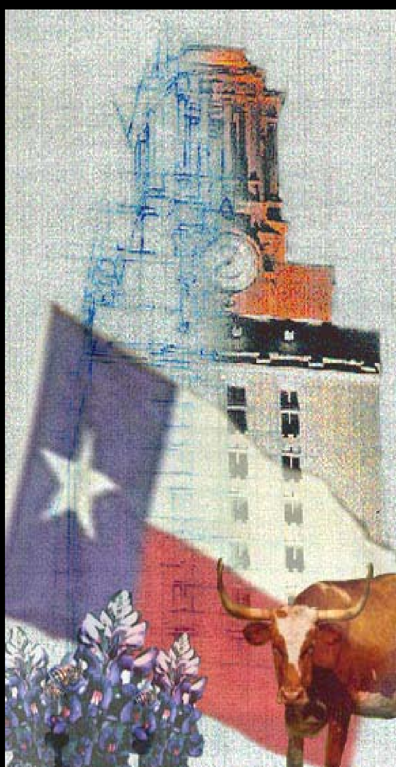
Development of a New Family of Normalized Modulus Reduction and Material Damping Curves



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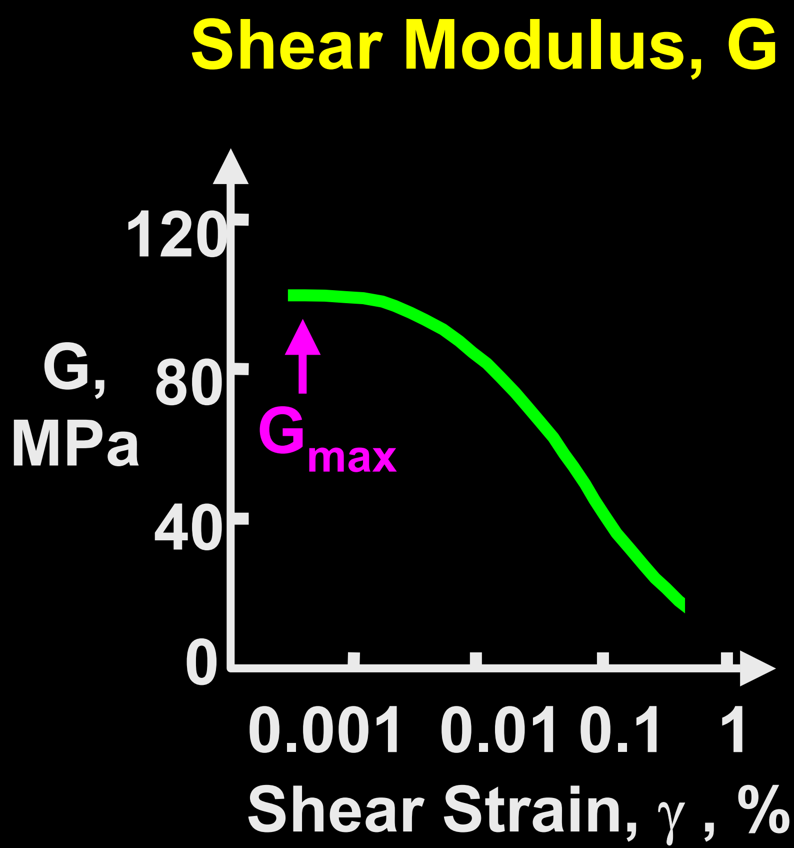
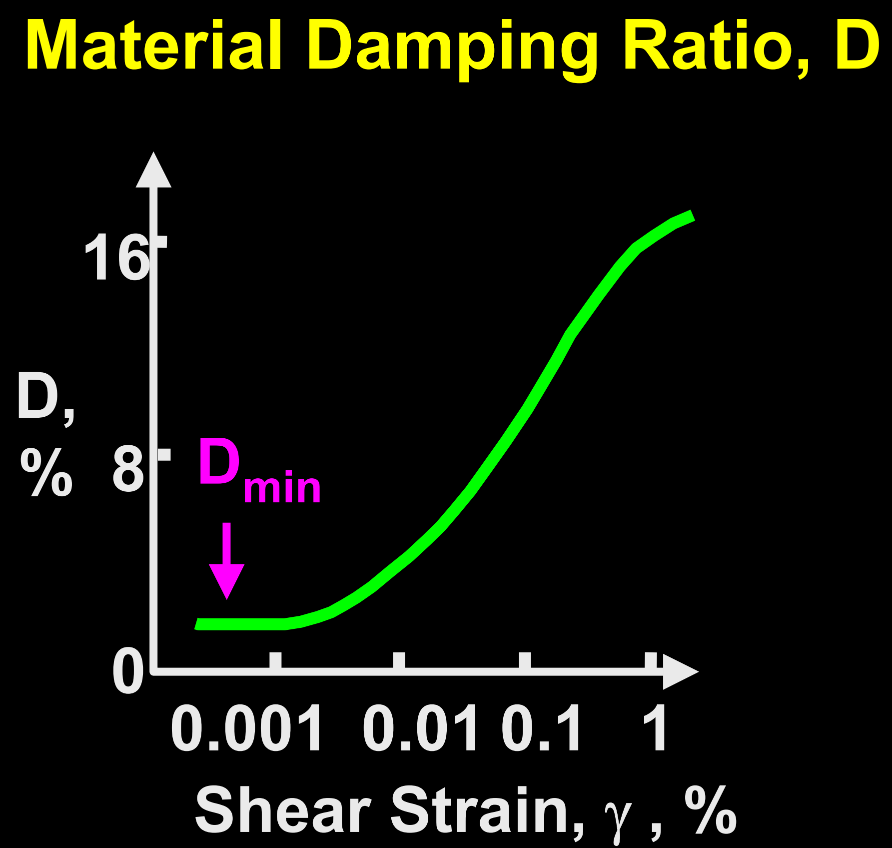
R.B. Gilbert
University of Texas at Austin

