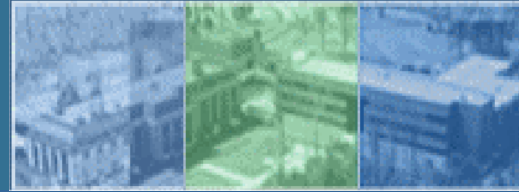


# Modeling Unbound Base And Subgrade Layers For Pavement Performance Prediction

**Cheryl Allen Richter**

**Federal Highway Administration  
Office of Infrastructure Research & Development  
Turner-Fairbank Highway Research Center  
McLean, VA**





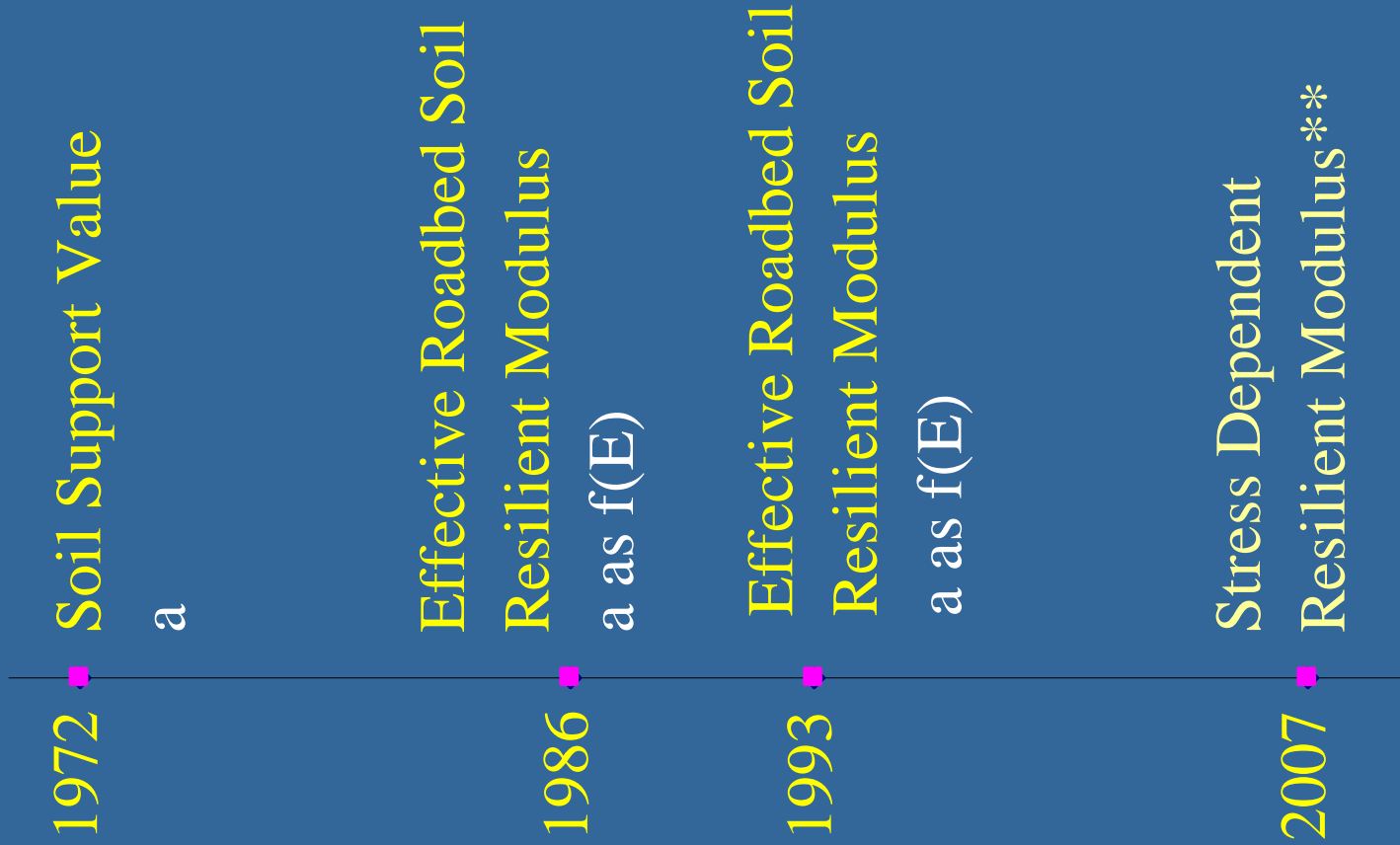
# Modeling Unbound Base and Subgrade Layers for Pavement Performance Prediction

