
Modeling Base Stability

Dallas N. Little

Texas A&M University

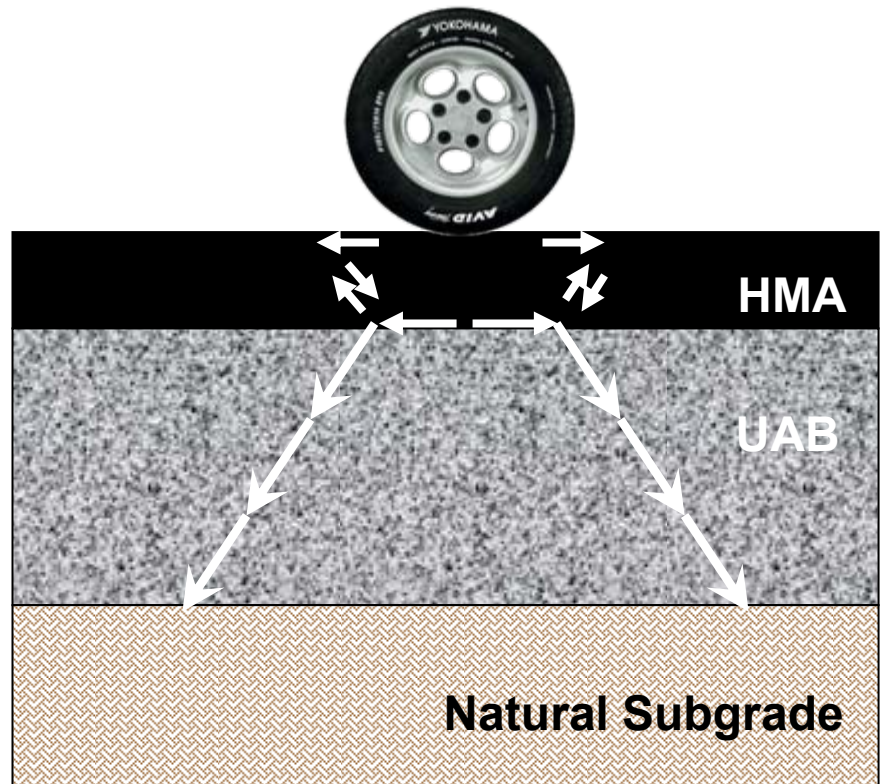
July 19th 2007

Outline

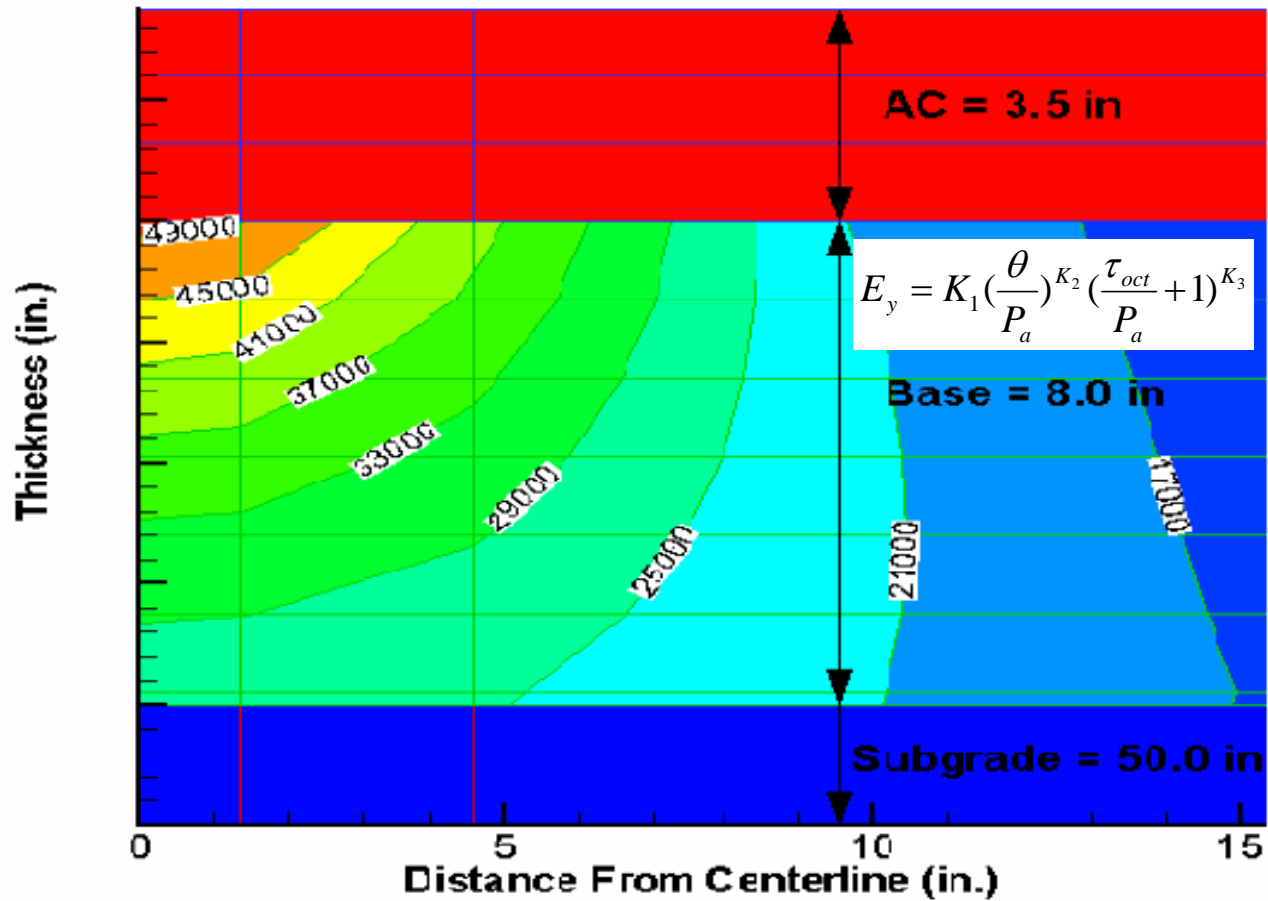
- Role of unbound aggregate base (UAB) in the pavement structure
 - Constitutive behavior of aggregate systems
 - Stress sensitivity
 - anisotropy
 - Protocols to assess constitutive behavior and stability
 - Factors influencing stability of the unbound aggregate bases
 - Conclusions
-

Role of Aggregate Base

- Support hot mix asphalt layer (HMA)
 - Reduce bending stresses
 - Reduce shearing stresses
- Protect subgrade
 - Reduce subgrade deformation

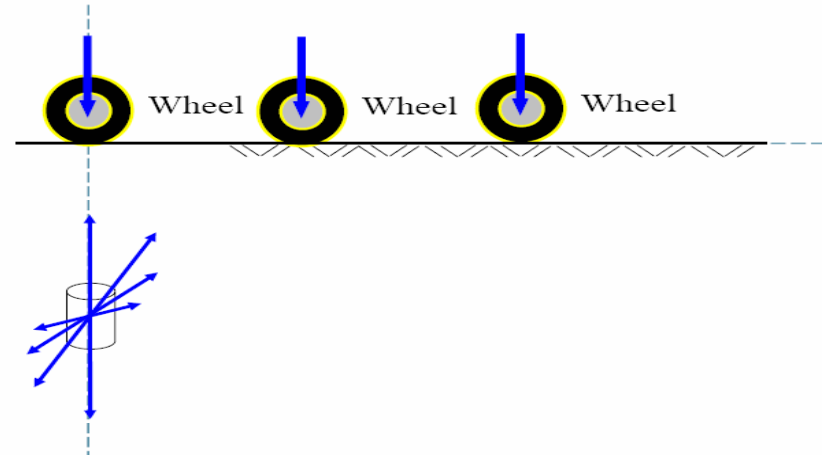


Stress Dependency of Modulus in Base Layer (Results from GT-PAVE)



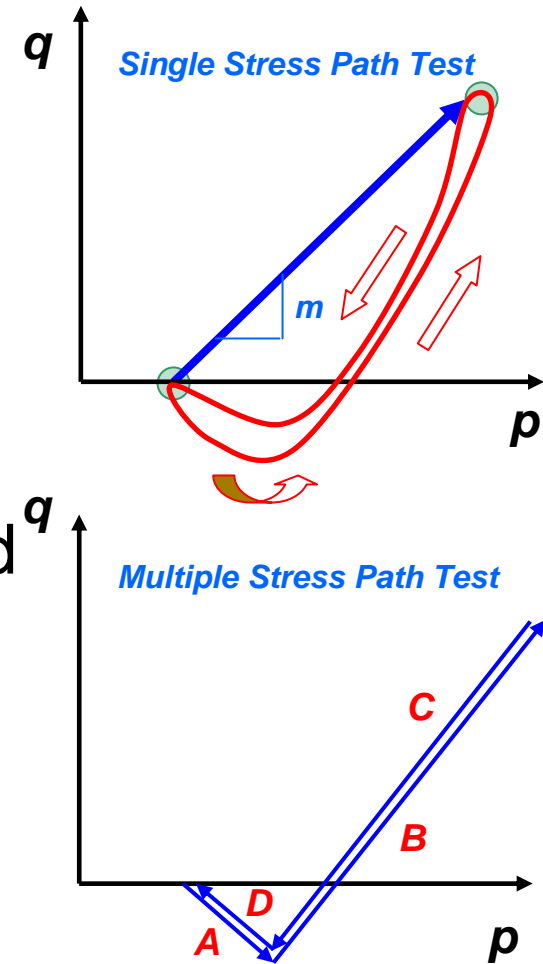
Moving Wheel Load

Rotation of Principal Stresses

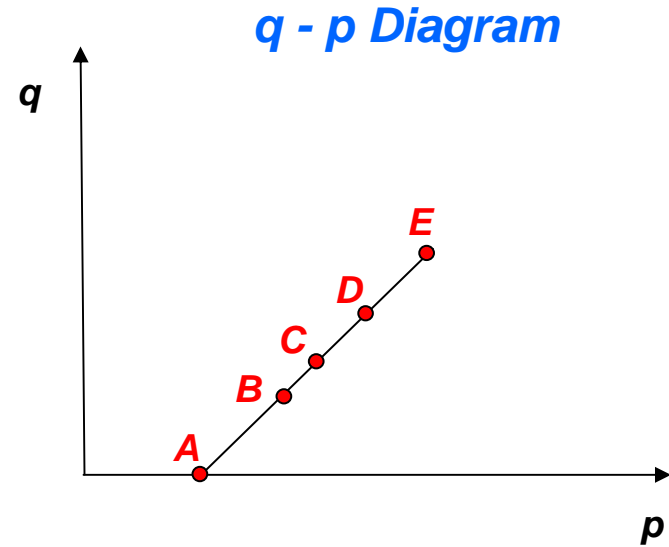
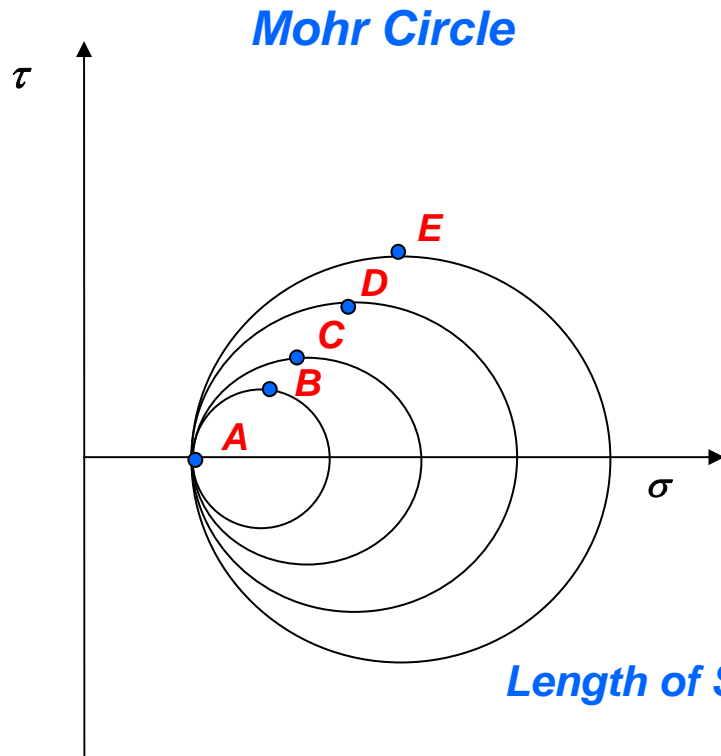


Stress History

The Testing protocol should be able to simulate the actual Extension - Compression - Extension nature of stress sequence observed in the approaching and departing wheel load.



