Pavement Subgrade Design Value

Presented by:
Richard L. Boudreau, P.E.
President – Boudreau Engineering, Inc.

Reference Materials

- AASHTO Test Procedure T307-99
- AASHTO 1993 Guide for Design of Pavement Structures

Shortcoming *– neither document provides a ‘how to’ in the selection of a single value to use for design*

Frequently Asked Question

Q: I just received results from a resilient modulus testing program. Which value should I use for my structural design?

A: Depends.

Because soils are typically stress-dependant (non-linear inelastic), the value depends on what level of insitu stress the subgrade soil will be subjected to.

Objectives

- Select a singular value from a test result of 15 data points
- Select a singular value from a group of test results representing a project
- Discuss the similarities between the 1993 Guide and the new M-E Guide

Project Level Testing

Site Sampling (hypothetical)

- 8 samples (representative of soils that could potentially exist in the uppermost zone of finished subgrade)

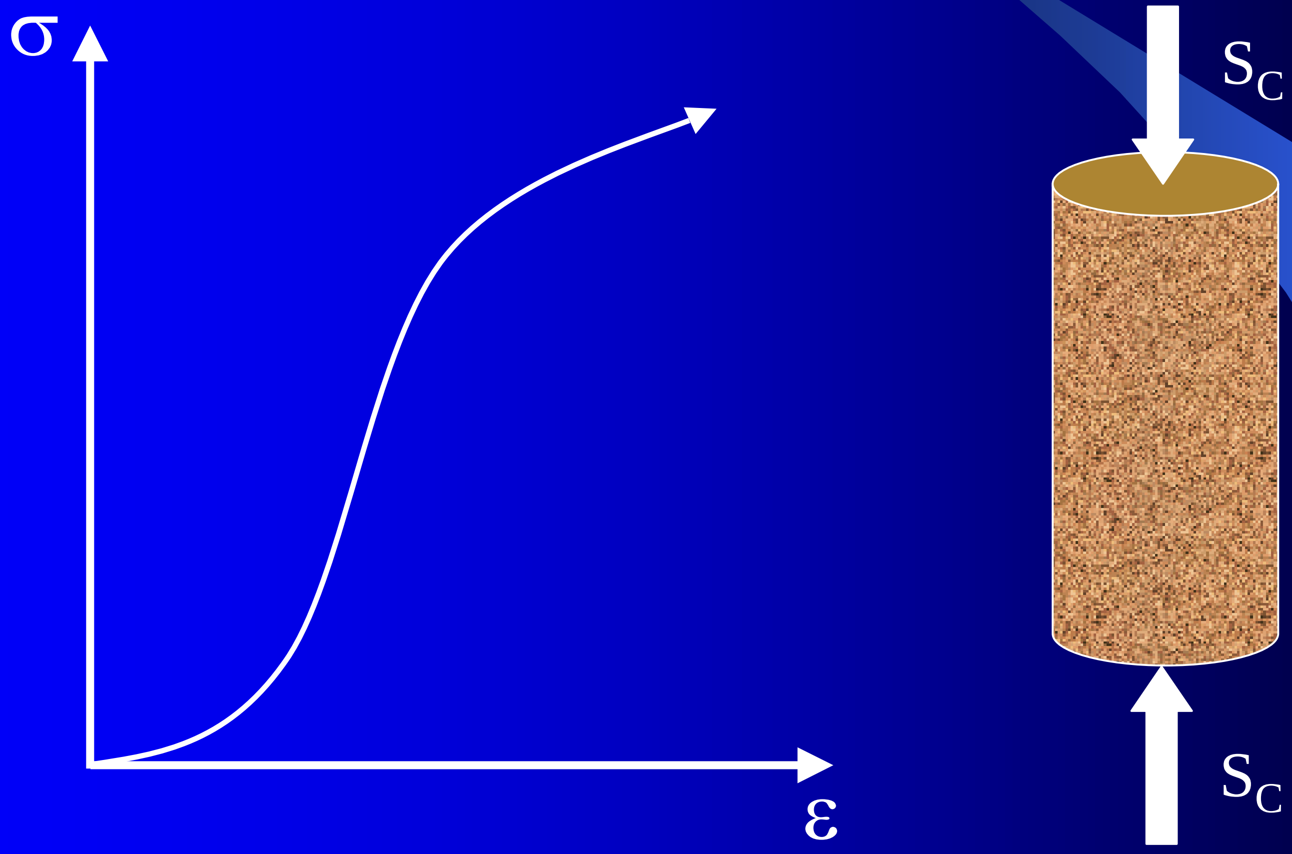
Material Characterization

- Classification
- Proctor
- Resilient Modulus (AASHTO T307-99)

