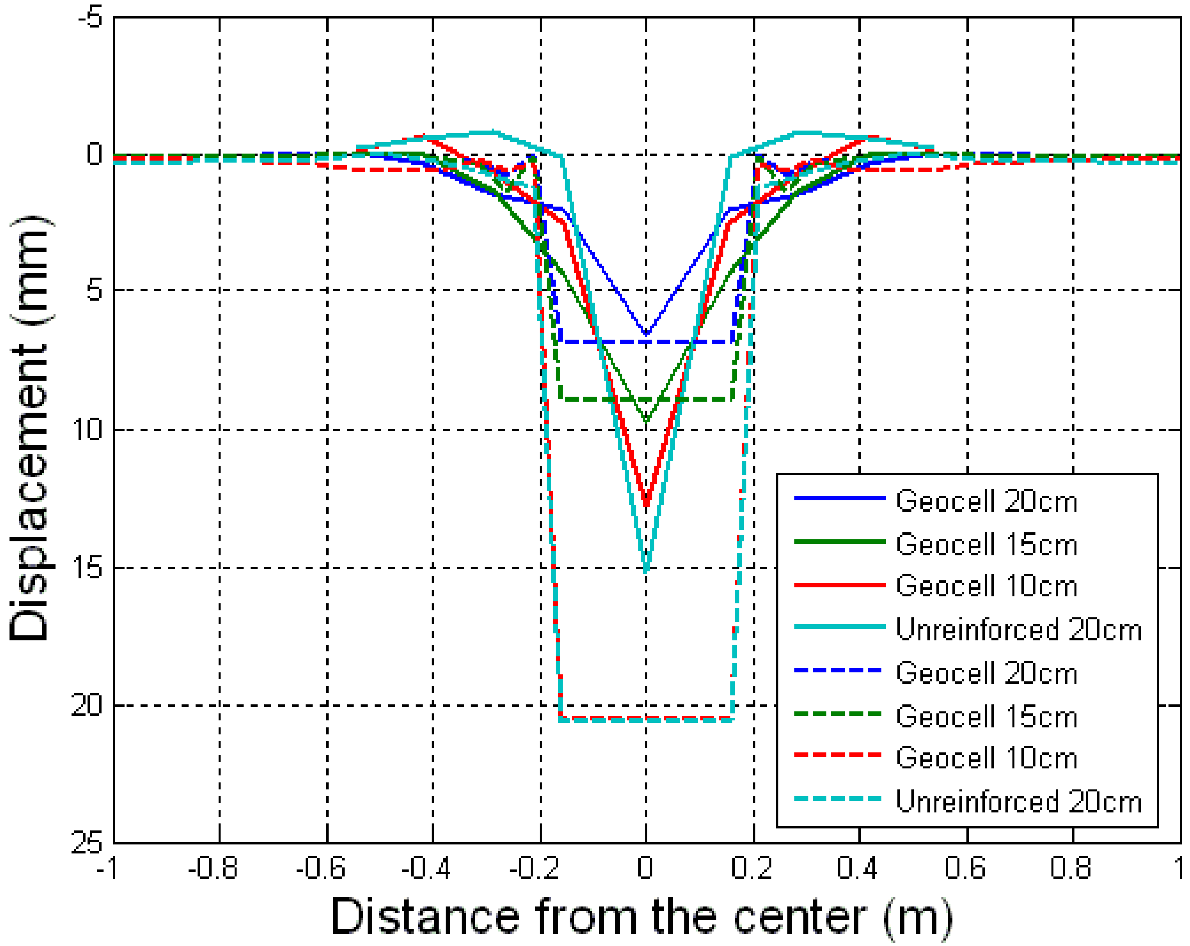




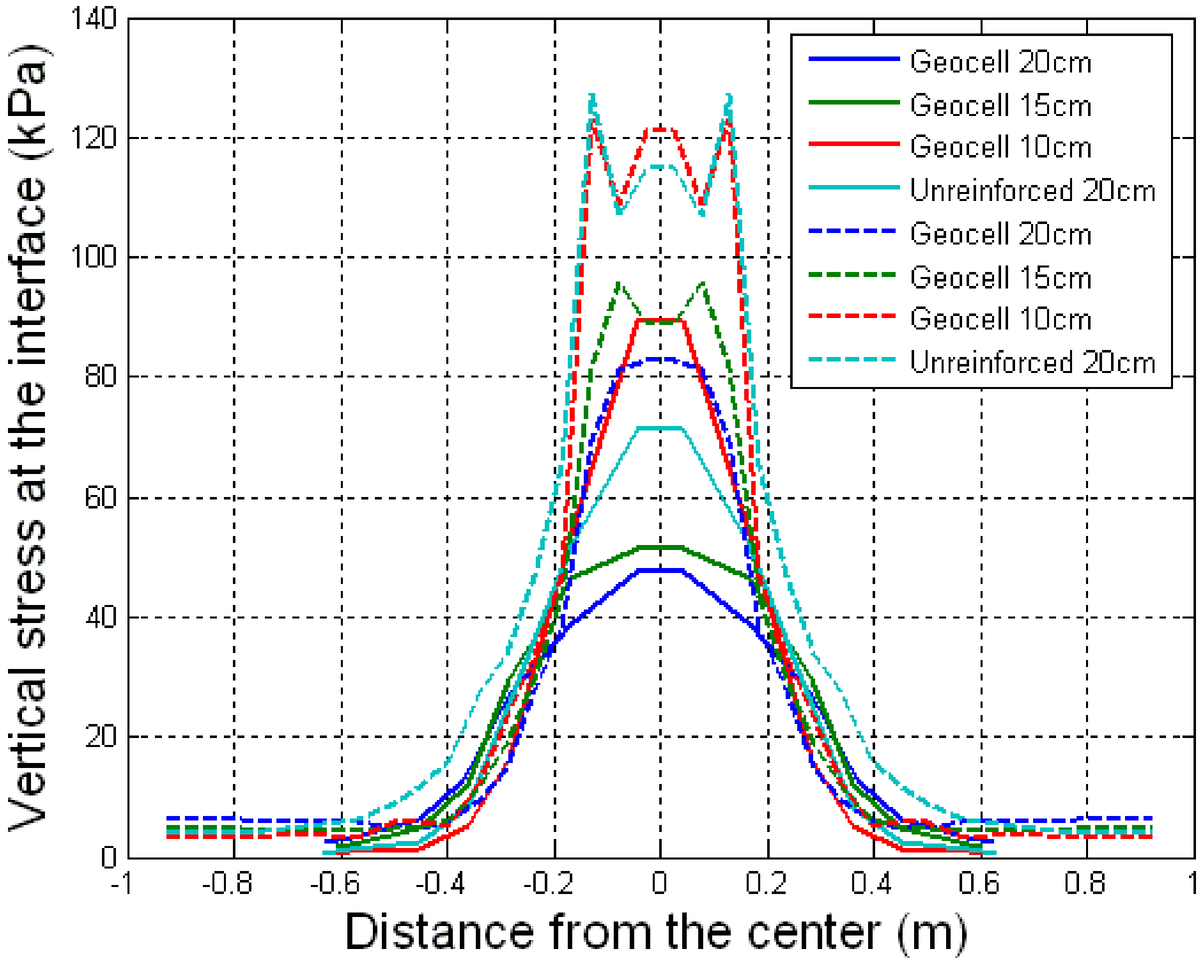
Load-Displacement Curve