Stress Path

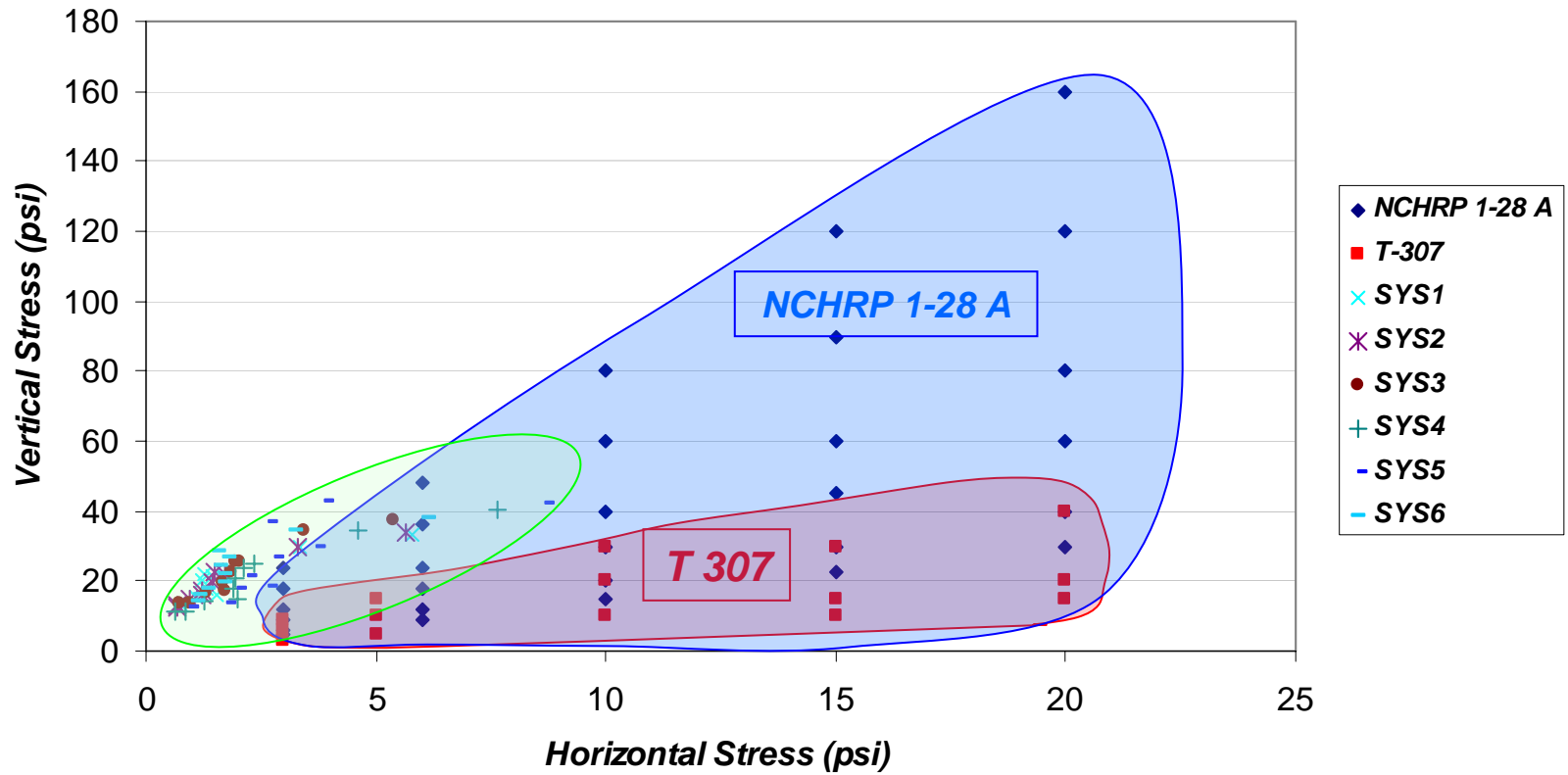


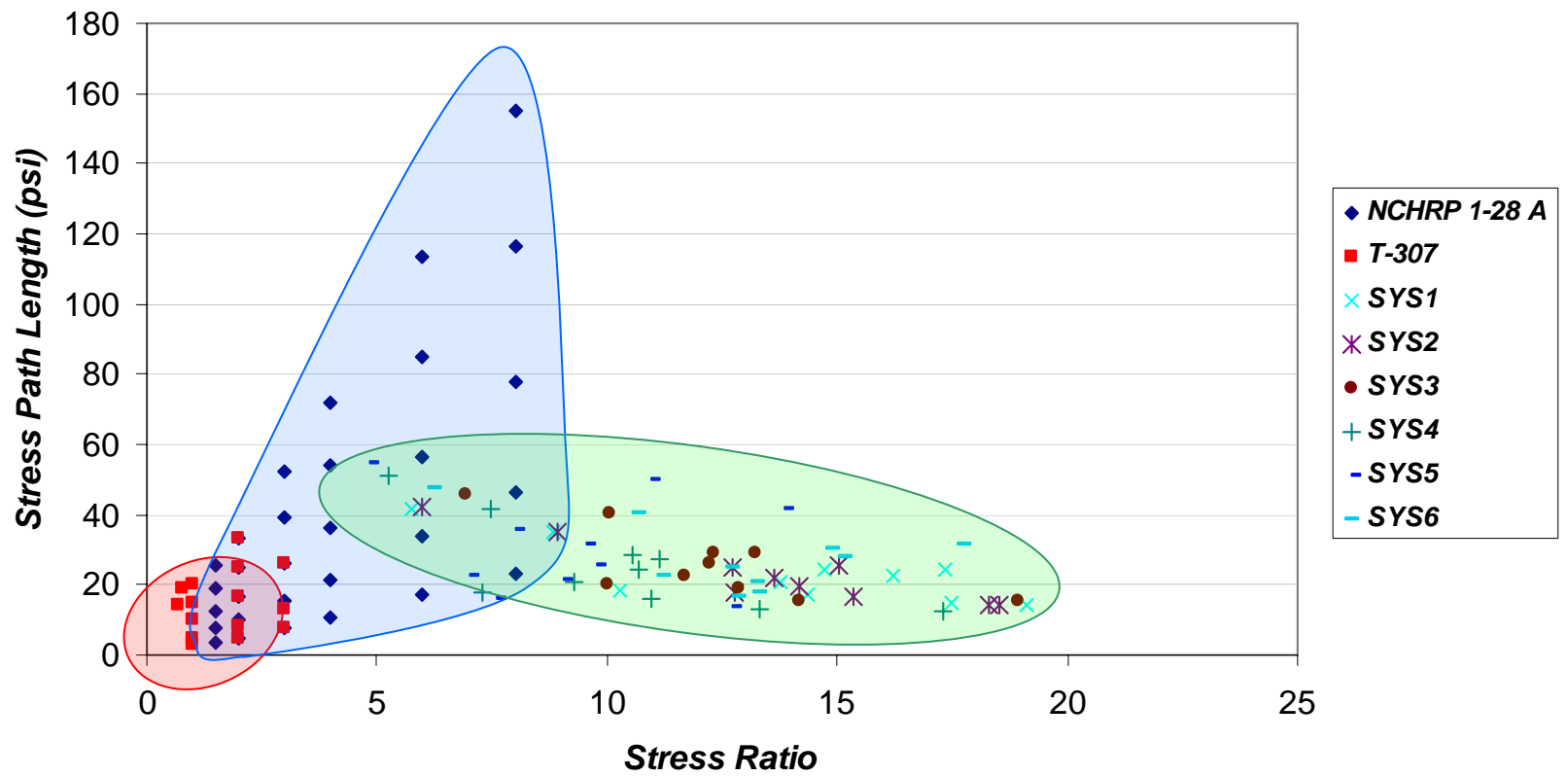
Length of Stress Path

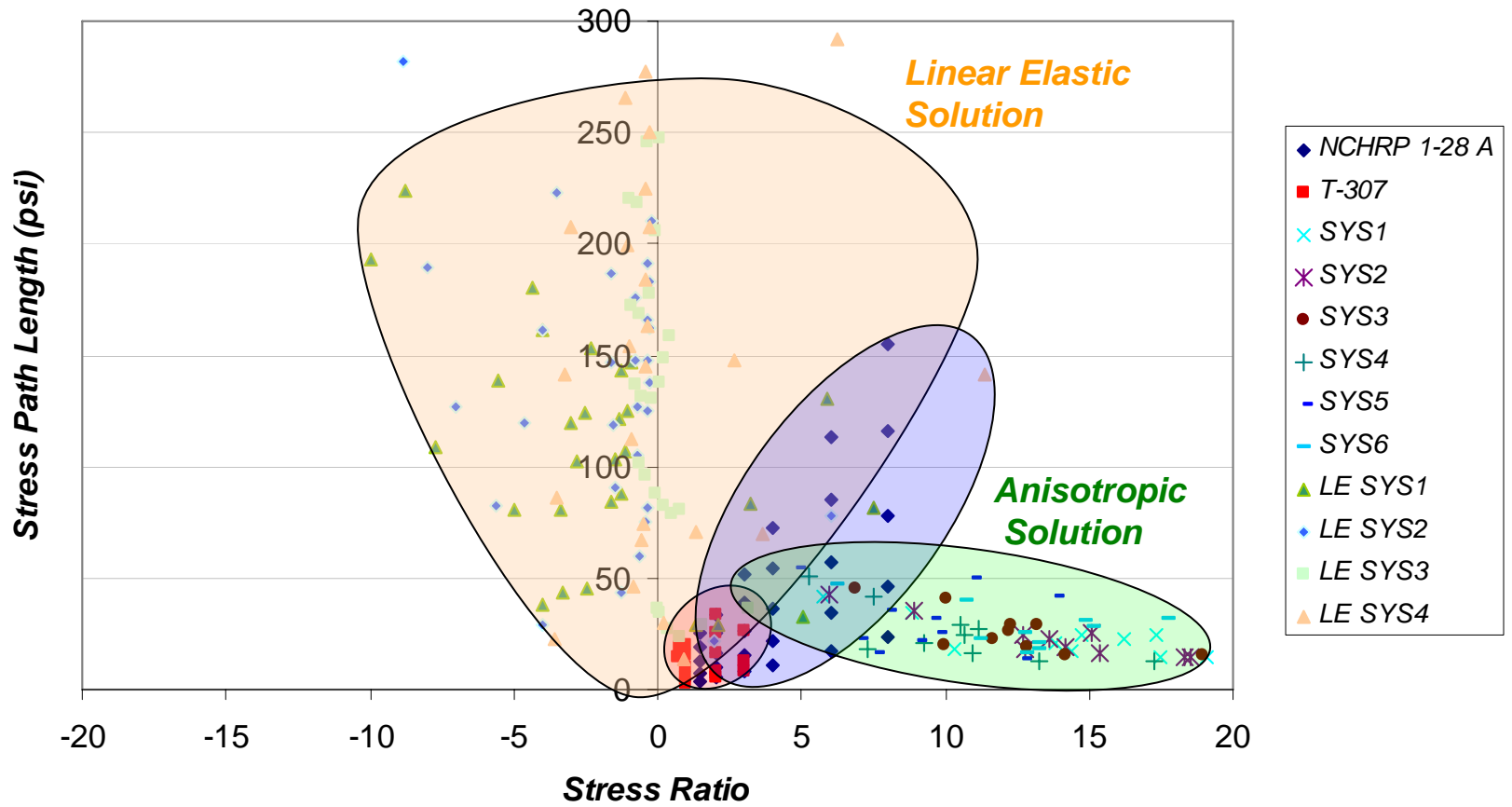
$$L = \sqrt{p^2 + q^2}$$

Slope of Stress Path

$$m = \frac{q}{p}$$

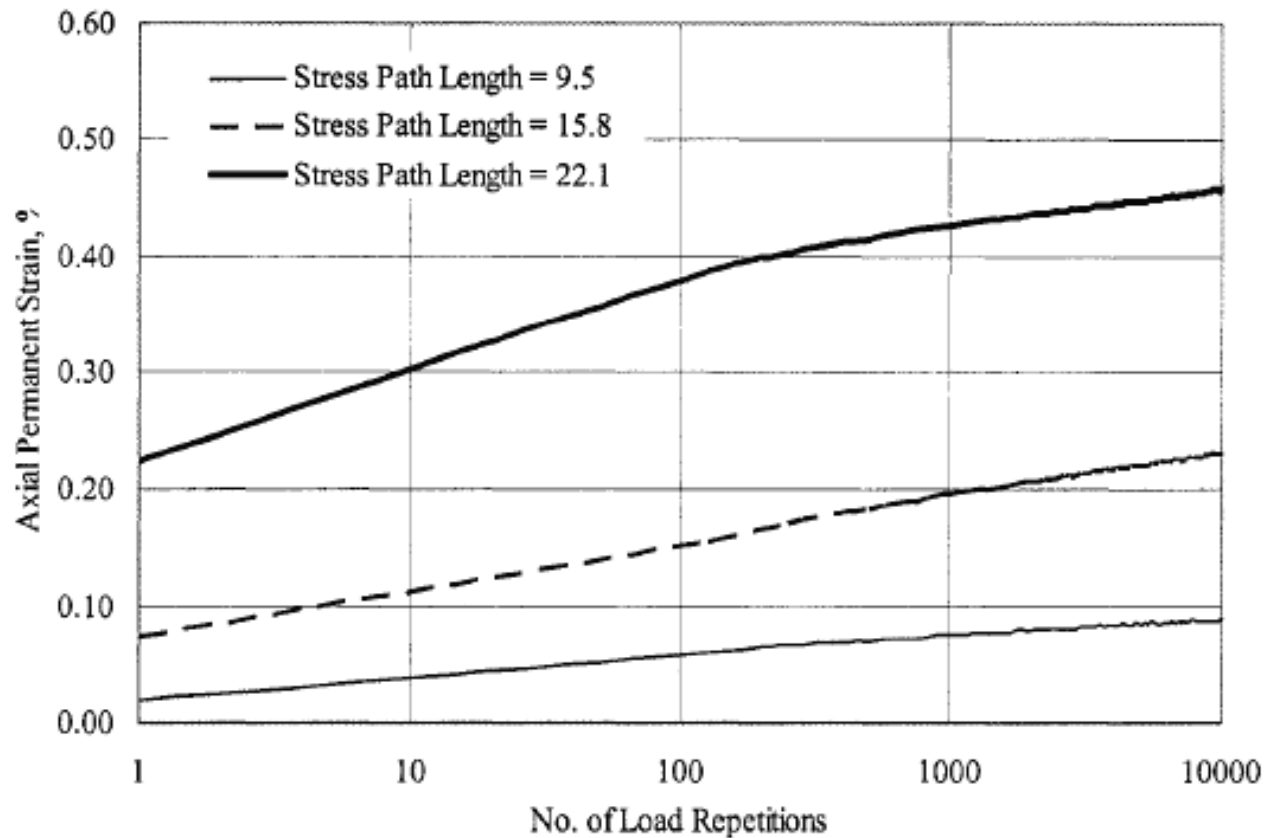






Effect of Length of Stress Path on Accumulation of Plastic Strain

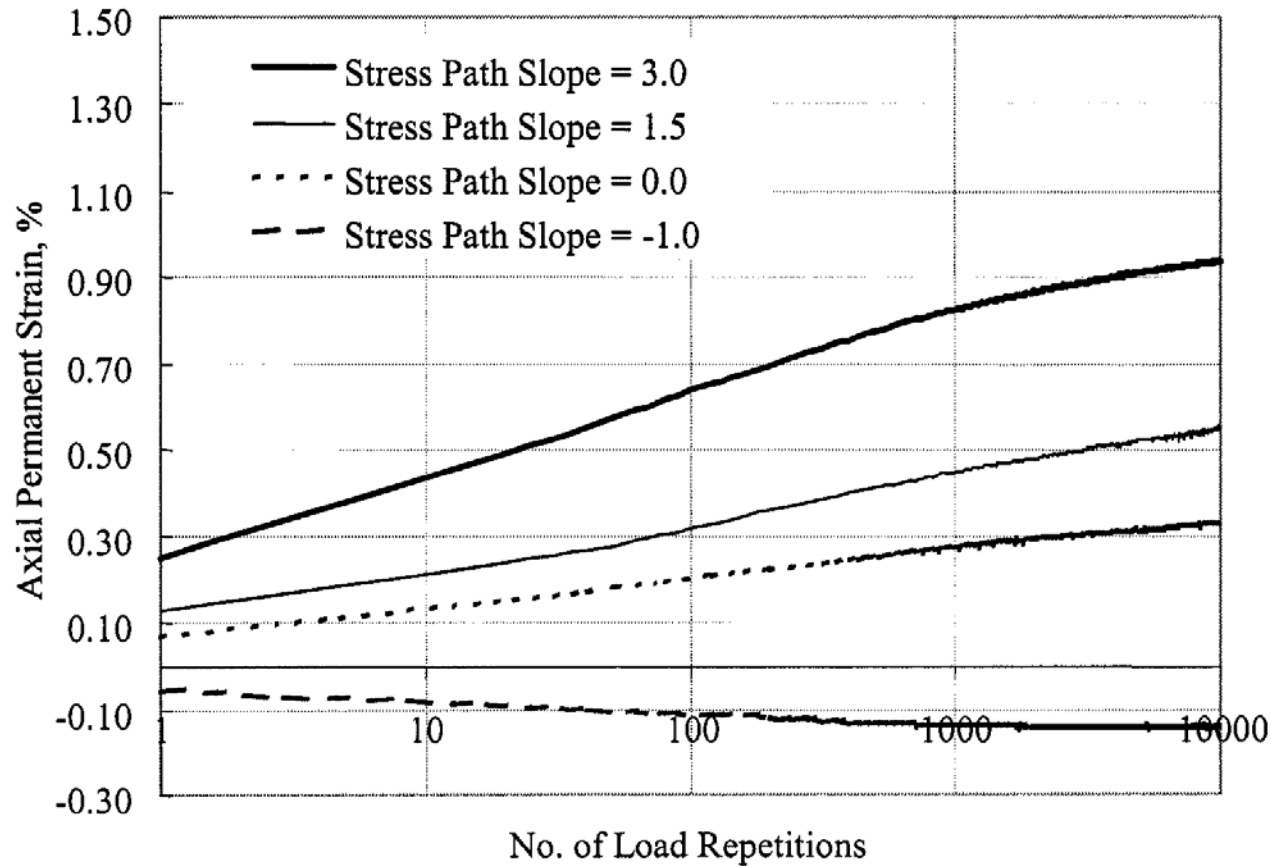
(After Tutumluer, 2005)



$$L = \sqrt{p^2 + q^2}$$

Effect of Slope of Stress Path on Accumulation of Plastic Strain

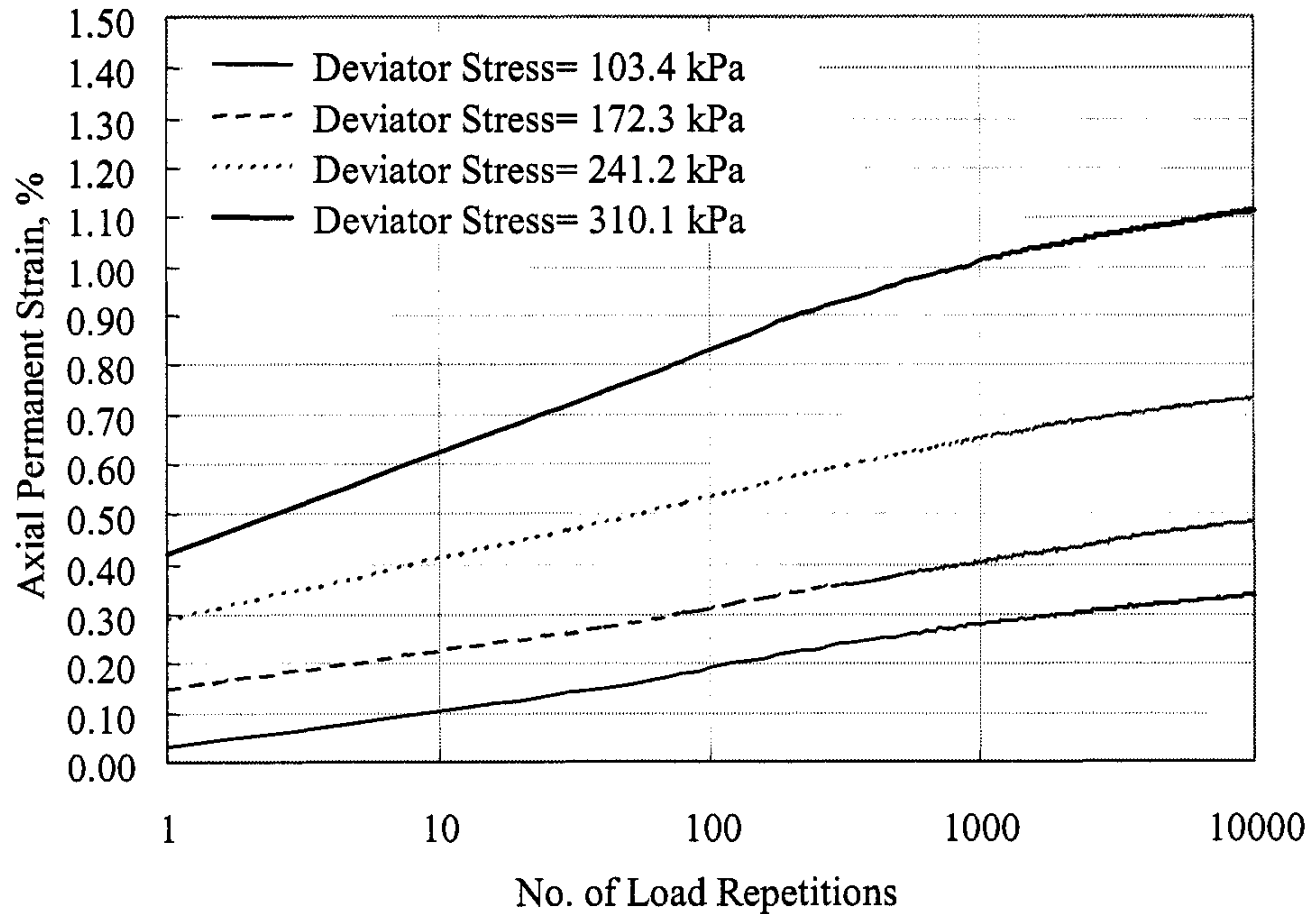
(After Tutumluer, 2005)



$$m = \frac{q}{p}$$

Effect of Deviatoric Stress on Plastic Strain

(After Tutumluer, 2005)



Case Studies

- Case 1: Impact of stabilizers (low levels)
 - Case 2: Impact of subgrade treatment
 - Case 3: Impact of anisotropy
-

Case Study

- **Case 1: Impact of stabilizers**
 - Case 2: Impact of subgrade treatment
 - Case 3: Impact of asphalt thickness
-



Tire Pressure : 100 psi

Contact Radius: 5.5 in

6''

$$E_y = 400,000 \text{ psi}$$

$$\nu = 0.35$$

Linear Isotropic

12''