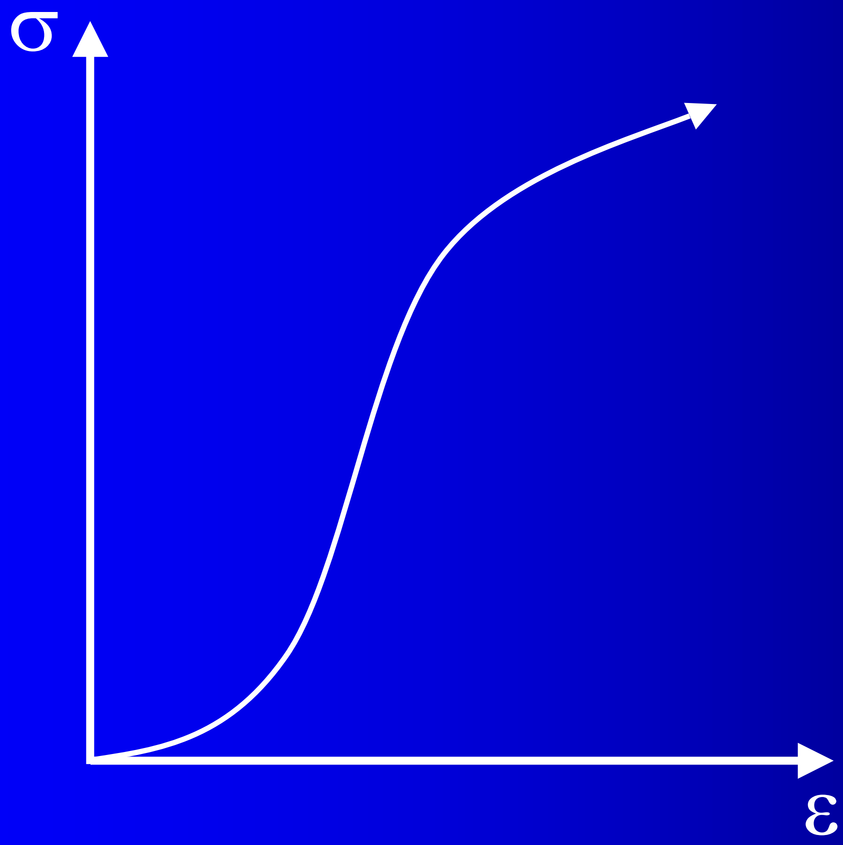
Laboratory Test

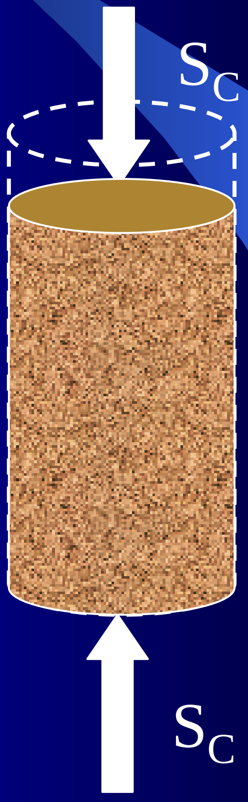
AASHTO T307 Resilient Modulus of Soils and Aggregate Materials