- A little history
- What we know
- The challenges before us





# Soil & Aggregate in AASHTO Design – Flexible





# Soil & Aggregate in AASHTO Design – Rigid

1972 ■ Modulus of Subgrade Reaction

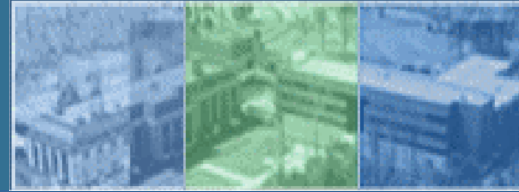
1986 ■ Effective Modulus of Subgrade Reaction

1993 ■ Effective Modulus of Subgrade Reaction

1996 ■ Effective Modulus of Subgrade Reaction

2007 ■ Resilient Modulus\*\*  
(converted to k)



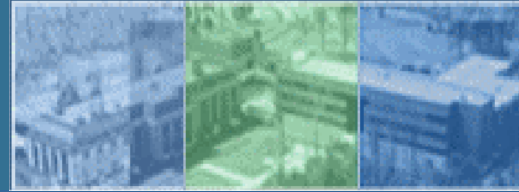


# Unbound Base and Subgrade Layers: What We Know

## Structural Properties ( $M_r$ or $E$ ) vary with...

- Material factors
  - Density
  - Gradation
  - Particle angularity
  - Surface texture
  - Plasticity
  - ...