k_1, k_2 and k_3

$$E_x/E_y$$

$$G_{xy}/E_y$$

$$V_{xx}/V_{xy}$$

Non-linear Anisotropic

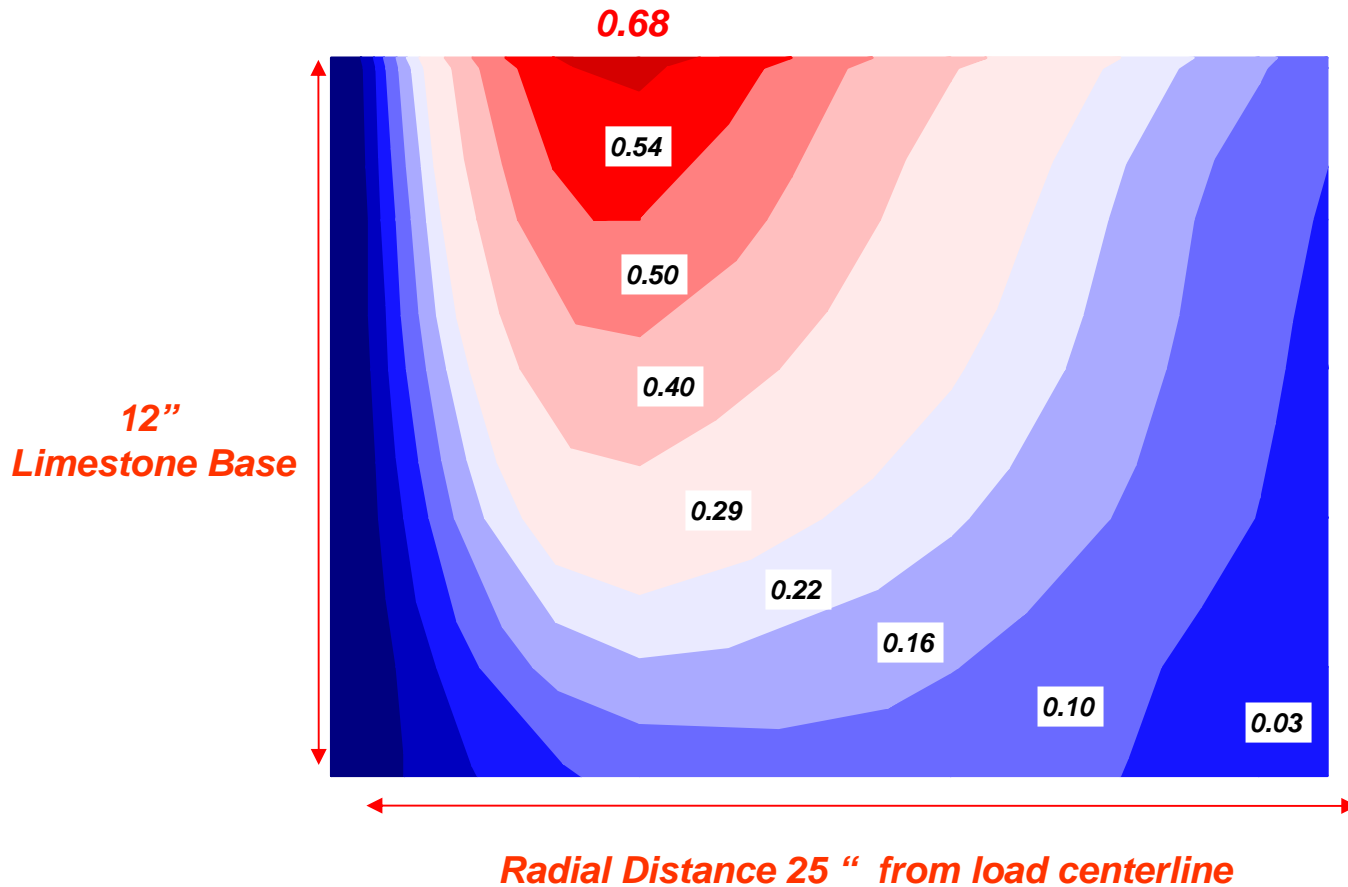
$$E_y = 6000 \text{ psi}$$

$$\nu = 0.45$$

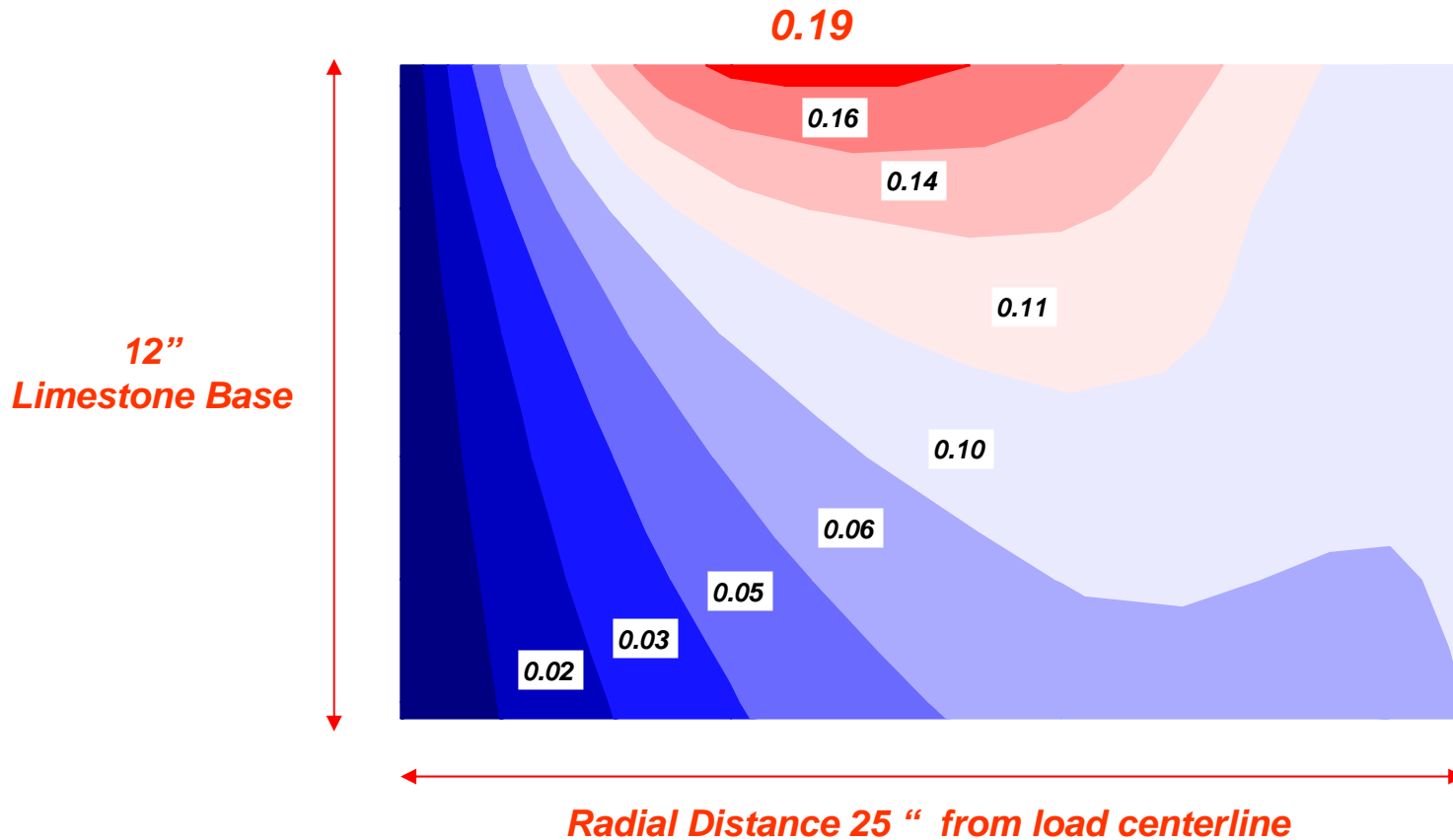
Linear Isotropic

Shear Strength Ratio for Controlled System

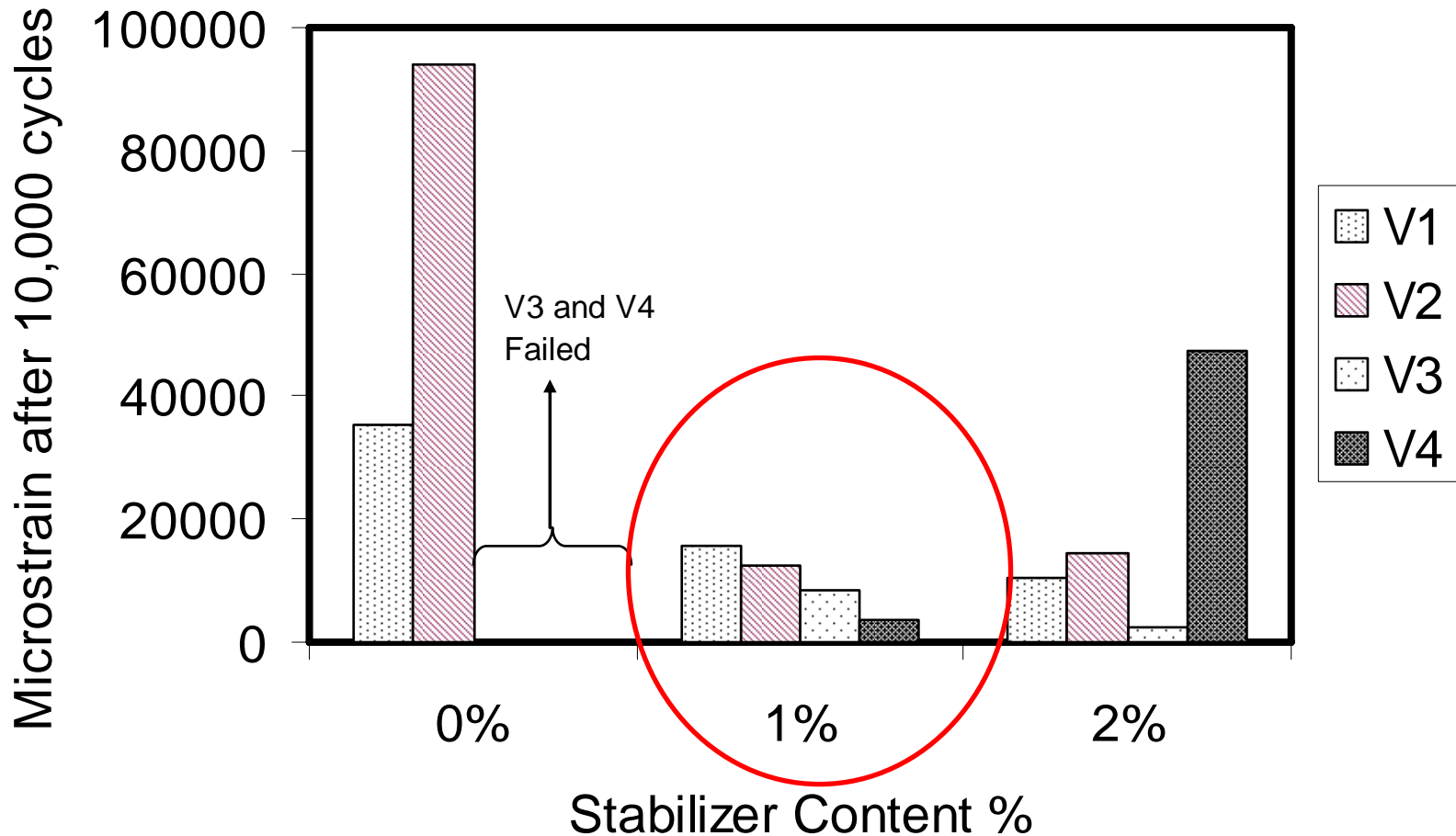
(Uniform gradation ASTM D-2940 without stabilizer)



Shear Strength Ratio for Lime Treated System

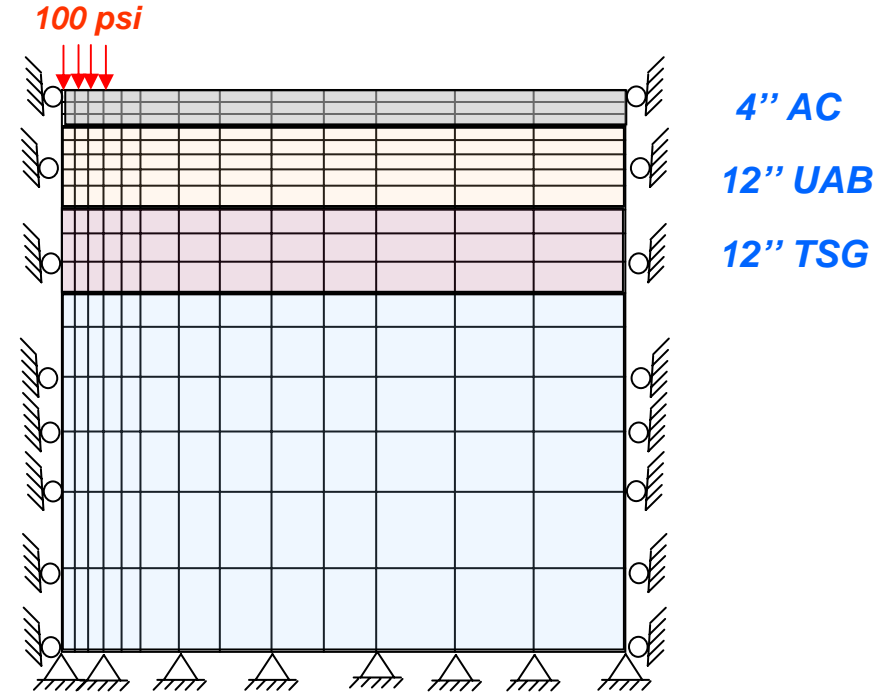
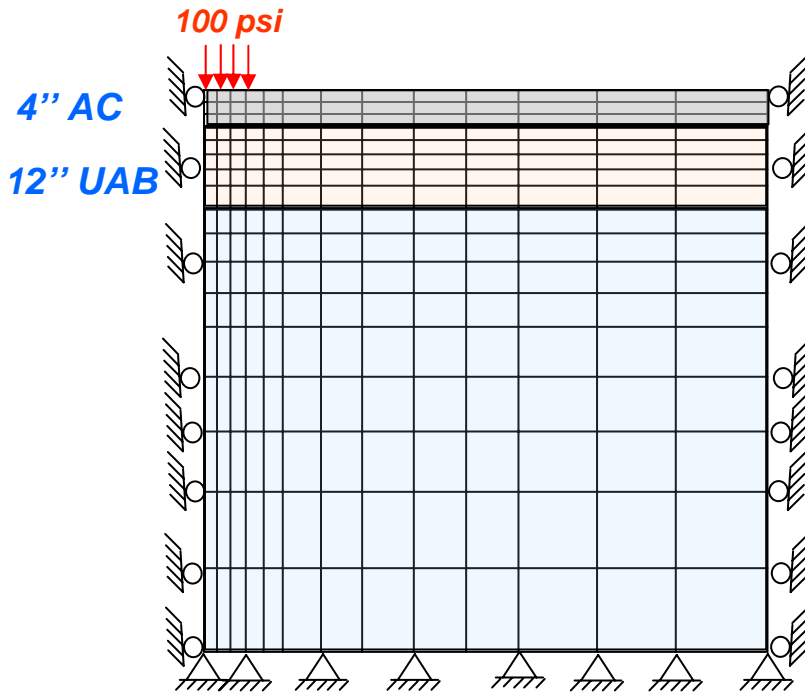