Resilient Modulus, M_r

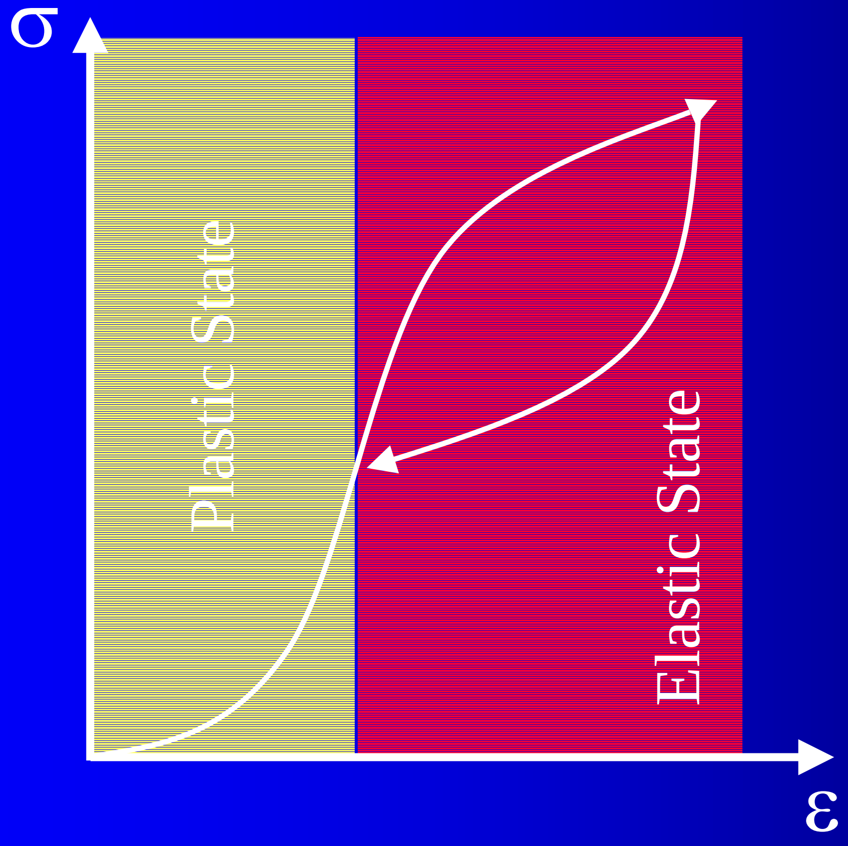


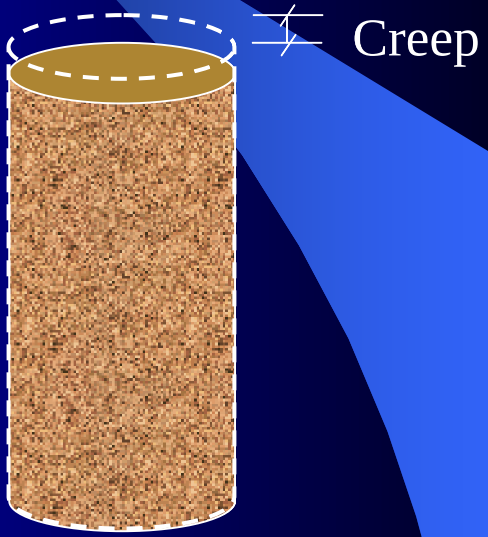
Resilient Modulus, M_r



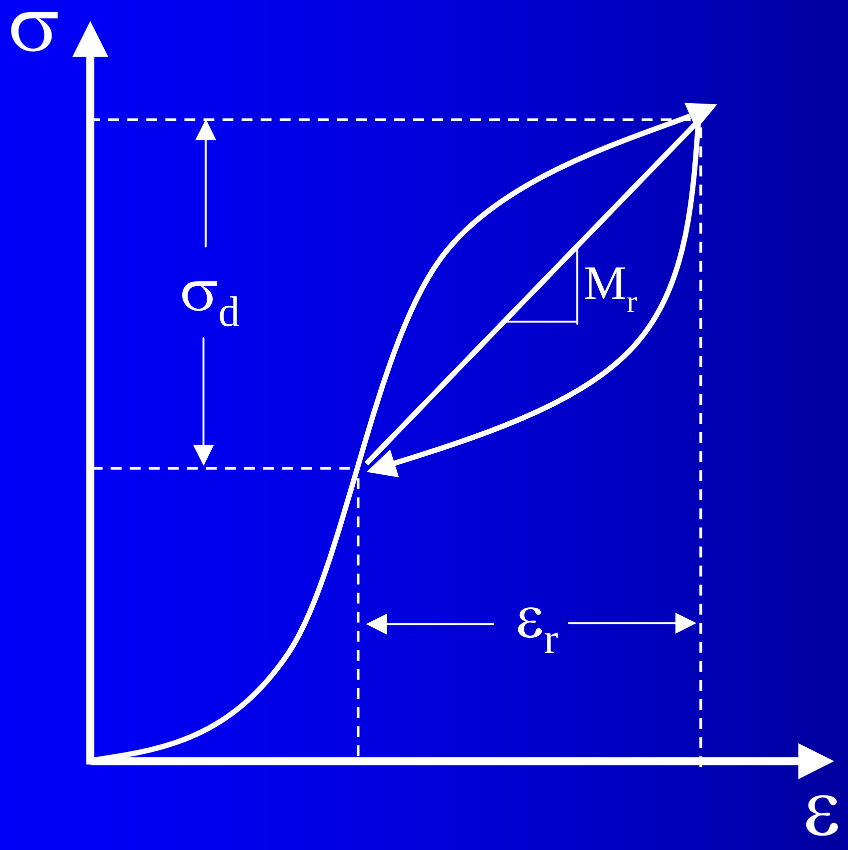


Resilient Modulus, M_r





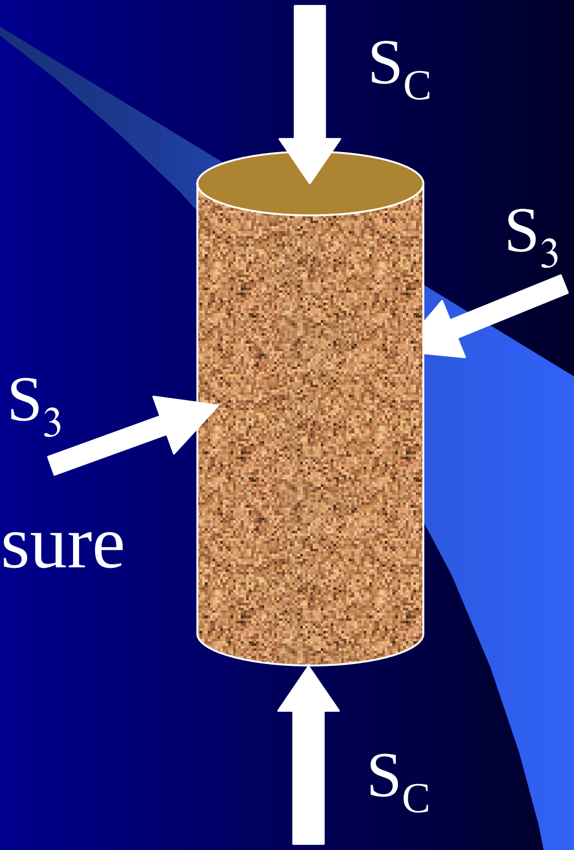