Int. Workshop on Uncertainties in Soil Properties and Site Response
March 2004

Dynamic Soil Properties

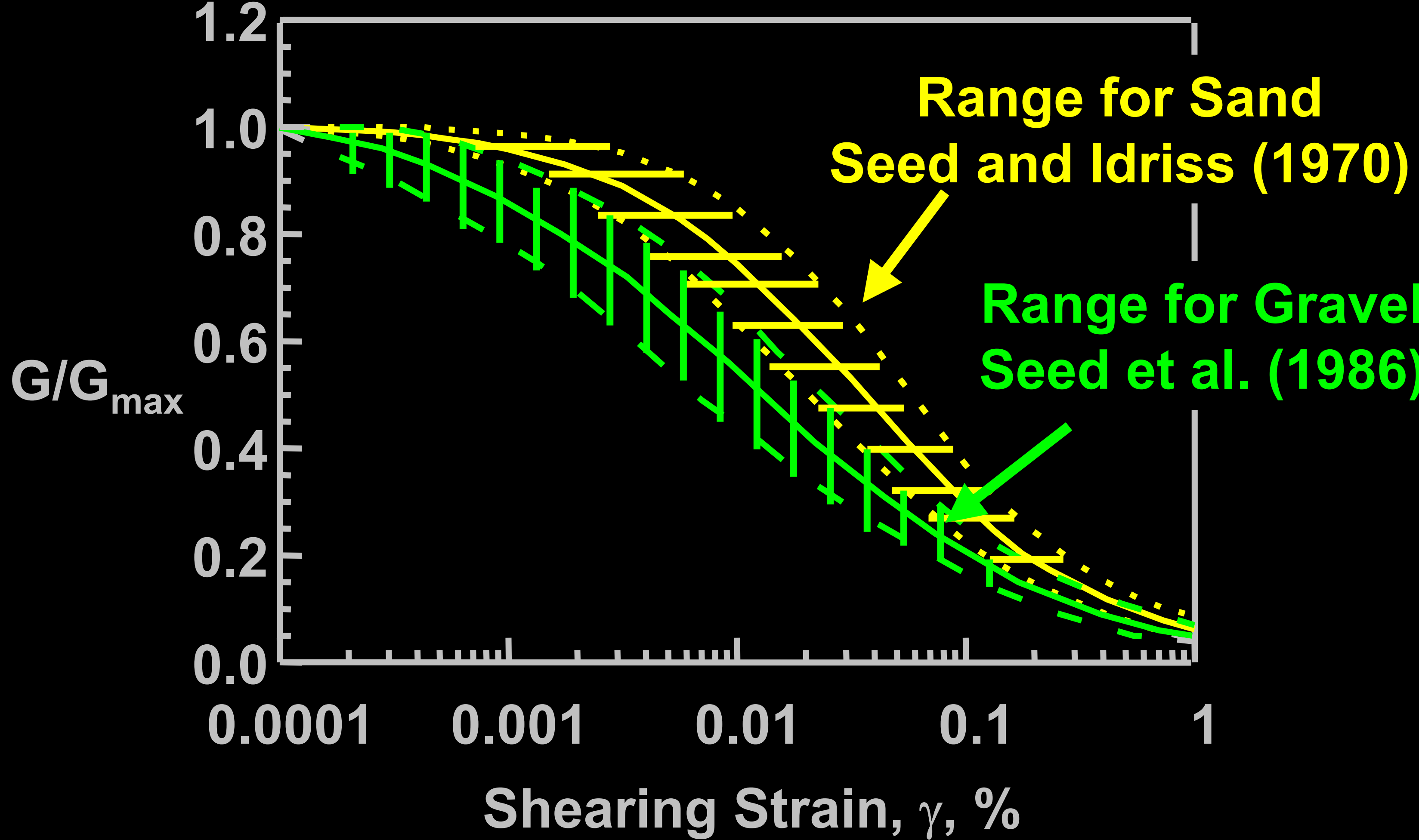




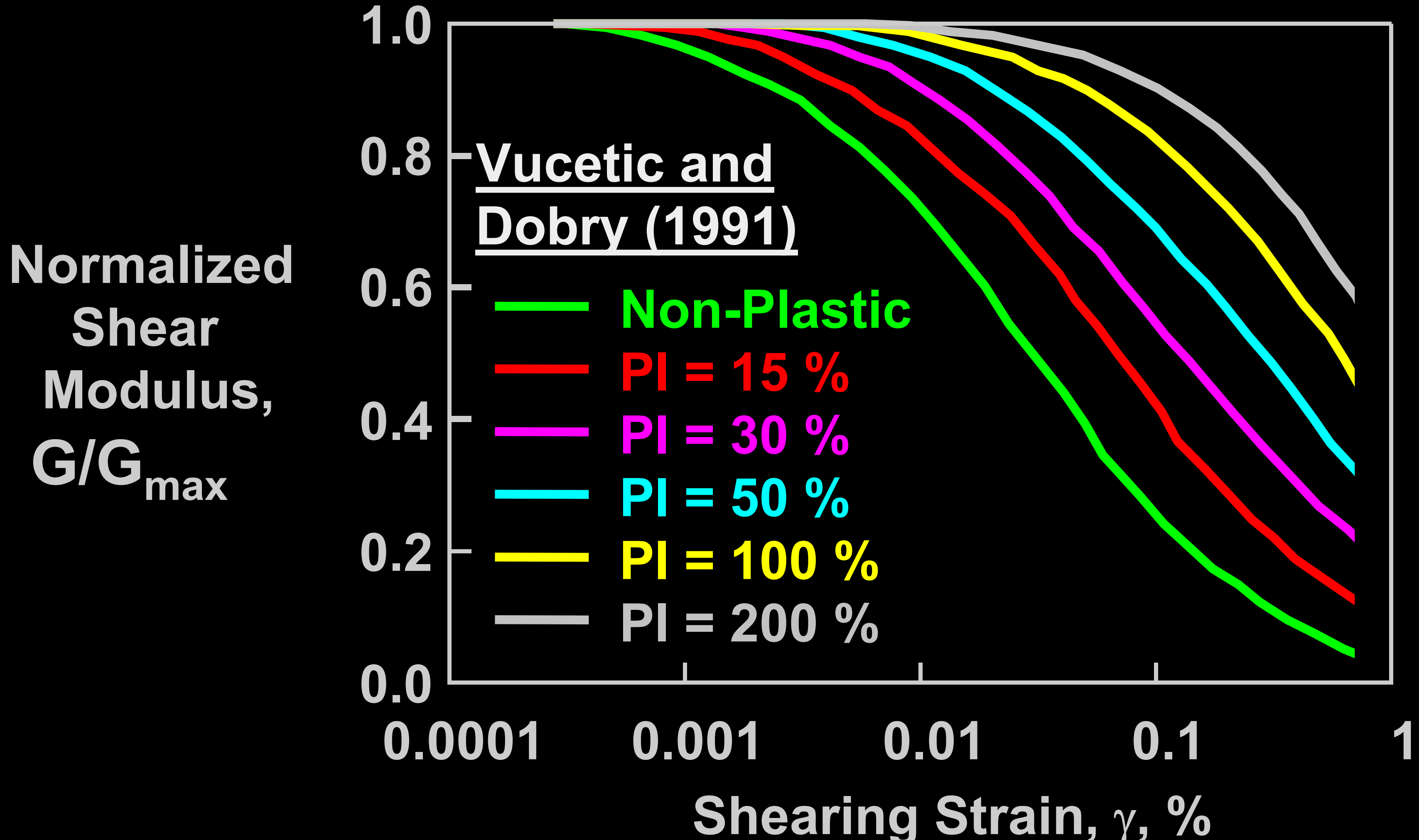
Examples of Empirical Relationships Based on Laboratory Studies

- Seed et al., 1970
- Hardin and Drnevich, 1972
- Kokusho, 1980
- Seed et al., 1986
- Sun et al., 1988
- Idriss, 1990
- Vucetic and Dobry, 1991
- Ishibashi and Zhang, 1993

Nonlinear Behavior of Sandy and Gravelly Soils



Effect of Soil Plasticity on Nonlinear Behavior (Vucetic and Dobry, 1991)



Objective

To generate a new family of empirical G/G_{max} – log γ and D – log γ curves such that the observed effects of various parameters on G/G_{max} and D are represented more accurately:

- Shearing Strain Amplitude, γ
- Soil Type (expressed by PI, C_u, D_{50})
- Effective Confinement, σ_o'
- Number of Cycles, N
- Loading Frequency, f
- Overconsolidation Ratio, OCR