Permanent Deformation Wet of Optimum



Case Study

- Case 1: Impact of stabilizers
 - **Case 2: Impact of subgrade treatment**
 - Case 3: Impact of asphalt thickness
-

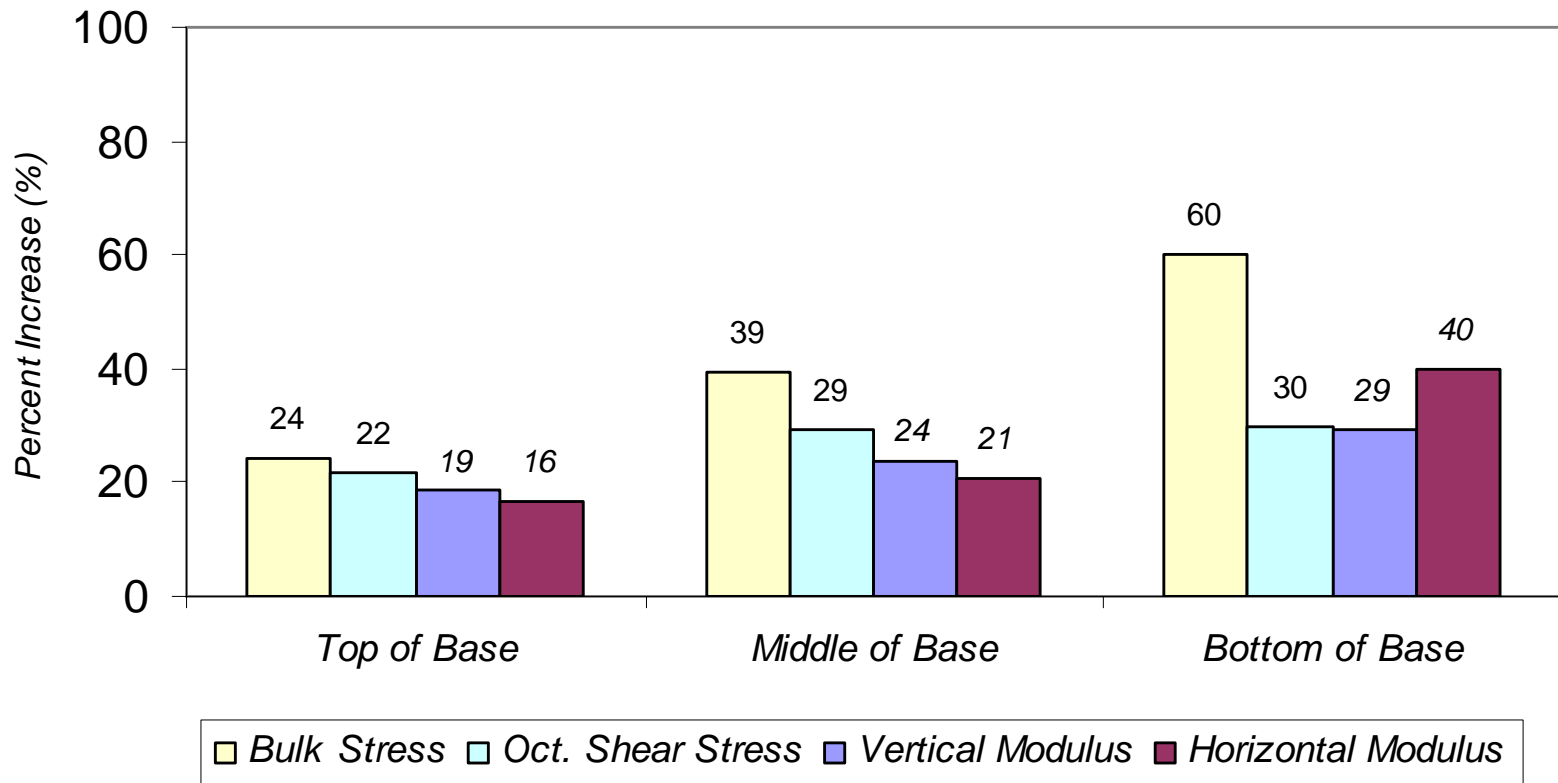


Asphalt	Linear Isotropic	$E_{AC}=400,000 \text{ psi}, \nu = 0.35$
UAB	Nonlinear Anisotropic	Modular Ratio= 0.15
Treated Subgrade	Nonlinear Isotropic	$E_{CTB}=30,000 \text{ psi}, \nu = 0.3$
Natural Subgrade	Nonlinear Isotropic	$E_{SG}=6,000 \text{ psi}, \nu = 0.45$

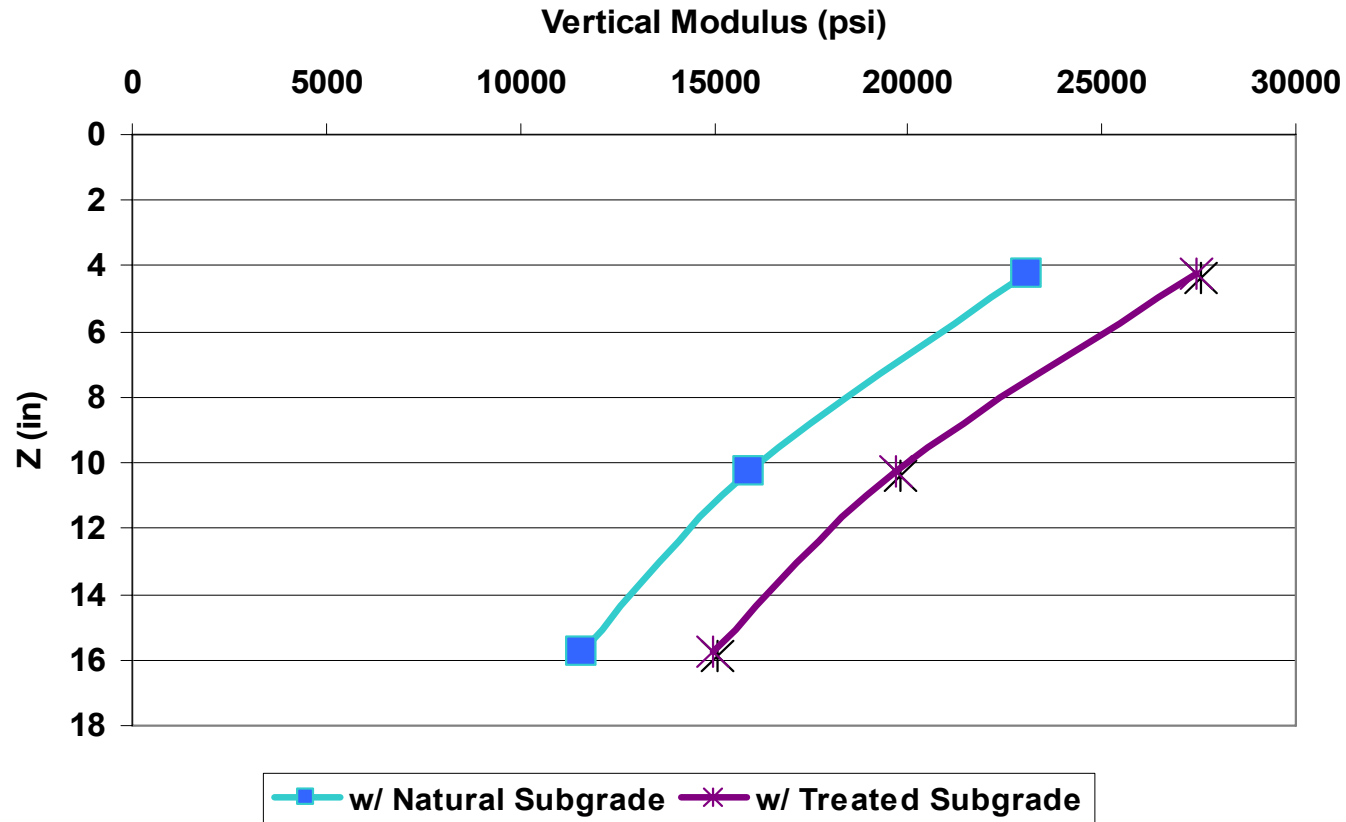
Impact of Subgrade Treatment on Pavement Response

$$E_y = K_1 \left(\frac{\theta}{P_a} \right)^{K_2} \left(\frac{\tau_{oct}}{P_a} + 1 \right)^{K_3}$$

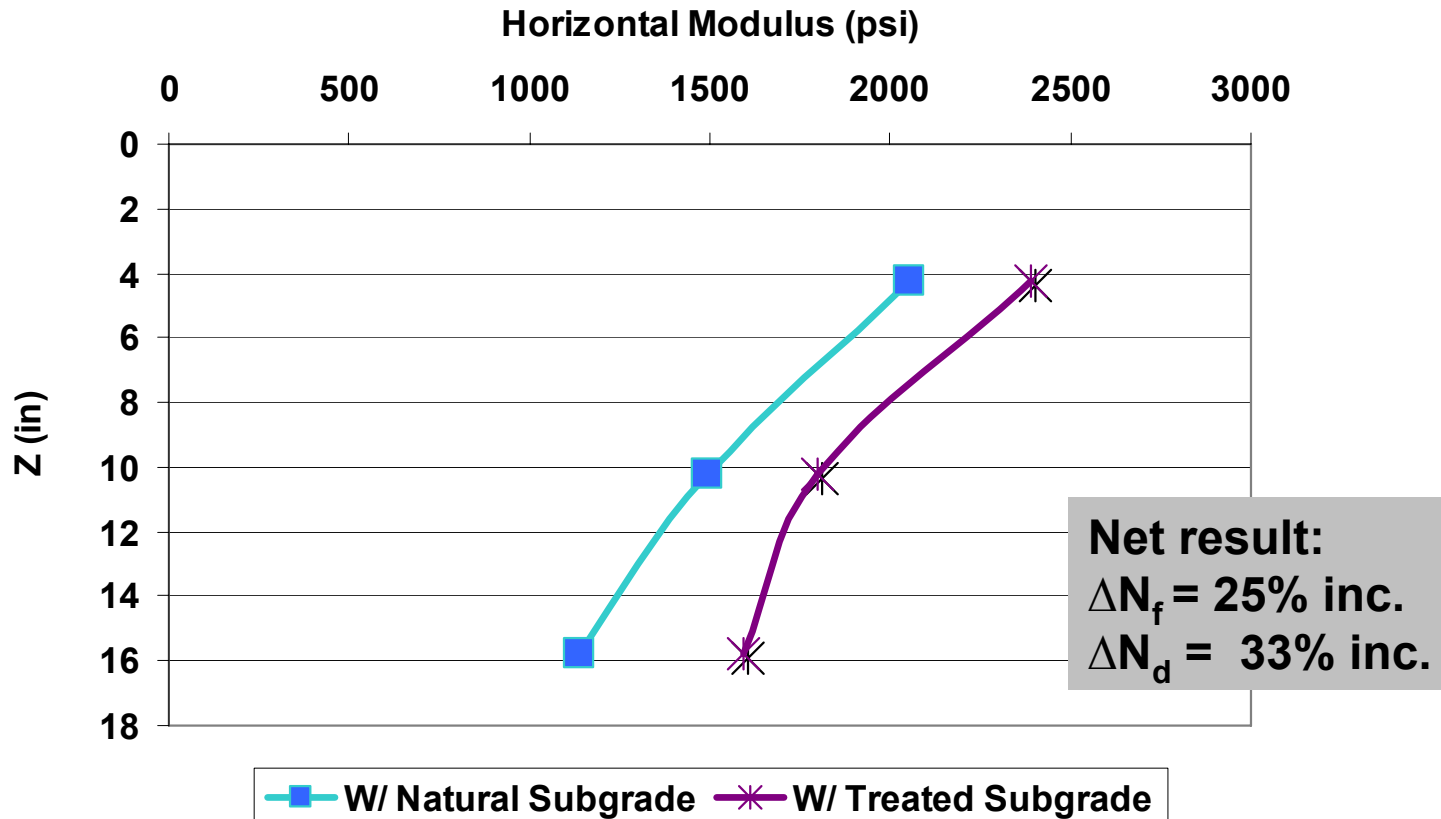
OR-NAB



Impact of Subgrade Treatment on Vertical Modulus in Base Layer



Impact of Subgrade Treatment on Horizontal Modulus in Base Layer



Case Study

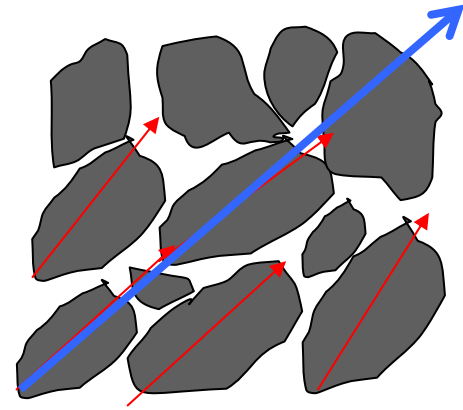
- Case 1: Impact of stabilizers
 - Case 2: Impact of subgrade treatment
 - Case 3: **Impact of anisotropy**
-