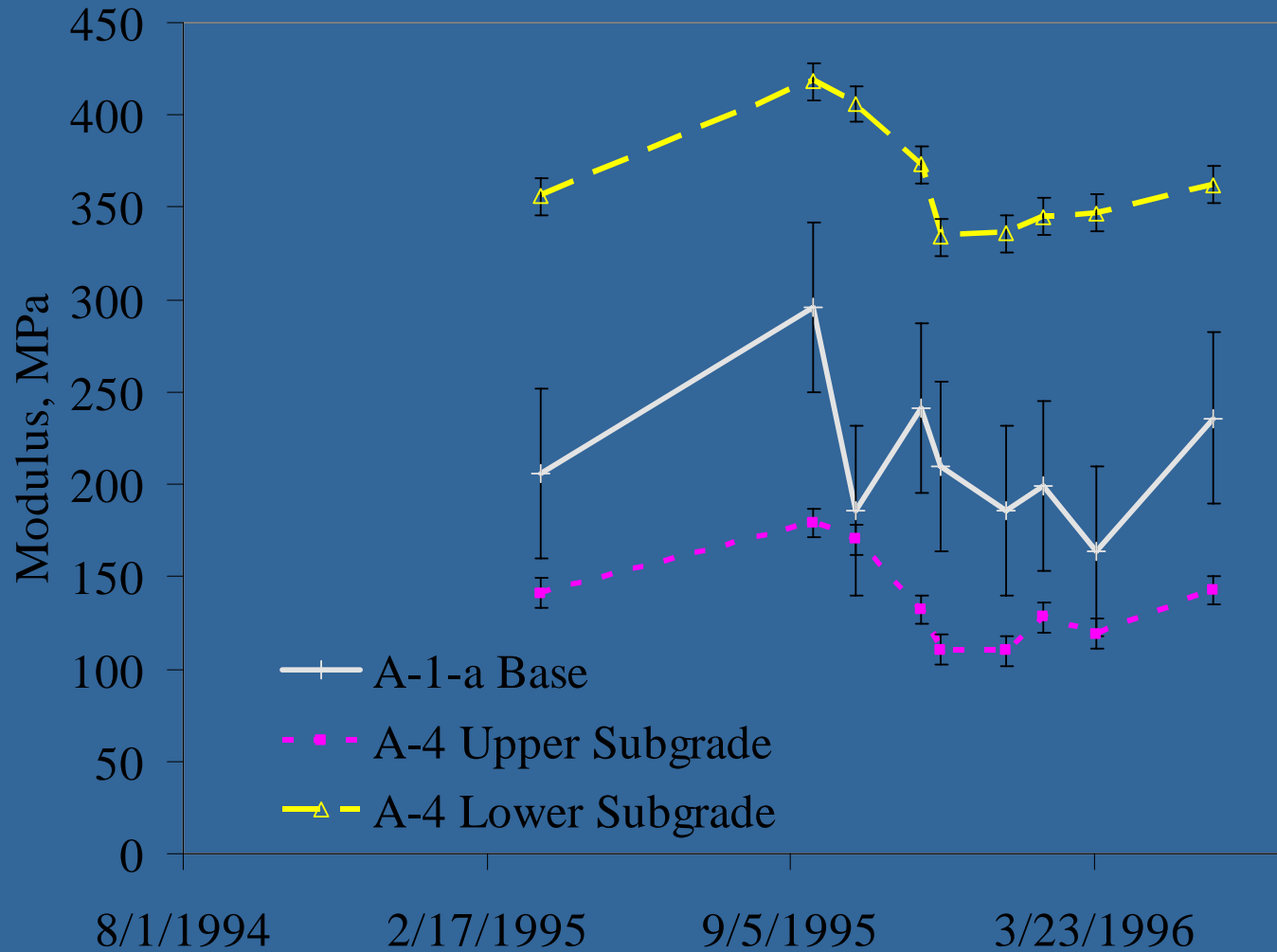
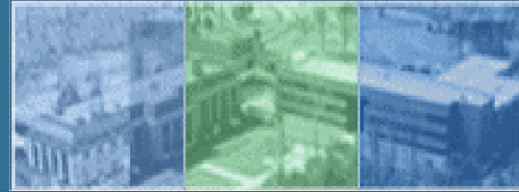
# Unbound Base and Subgrade Layers: What We Know

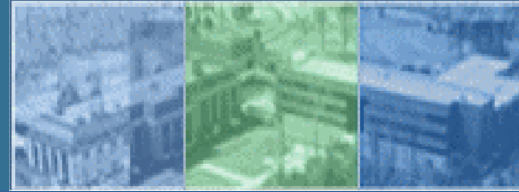
Structural Properties ( $M_r$  or  $E$ ) vary with...

- Environmental conditions
  - Moisture
  - Temperature (frost)



# TURNER-FAIRBANK HIGHWAY RESEARCH CENTER



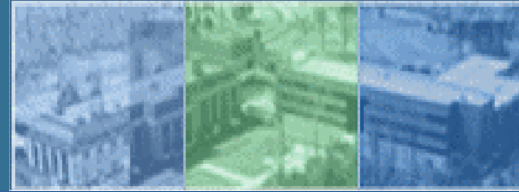


# Unbound Base and Subgrade Layers: What We Know

Structural Properties ( $M_r$  or  $E$ ) vary with...

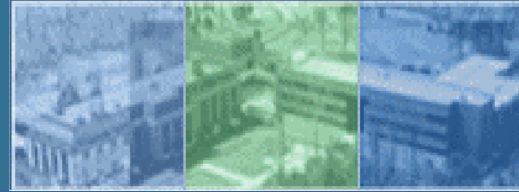
- Stress state
  - Confinement (overburden)
  - Load-induced





So what do we do about modeling?