Resilient Modulus, M_r



$$M_r = \frac{\sigma_d}{\varepsilon_r}$$

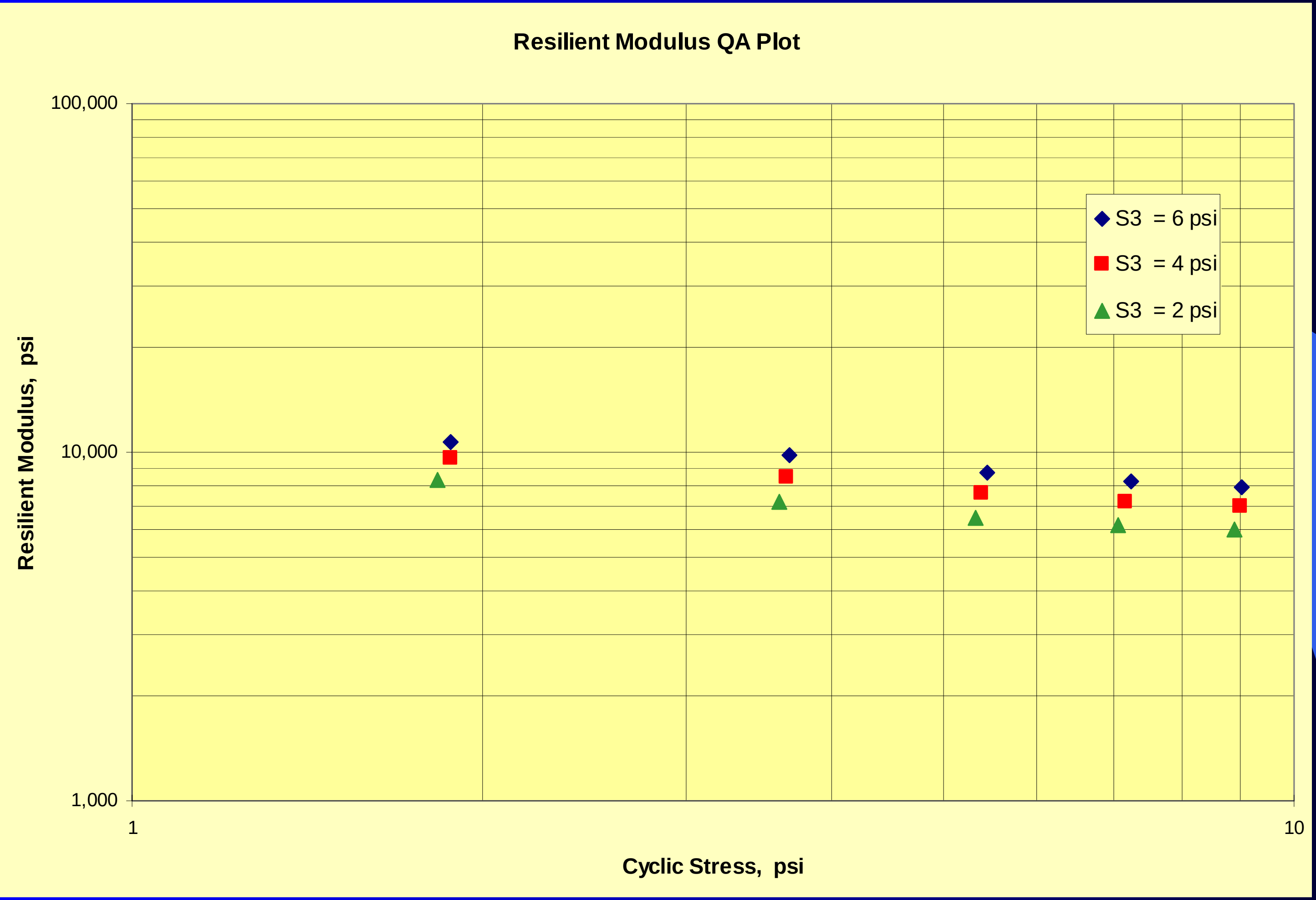
Resilient Modulus, M_r

- Test Soil in Elastic State
- Not a constant
- Dependent on confining pressure
- Dependent on Load