Sources of Anisotropy

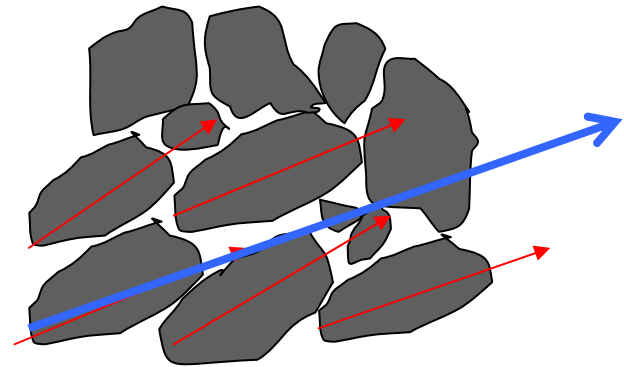
Inherent Anisotropy

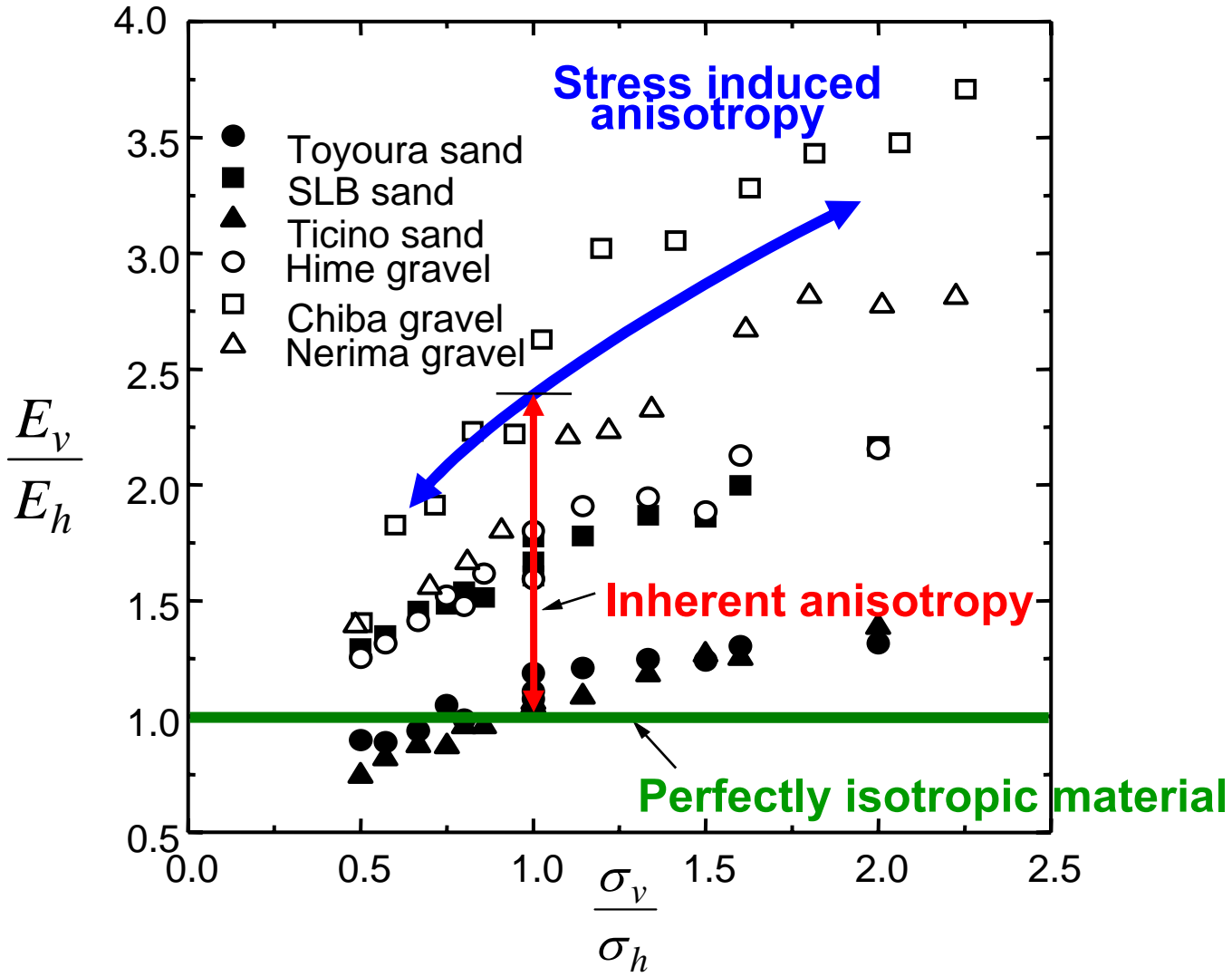
- Particle arrangement and optimum packing is a function of aggregate shape properties.
- Maximum dimension tend to align in the horizontal plane.

Before Compaction



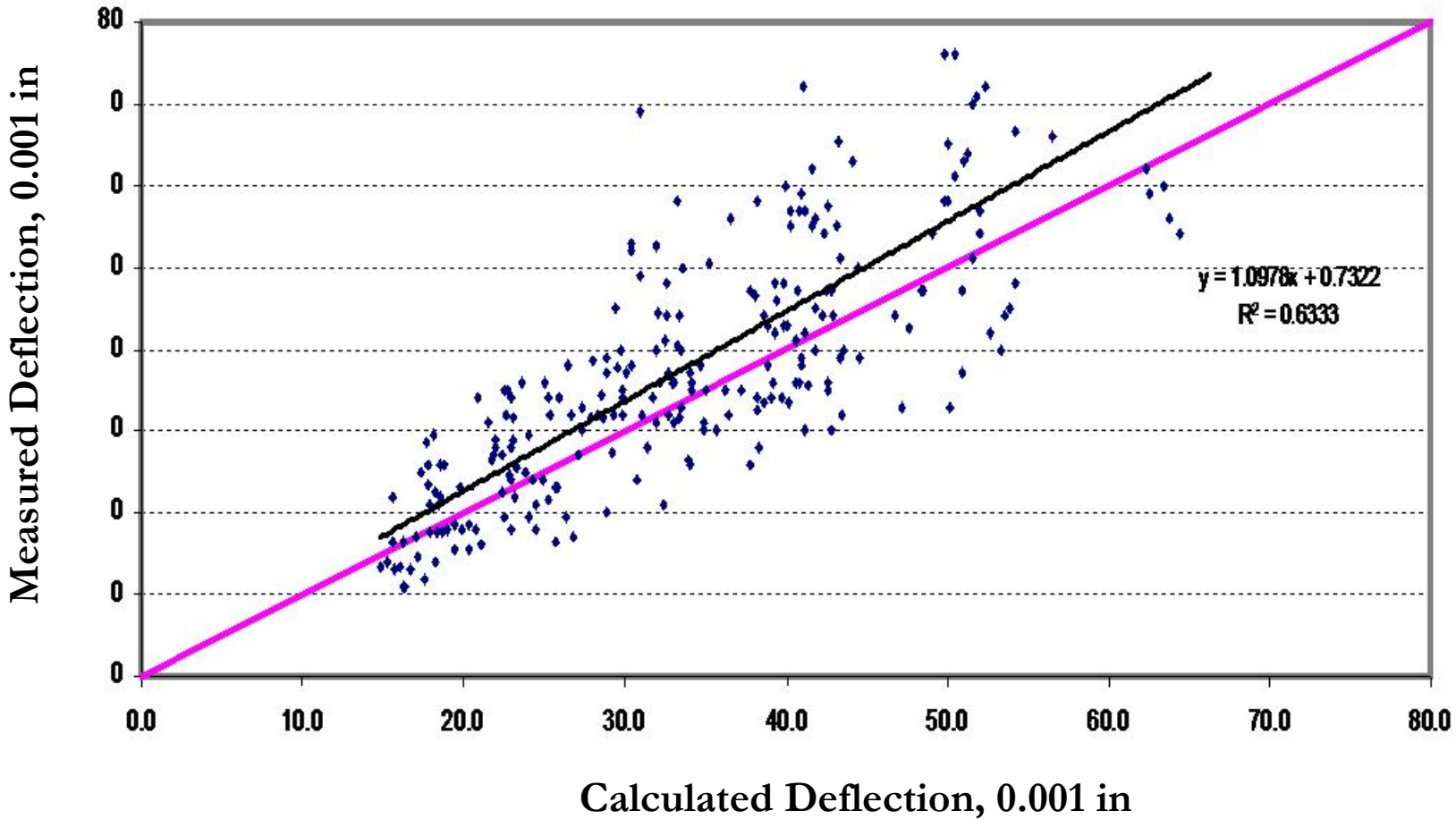
After Compaction





n = 0.3, $\mu = 1.5$

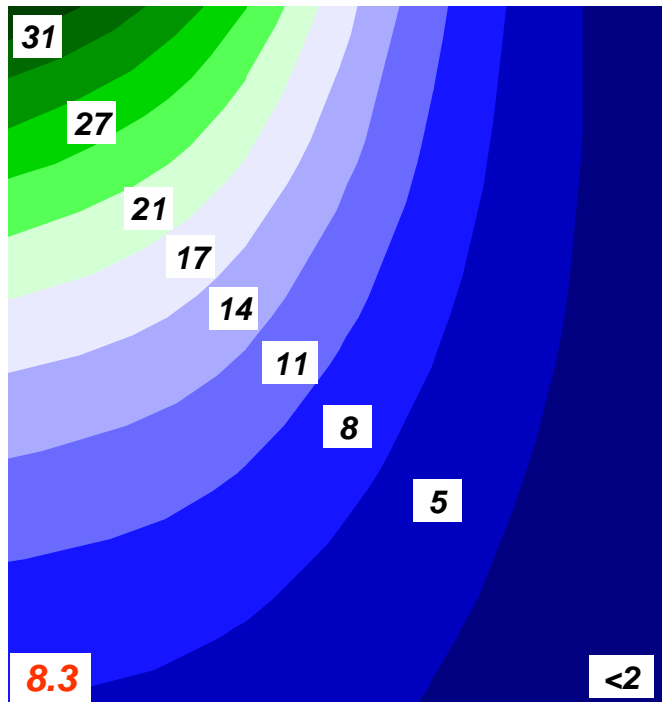
• Anisotropic — Equality Line — Linear (Anisotropic)