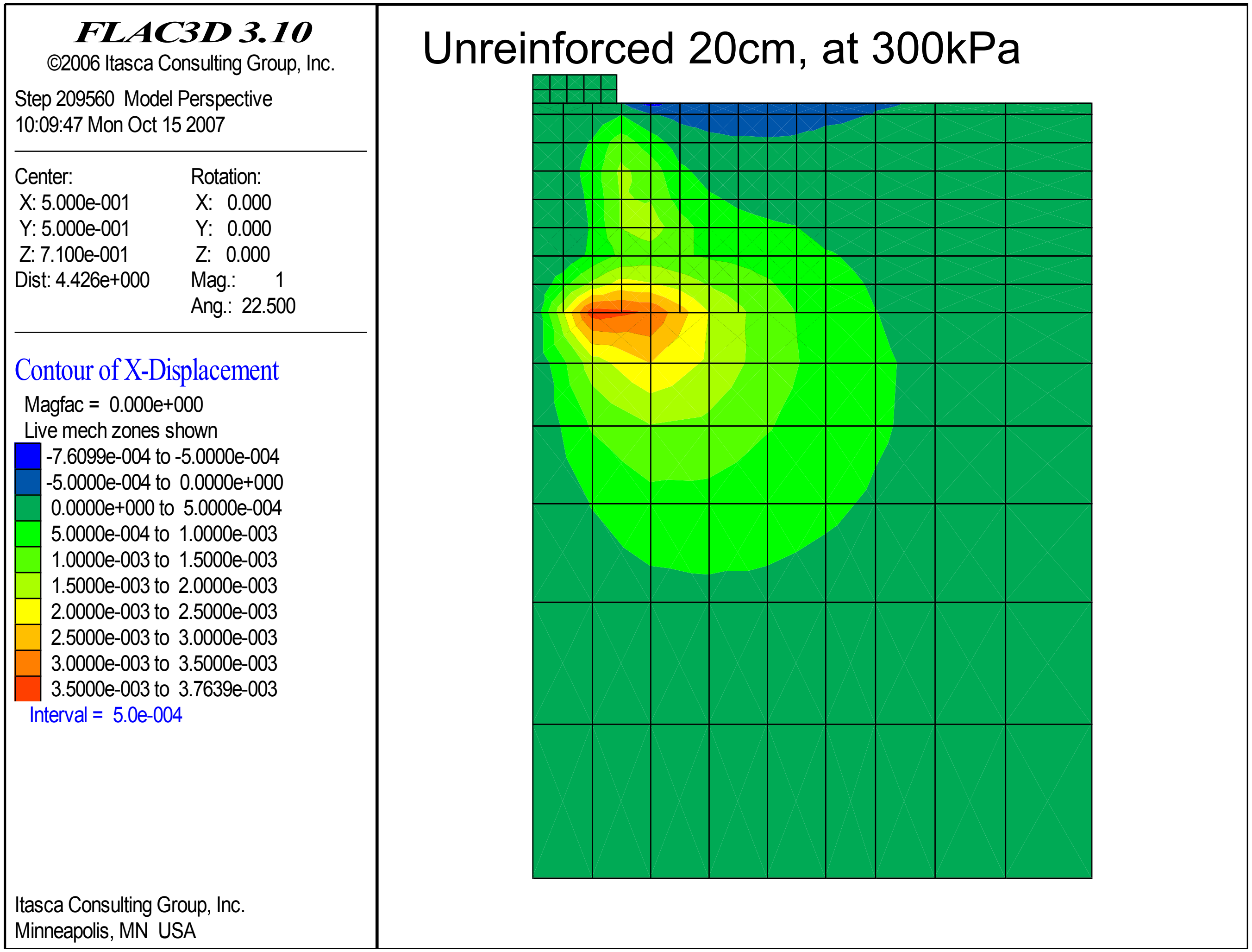
Displacement Profile



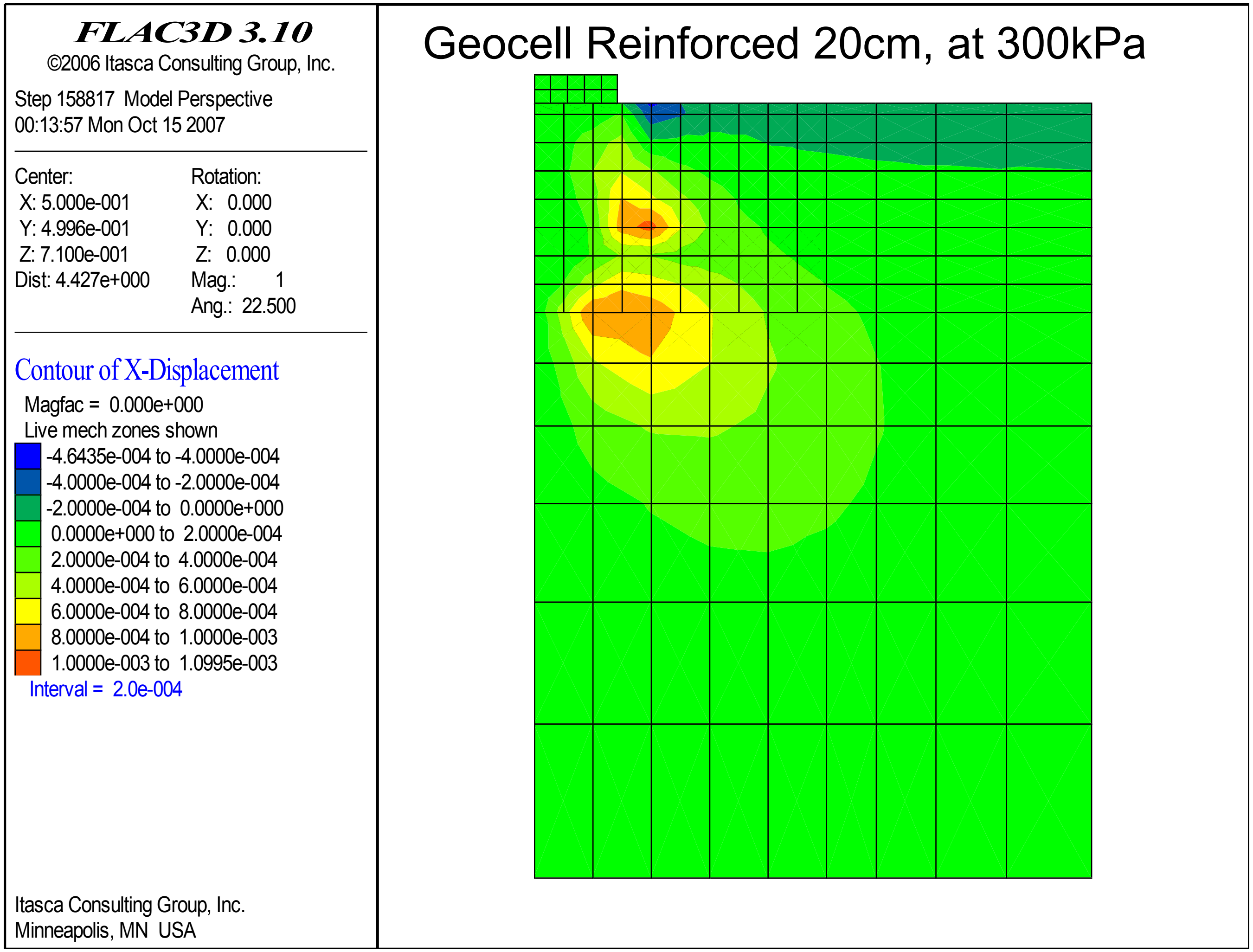
Stress Distribution



Horizontal Displacement – Unreinforcement



Horizontal Displacement – Reinforcement



Vertical Displacement