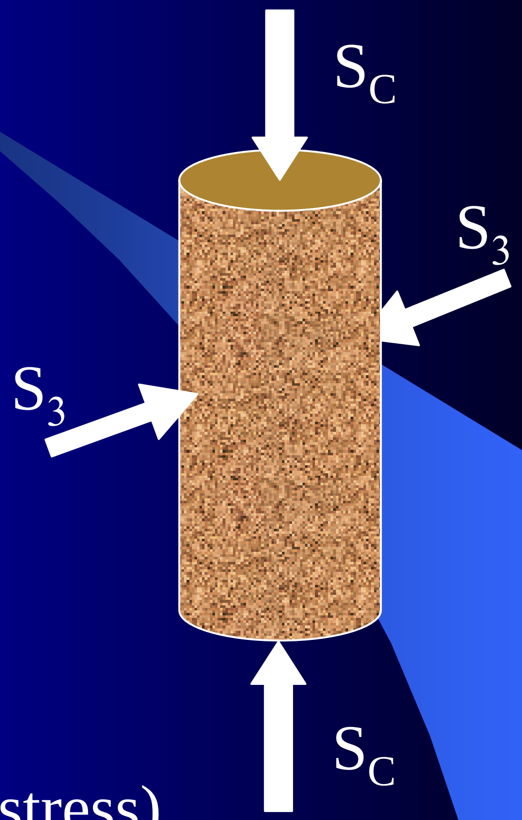


Graphical Representation

$M_r = K1(S_c^{K2})(S_3^{K5})$



Modeling



Constitutive model

Stress-strain response

$$M_r = K1(S_c^{K2})(S_3^{K5})$$

where: S_C = cyclic stress (vertical)