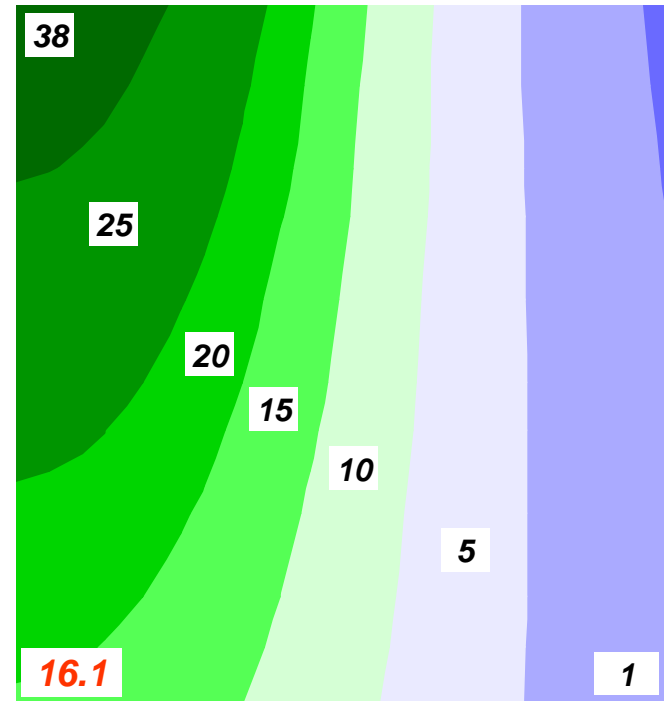
Pavement Response Analysis

Vertical Stress in Base layer

Linear Isotropic
 $E_x = E_y$



Nonlinear Anisotropic
 $E_x = 0.3 E_y$

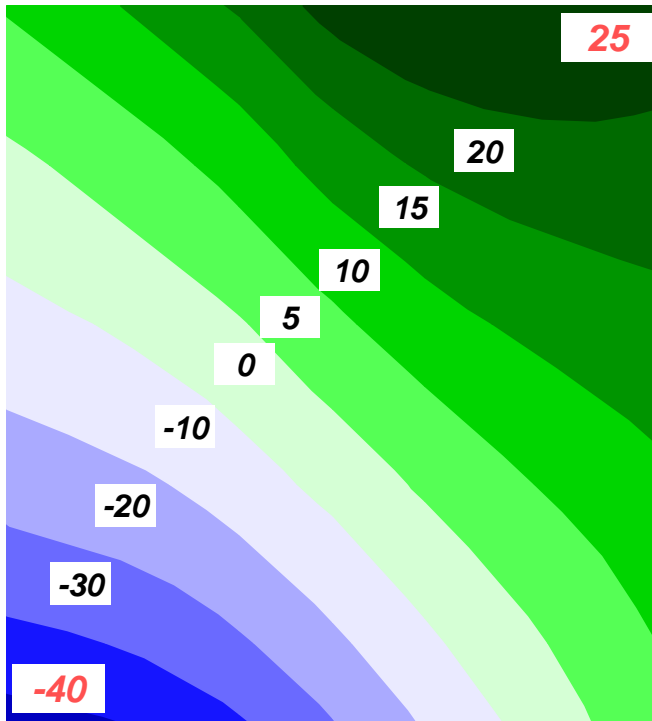


Pavement Response Analysis

Horizontal Stress in Base layer

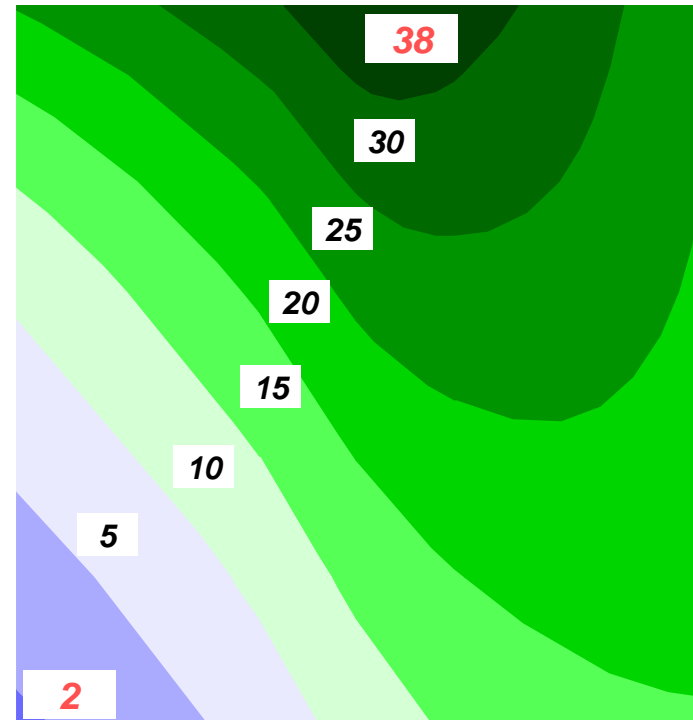
Linear Isotropic

$$E_x = E_y$$

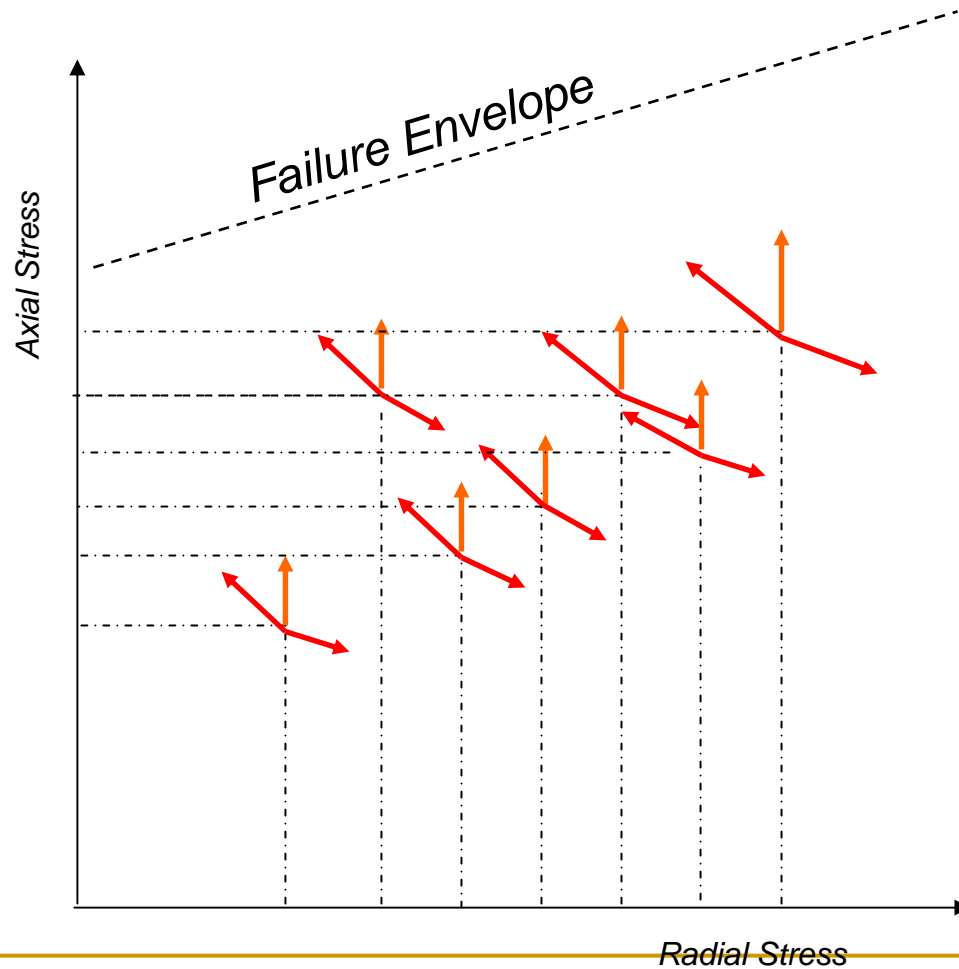


Nonlinear Anisotropic

$$E_x = 0.3 E_y$$



Schematic Stress Path in ICAR Protocol



Modular Ratios as characterizers of Level of Anisotropy

$$\frac{E_x}{E_y} = \left(\frac{K_4}{K_1}\right) \left(\frac{\theta}{P_a}\right)^{(K_5-K_2)} \left(\frac{\tau_{oct}}{P_a}\right)^{(K_6-K_3)}$$

$$\frac{G_{xy}}{E_y} = \left(\frac{K_7}{K_1}\right) \left(\frac{\theta}{P_a}\right)^{(K_8-K_2)} \left(\frac{\tau_{oct}}{P_a}\right)^{(K_9-K_3)}$$

Features of the Aggregate Database

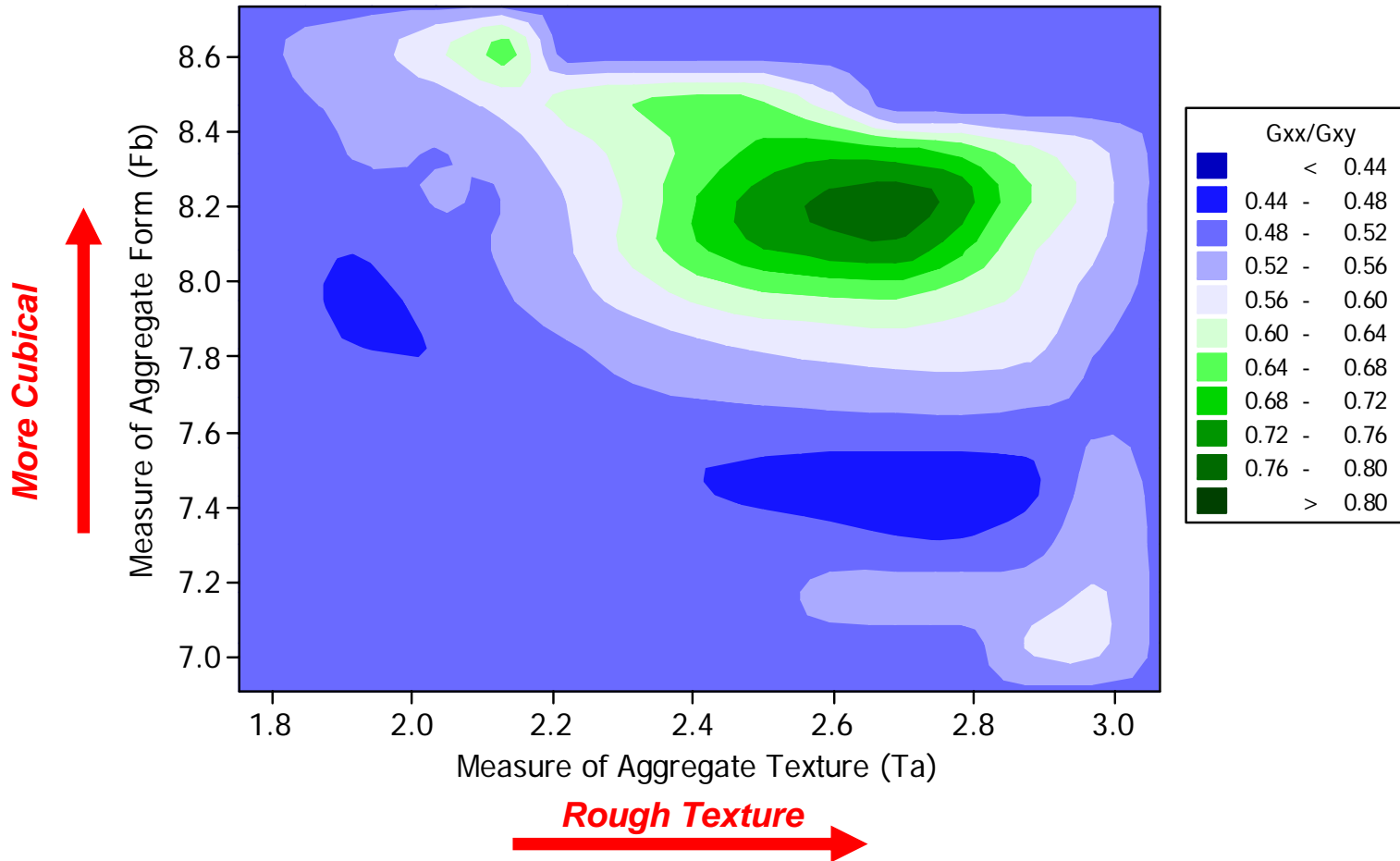
- ✓ K values (K_1 through K_9)
 - ✓ Angularity, Form and Texture (from AIMS)
 - ✓ Dry Compacted Fine (Modified Rigden Test)
 - ✓ Methylene Blue Value
 - ✓ Gradation Parameters
 - ✓ Moisture content
 - ✓ Dry density
 - ✓ Percent fine portion (materials smaller than 75μ)
-