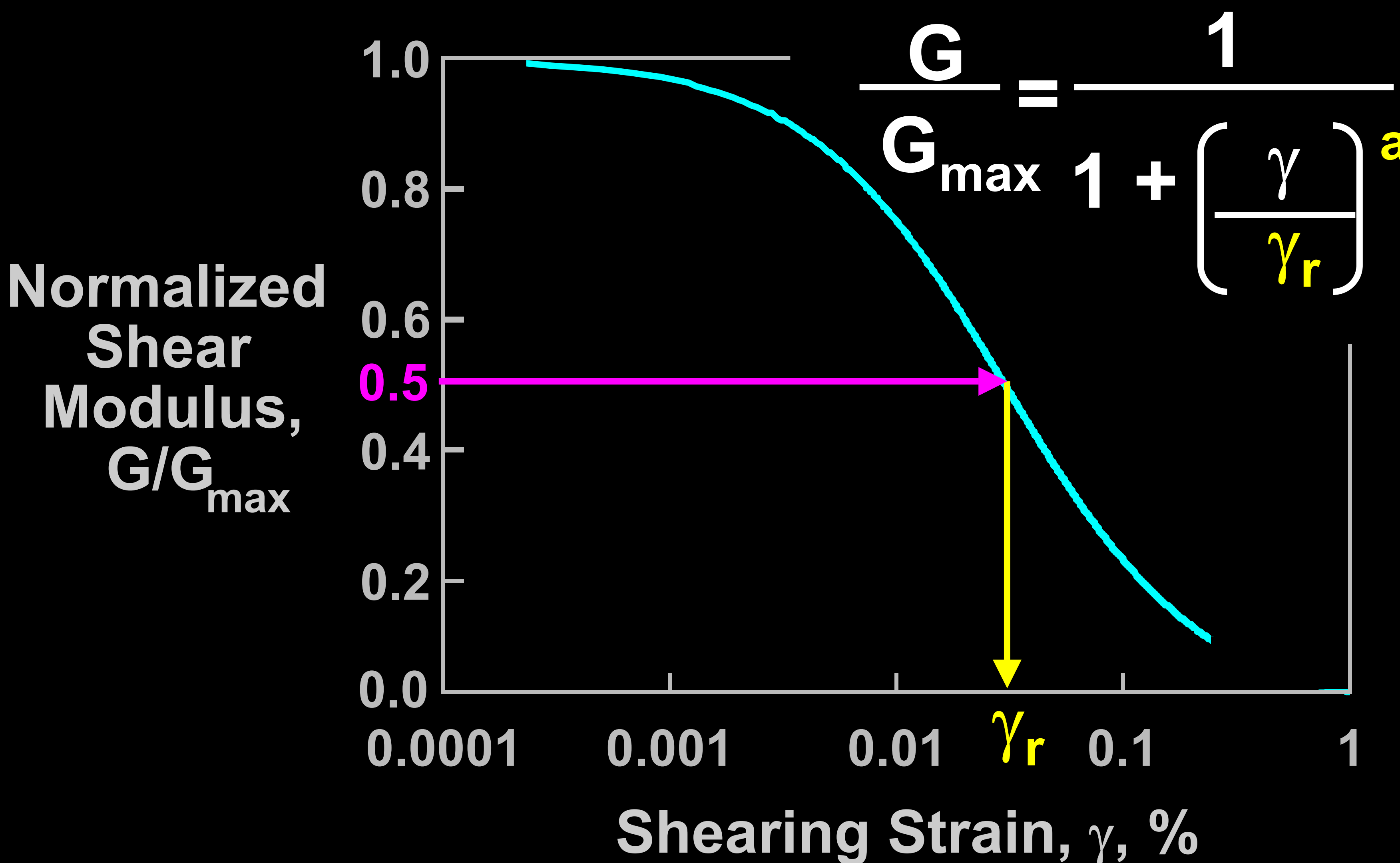
} much like Hardin and Drnevich, 1972

Proposed 5- Parameter Model (Modified Hyperbolic Model)

$$\frac{G}{G_{max}} = \frac{1}{1+\left(\frac{\gamma}{\gamma_r}\right)^a}$$

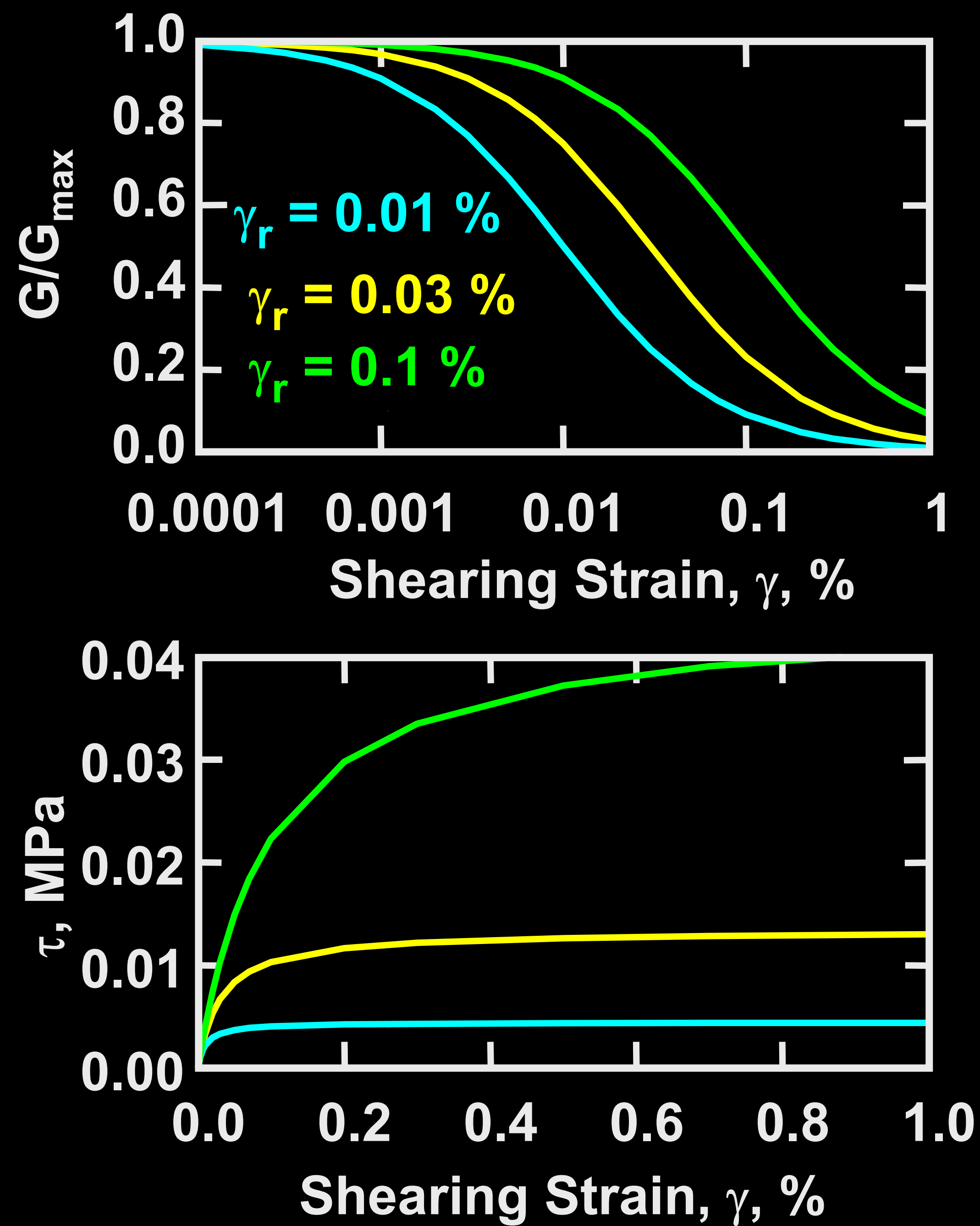
$$D = D_{min} + D_{Masing} * \left(b * (G/G_{max})^c \right)$$