S_3 = confining pressure (horizontal stress)

K1, K2 and K5 = regression constant and coefficients

Testing Results (AASHTO T307-99)

$M_r = K1(S_c^{K2})(S_3^{K5})$

Sample #	Regression Coefficients		
	K1	K2	K5
1	9,838	-0.13187	0.22194
2	6,259	-0.14293	0.21102
3	13,123	-0.14105	0.21493
4	7,502	-0.12825	0.23100
5	10,387	-0.15483	0.23229
6	9,463	-0.05394	0.29379
7	10,294	-0.10049	0.17310
8	8,670	-0.23156	0.21455

Iterative Process

- Step 1: Assume an insitu stress state and compute the resilient modulus using the constitutive model for each sample. Compute the 85th percentile value for the project (M_{ri}).

- Step 2: Use M_{ri} and solve for SN in AASHTO 1993 Guide.

Iterative Process (continued)

- Step 3: Construct a hypothetical pavement cross-section which satisfies the SN criteria. Impart a design load on this pavement structure and perform stress/strain computations (ELSYM5).

- Step 4: Compare the assumed stress values with the calculated stress values. Iterate again if necessary.

Example – Trial 1 (Step 1)

$M_r = K1(S_c^{K2})(S_3^{K5})$

Sample #	Regression Coefficients			Est. Resilient Modulus (psi)*
	K1	K2	K5	
1	9,838	-0.13187	0.22194	11,146
2	6,259	-0.14293	0.21102	6,879
3	13,123	-0.14105	0.21493	14,538
4	7,502	-0.12825	0.23100	8,650
5	10,387	-0.15483	0.23229	11,564
6	9,463	-0.05394	0.29379	13,196
7	10,294	-0.10049	0.17310	11,384
8	8,670	-0.23156	0.21455	8,468
85^{th} percentile value				8,477

*Calculated using constitutive model: $M_r = K1S_c^{K2}S_3^{K5}$ at 4 psi v and h

Example – Trial 1 (Step 2)

- Use M_{ri} = 8,500 psi
- SN = 3.2 (nomograph solution – see paper for specific traffic and other variable inputs)

Example – Trial 1 (Step 3)

- Pavement cross-section satisfying SN 3.2

  AC = 5.0 inches (layer coeff. = 0.44)

  GAB = 8.0 inches (layer coeff. = 0.14)

- ELSYM5 stresses compute to vertical and horizontal stresses of 5.3 and 0.9 psi, respectively (compared to 4 and 4 psi …. not a good match!)

Example – Trial 2 (Step 1)

$M_r = K1(S_c^{K2})(S_3^{K5})$

Sample #	Regression Coefficients			Est. Resilient Modulus (psi)*
	K1	K2	K5	
1	9,838	-0.13187	0.22194	7,957
2	6,259	-0.14293	0.21102	4,973
3	13,123	-0.14105	0.21493	10,458
4	7,502	-0.12825	0.23100	6,103
5	10,387	-0.15483	0.23229	8,096
6	9,463	-0.05394	0.29379	8,676
7	10,294	-0.10049	0.17310	8,757
8	8,670	-0.23156	0.21455	5,973
			85^{th} percentile value	5,979

Calculated using constitutive model: $M_r = K1S_c^{K2}S_3^{K5}$ at 5psi v and 1psi h

Example – Trial 2 (Step 2)

- Use M_{ri} = 6,000 psi
- SN = 3.6 (nomograph solution – see paper for specific traffic and other variable inputs)

Example – Trial 2 (Step 3)

- Pavement cross-section satisfying SN 3.6

  AC = 5.5 inches (layer coeff. = 0.44)

  GAB = 9.0 inches (layer coeff. = 0.14)

- ELSYM5 stresses compute to vertical and horizontal stresses of 3.8 and 0.4 psi, respectively (compared to 5 and 1 psi …. Closer, but not a good enough!)