Selected Features

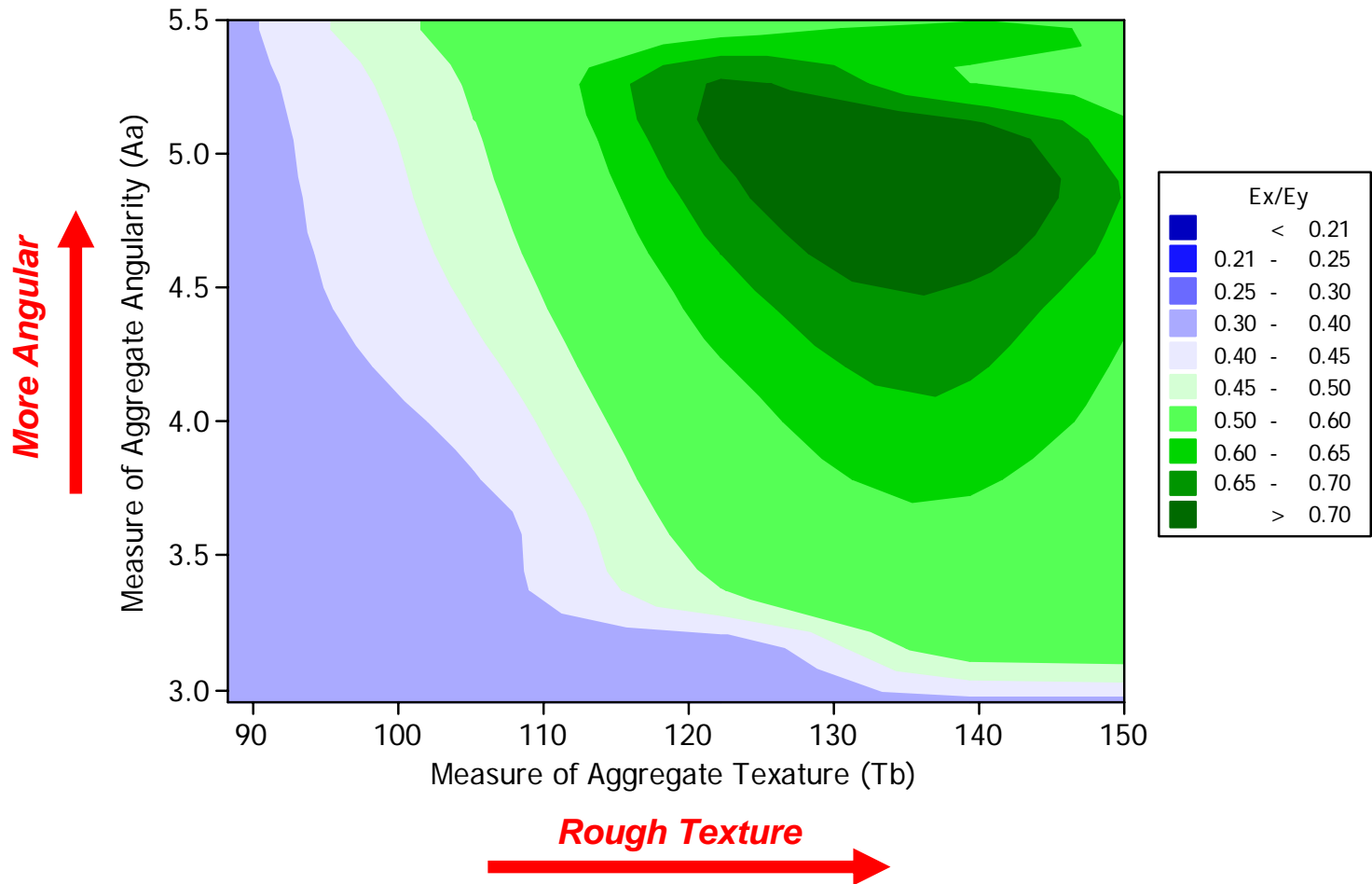
$$\left(\frac{K_4}{K_1}, \frac{K_7}{K_1} \right) = f \left(K_1, K_2, K_3, G_\alpha, \omega, A_\beta, T_\alpha, MB, DCF \right)$$

- K_1 - K_3 : Mechanistic response parameters from triaxial test
- G_α : Gradation parameter (**Cumulative Distribution Shape Factor**)
- ω : Moisture content at the time of testing
- A_β : Angularity parameter (**Cumulative Distribution Scale Factor**)
- T_α : Texture parameter (**Cumulative Distribution Shape Factor**)
- MB: Methylene blue value
- DCF: Dry Compacted fines (percent)

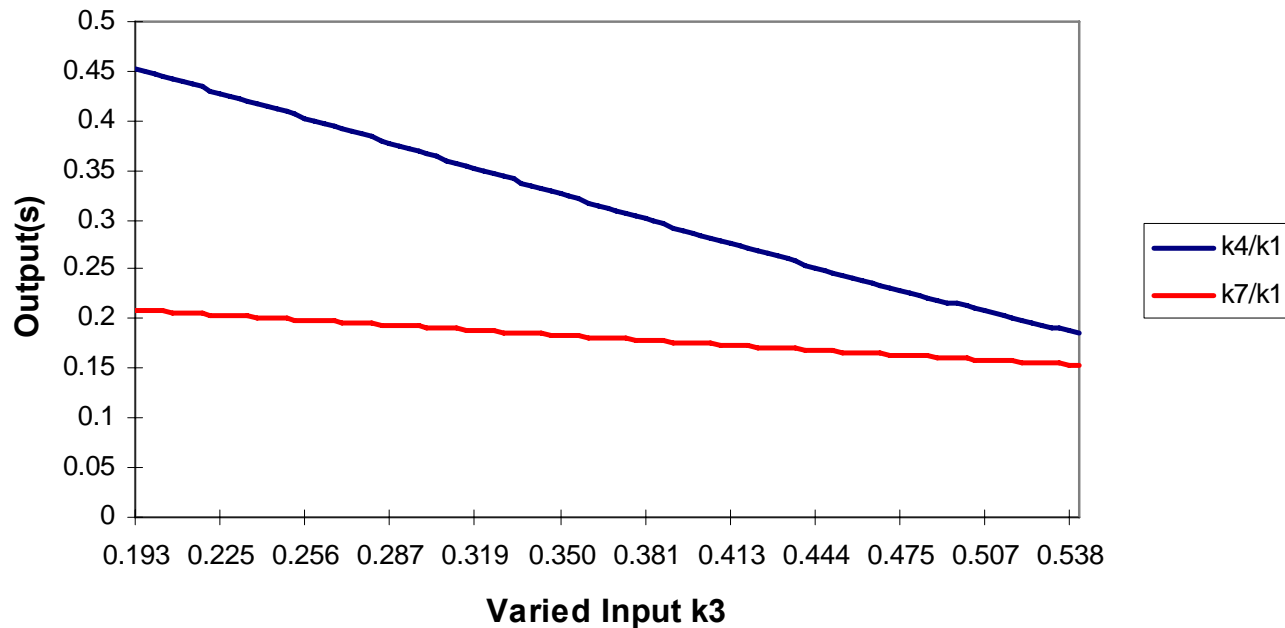
Effect of Aggregate Form and Texture on Anisotropy Level



Effect of Aggregate Angularity and Texture on Anisotropy Level



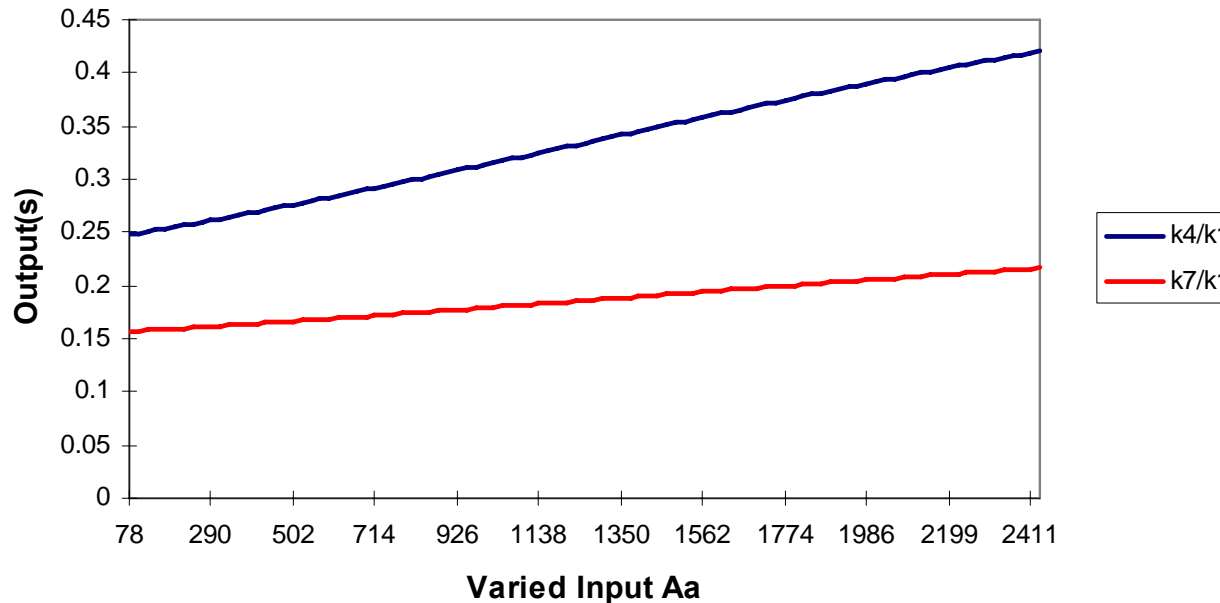
Sensitivity Analysis of the Anisotropic Characterizers - Softening Parameter K_3



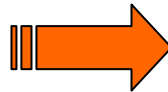
Higher K_3  More Softening  More Anisotropic Behavior

K_4/K_1 (a measure of E_x/E_y) proved to be very sensitive to softening exponent of the constitutive model (K_3)

Sensitivity Analysis of the Anisotropic Characterizers - Aggregate Angularity A_a

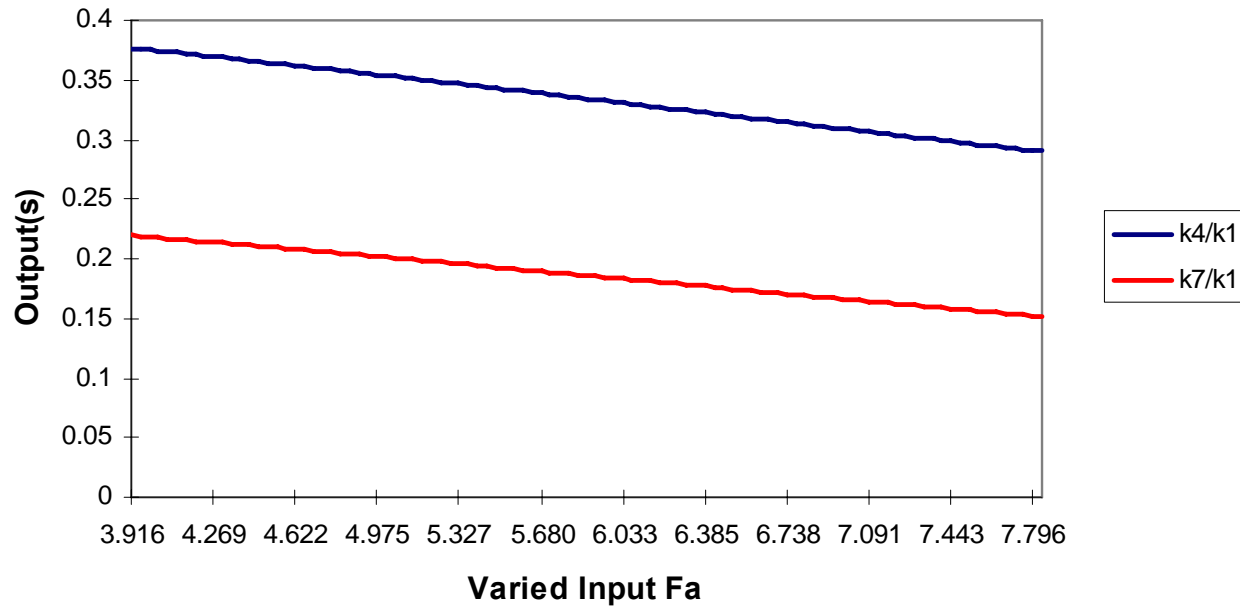


More Angular Particles



Less Anisotropic Behavior

Sensitivity Analysis of the Anisotropic Characterizers - Aggregate Form



More flaky particles



More Anisotropic Behavior

Conclusions

- In order to properly assess the stability of a UAB, a proper constitutive model is required which
 - must accommodate stress sensitivity
 - must accommodate nonlinearity
 - must consider a reasonable stress path
 - should be able to consider anisotropy
-

Conclusions, continued

- The most direct approach to improve the stability of the UAB is through chemical stabilization
 - Low levels of stabilizers can be used to increase the modulus and shear strength without making the system overly rigid
 - Candidates include: Ca(OH)_2 , Portland cement, fly ash, CaCl_2 , kiln dust, etc.
 - The efficacy of this depends on environmental factors
 - The obvious result is a reduced stress ratio within the treated aggregate base (TAB)

Conclusion, continued

- A second method to improve UAB stability is by improving the stress states within the UAB through subgrade stabilization
 - Increase bulk stress throughout UAB
 - Decrease shearing stress ratio in UAB
 - Increase E_y and E_x in UAB
 - Reduce bending stresses in HMA and compressive stresses in untreated subgrade through “ripple effect”
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Conclusions, continued

- Reduce level of anisotropy
 - Address shape, angularity and textural deficiencies of aggregate
 - Add low levels of stabilizer and or fines + stabilizer