Proposed Model: G/G_{max} – log γ

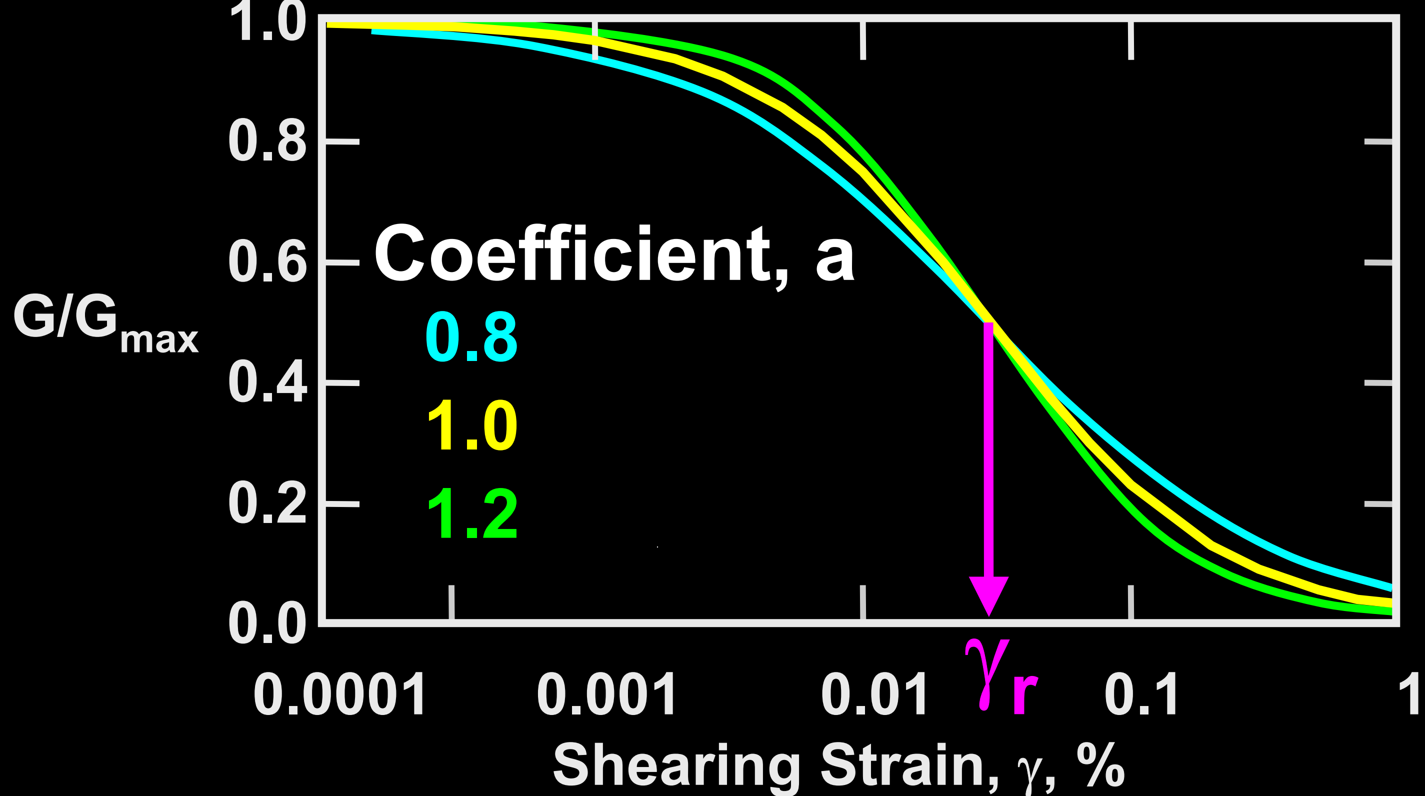


Effect of Reference Strain, γ_r, on:

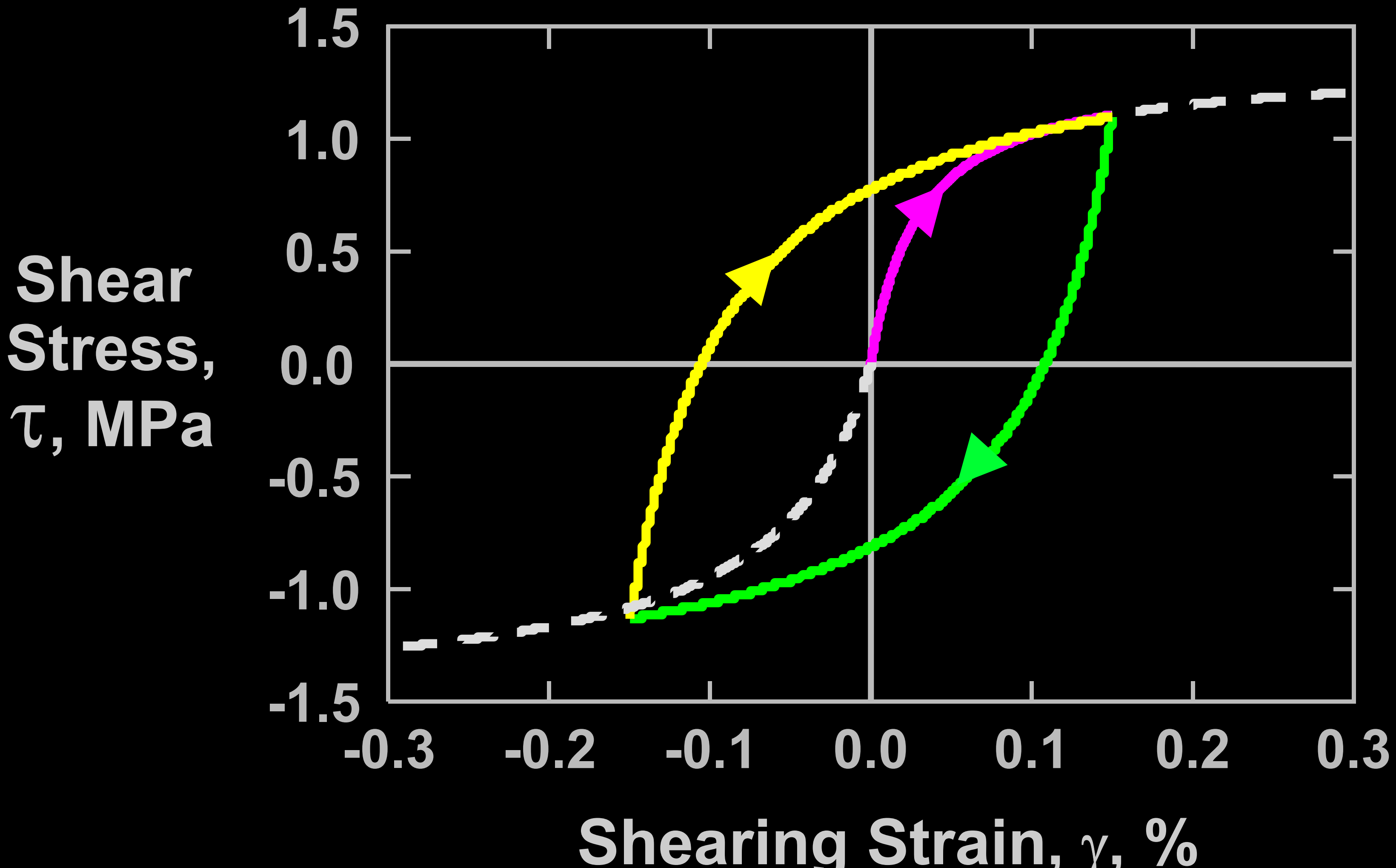
1. G/G_{max} – log γ
2. τ – log γ (a = 1)