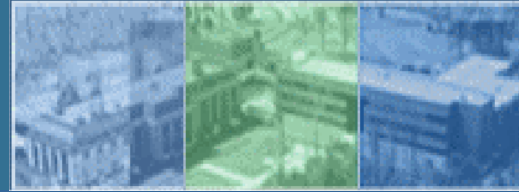
## ME PDG Approach - Stress (Level 1)

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

$$\theta = \sigma_1 + \sigma_2 + \sigma_3$$

$$\tau_{oct} = \frac{1}{3} \sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_1 - \sigma_3)^2 + (\sigma_2 - \sigma_3)^2}$$





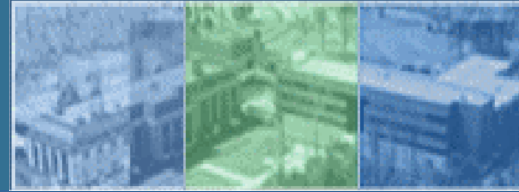
## So what do we do about modeling? ME PDG Approach – Moisture (All Levels)

$$\log \frac{M_r}{M_{ropt}} = a + \frac{b - a}{1 + \text{EXP} \left[ \ln \frac{-b}{a} + k_m * (S - S_{opt}) \right]}$$

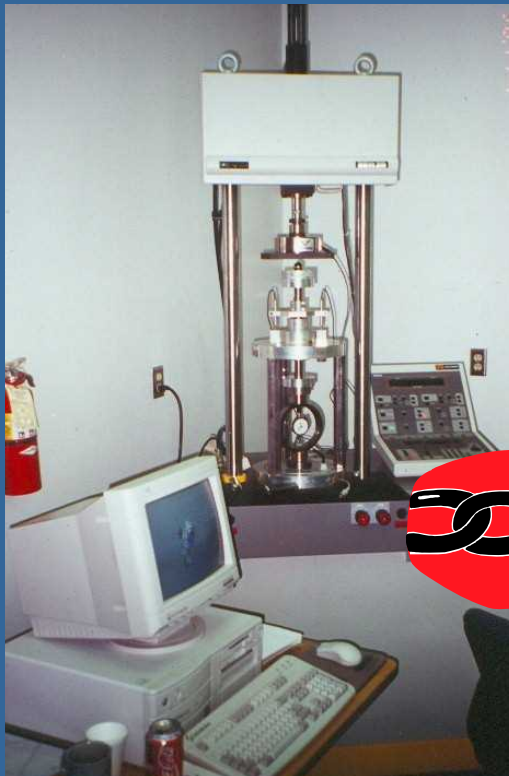
$$a = \min \left[ \log \left( M_r / M_{ropt} \right) \right]$$

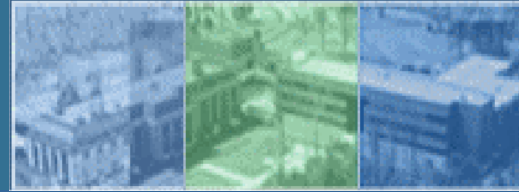
$$b = \max \left[ \log \left( M_r / M_{ropt} \right) \right]$$