Example – Trial 3 (Step 1)

$M_r = K1(S_c^{K2})(S_3^{K5})$

Sample #	Regression Coefficients			Est. Resilient Modulus (psi)*
	K1	K2	K5	
1	9,838	-0.13187	0.22194	8,194
2	6,259	-0.14293	0.21102	5,134
3	13,123	-0.14105	0.21493	10,792
4	7,502	-0.12825	0.23100	6,280
5	10,387	-0.15483	0.23229	8,381
6	9,463	-0.05394	0.29379	8,781
7	10,294	-0.10049	0.17310	8,955
8	8,670	-0.23156	0.21455	6,289
			85^{th} percentile value	6,281

*Calculated using constitutive model: $M_r = K1S_c^{K2}S_3^{K5}$ at 4psi v and 1psi h

Example – Trial 3 (Step 2)

- Use M_{ri} = 6,300 psi
- SN = 3.5 (nomograph solution – see paper for specific traffic and other variable inputs)

Example – Trial 3 (Step 3)

- Pavement cross-section satisfying SN 3.5

  AC = 5.5 inches (layer coeff. = 0.44)

  GAB = 8.0 inches (layer coeff. = 0.14)

- ELSYM5 stresses compute to vertical and horizontal stresses of 4.1 and 0.7 psi, respectively (compared to 4 and 1 psi …. Good enough!)

Discussion

- Pavement overburden pressures applied to vertical and horizontal stresses have been ignored.

- This process is a simplified approach to use mechanistic information provided by test results to fully characterize soil and apply this information to structural design.

Recommendations

- A published document is required to standardize the test-to-design process (bridge the gap).

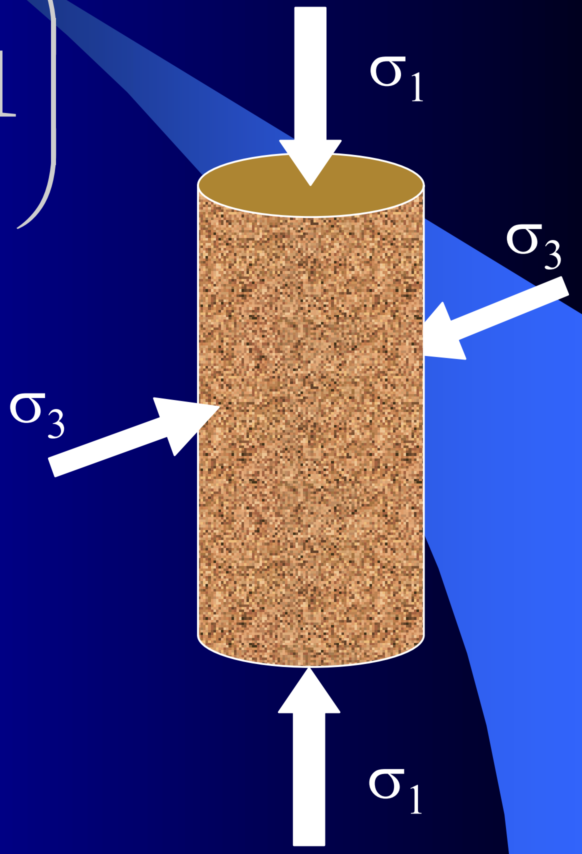
1993 Guide vs. New M-E Guide?

- Both processes require a single value of subgrade M_r for design purposes (Level 2 and 3 design inputs for M-E Guide).
- Level 1 M-E design requires regression constant and coefficient input.
- M-E Guide requires a different constitutive equation based upon a hybrid lab test.

Constitutive Model

$$M_r = k_1 P_a \left(\frac{\theta}{P_a} \right)^{k_2} \left(\frac{\tau_{oct}}{P_a} + 1 \right)^{k_3}$$

$$M_r = k_4 (\sigma_1)^{k_5} (\sigma_3)^{k_6}$$



Thank you – Questions?