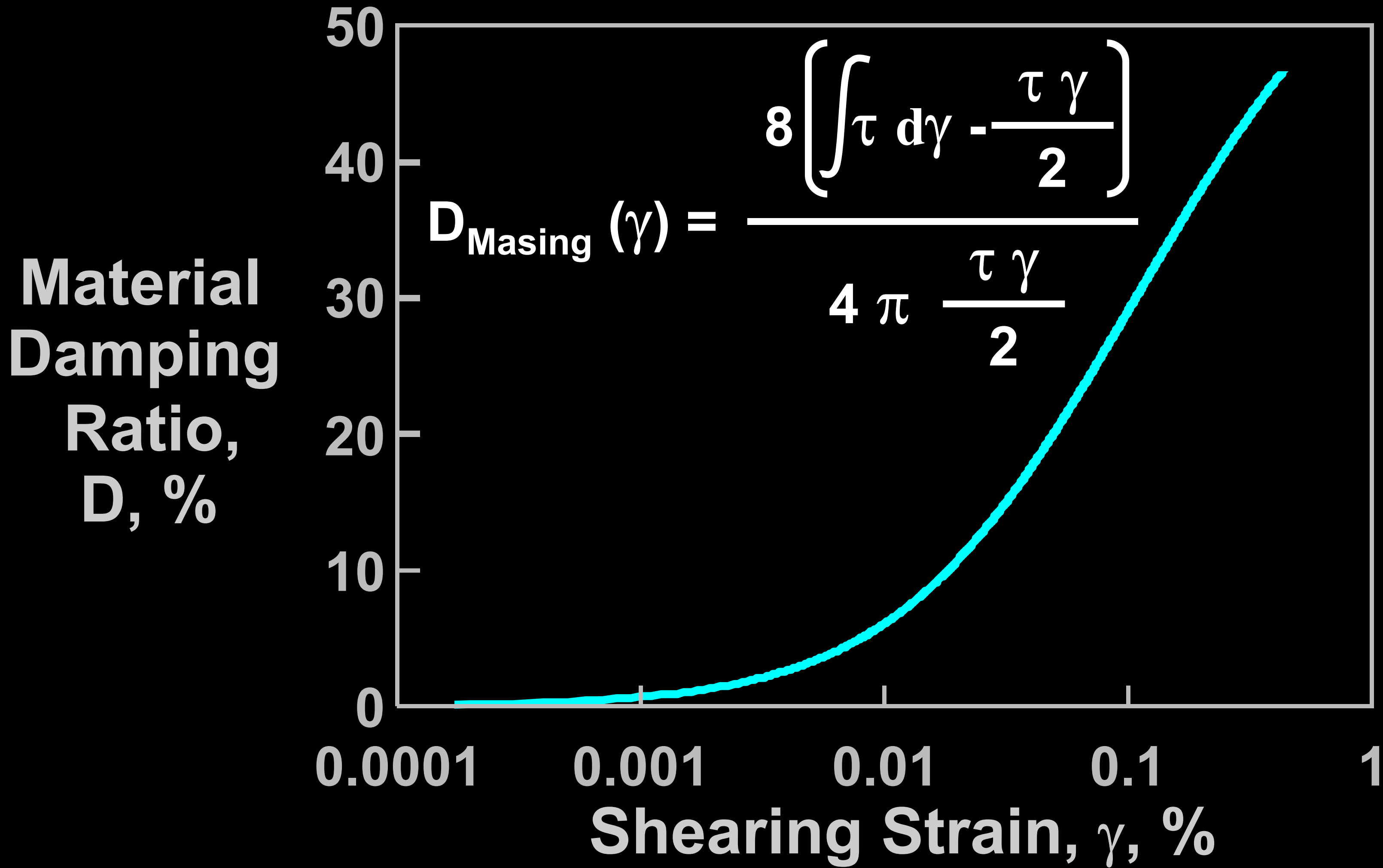
Effect of Coefficient "a" on G/G_{max} – log γ Curves