## The Challenges Before Us





$$E = k_1 P_a (\theta/P_a)^{k_2} (\tau/P_a + 1)^{k_3}$$

EXPECTATION

$$k_2 > 0$$

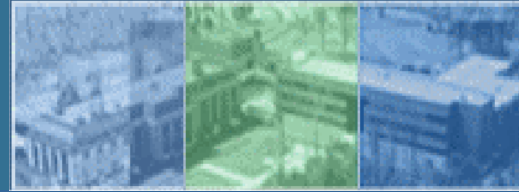
$$k_3 < 0$$

REALITY

$$k_2 < 0$$

$$k_3 > 0$$

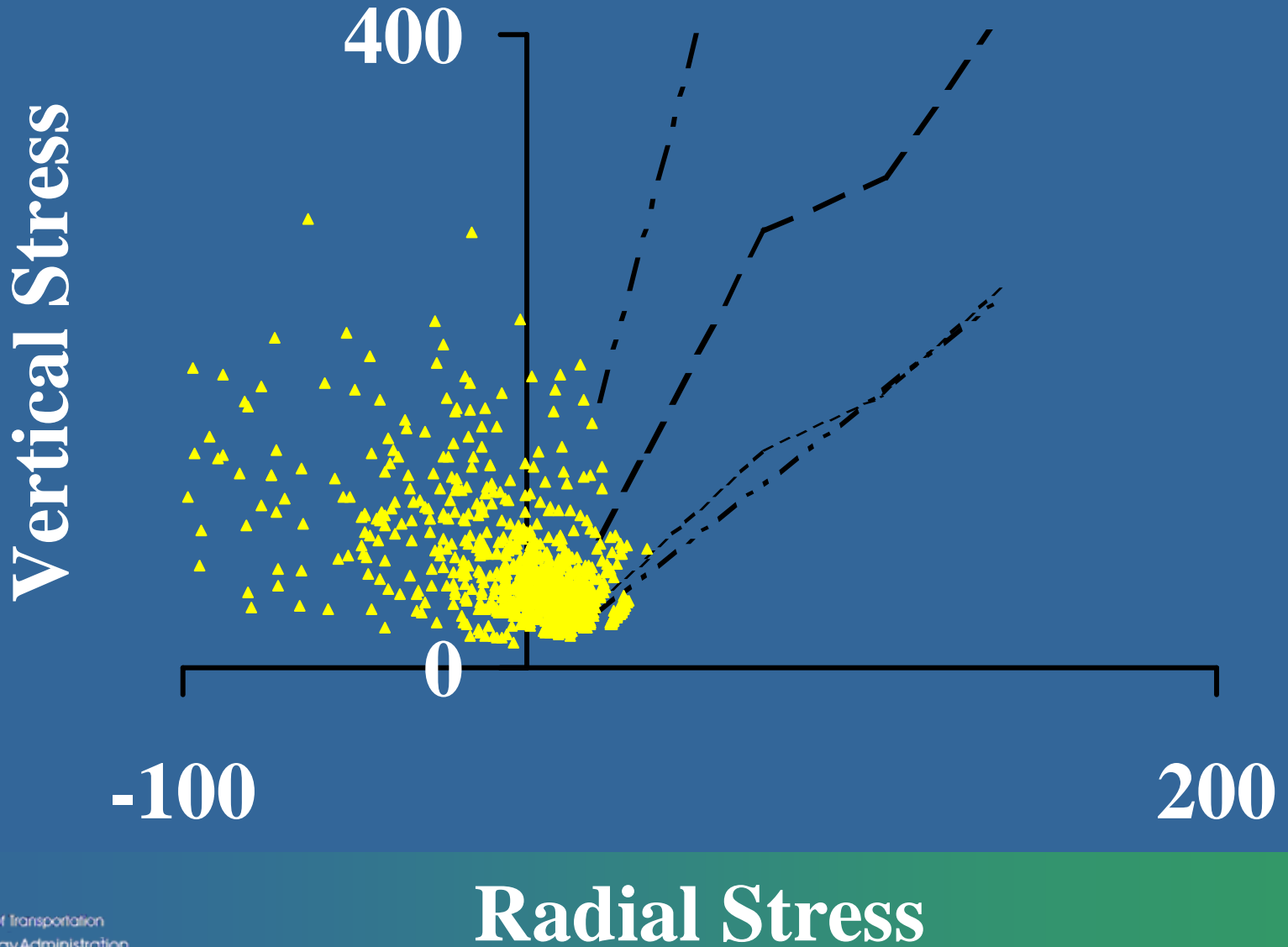
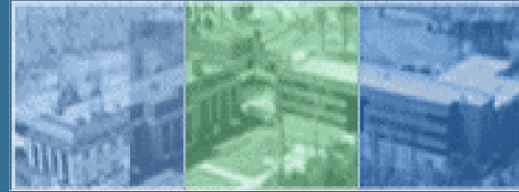


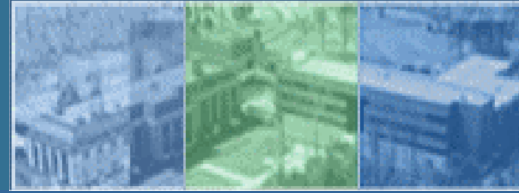


## The Challenges Before Us Applied Stresses

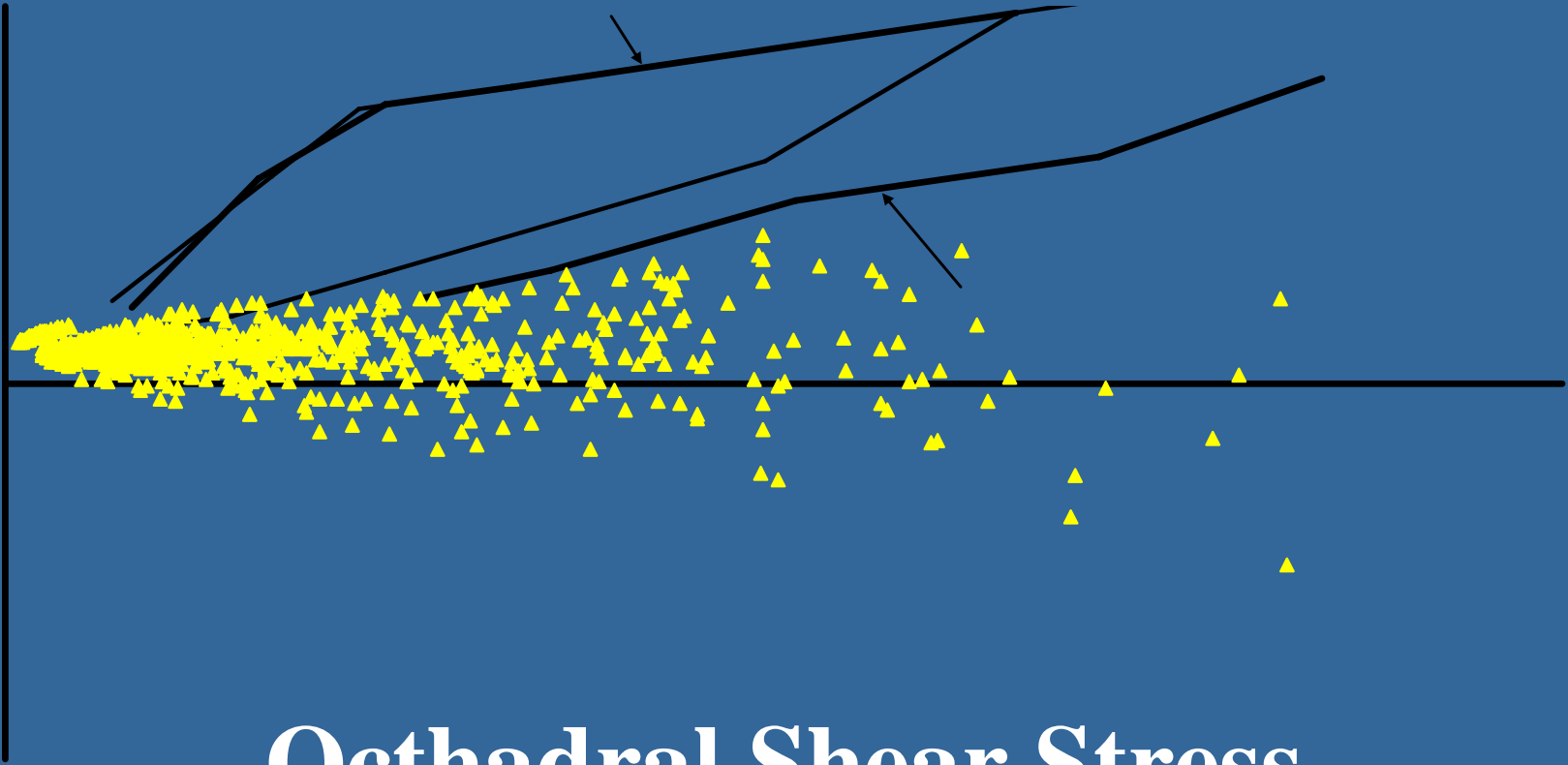
<b>Lab</b>	<b>Field</b>
<b>Measured</b> <b>Independent of <math>M_r</math></b> <b>Compressive</b> <b>Independent</b> <b>Apply to Sample</b>	<b>Computed</b> <b><i>NOT</i> Independent of <b>E</b></b> <b>Sometimes Tensile</b> <b><i>NOT</i> Independent</b> <b>Point-Specific</b>





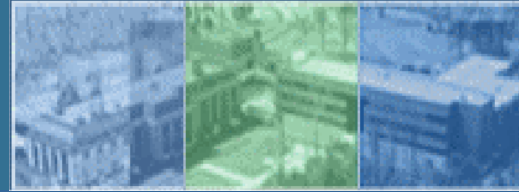


Bulk Stress



Octahedral Shear Stress

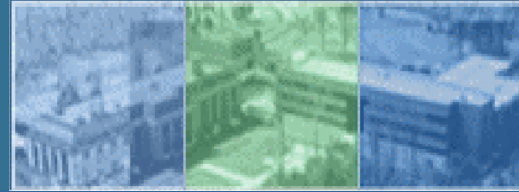




# Implications for Modeling

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



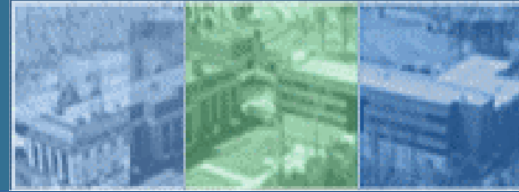


# The Challenges Before Us

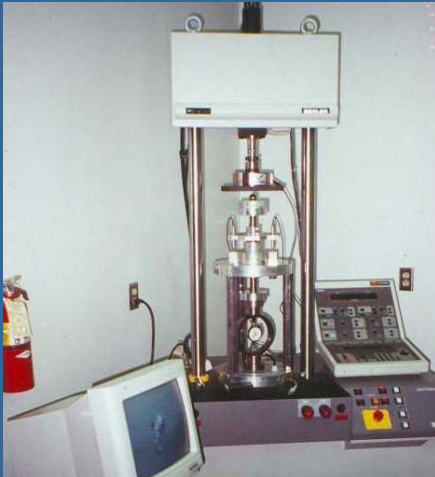
## Improvements in:

- Pavement Structural Models
- Material Constitutive Models
- Testing & Data Interpretation Procedures  
(FWD & Backcalculation?)





## The Challenges Before Us





# Soil & Aggregate in AASHTO Design

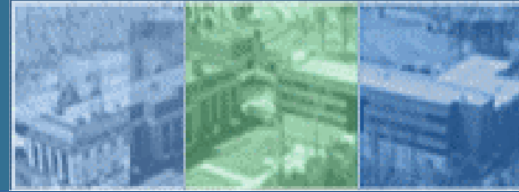
1972 Modulus of Subgrade Reaction

1986 Effective Roadbed Resilient Modulus or Modulus of Subgrade Reaction,  $a$  as  $f(M_f)$

2007 Stress Dependent Resilient Modulus  $**$  (converted to  $k$  for PCC)

20?? "Universal" foundation parameter(s) as  $f(\text{stress, moisture...})$





Thank you!