Masing (1926) Behavior

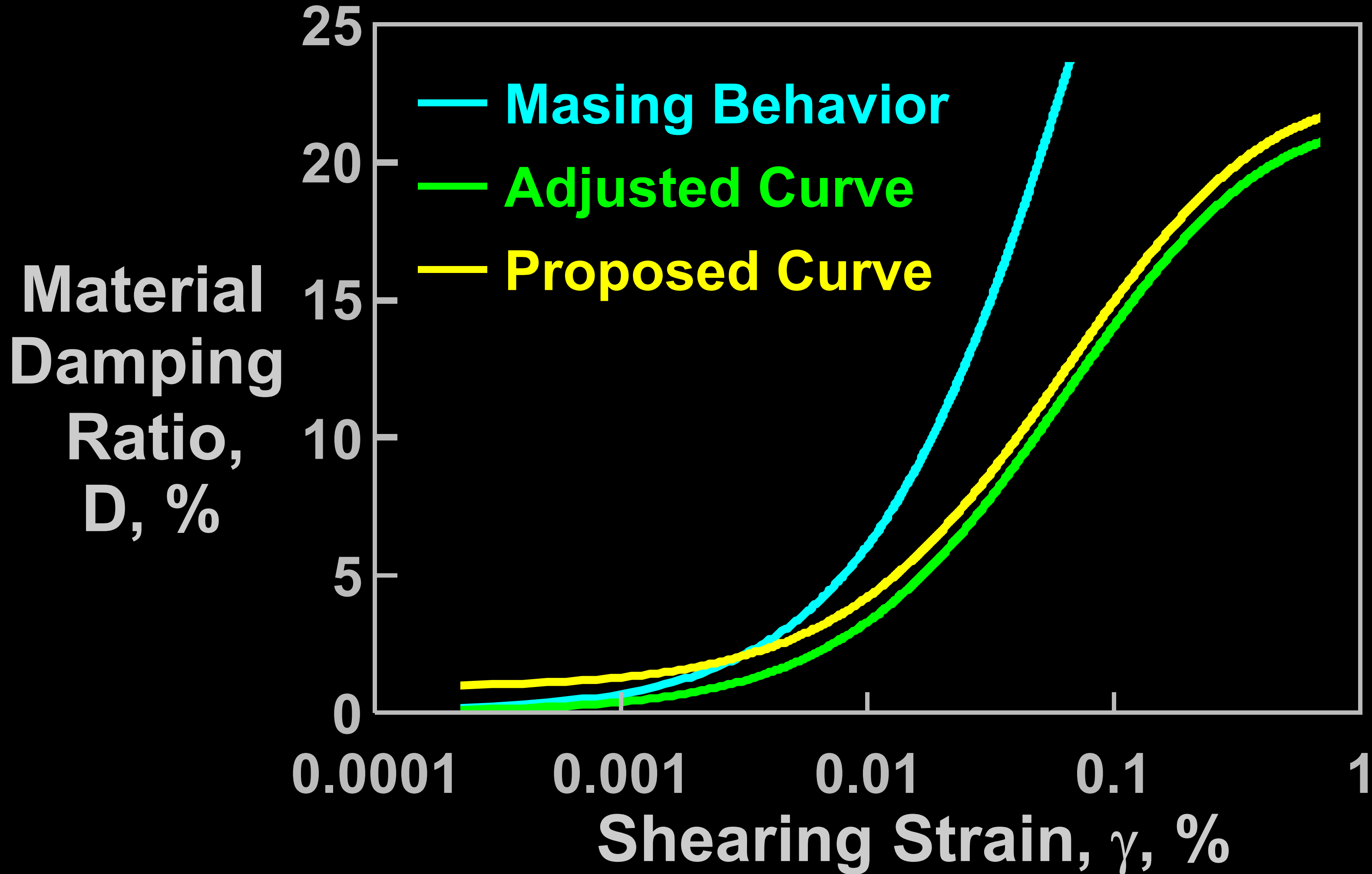


Masing Behavior: D – log γ

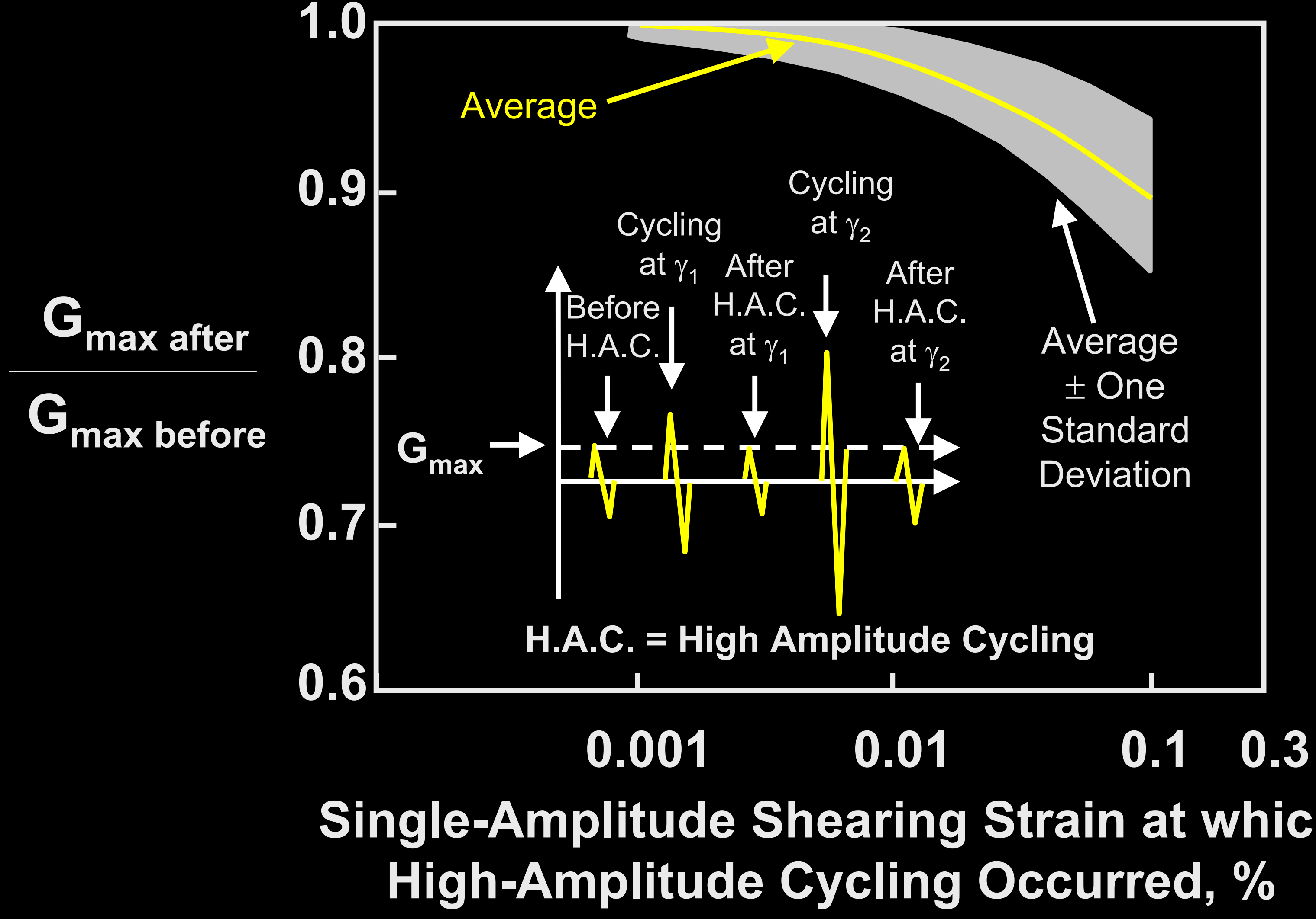


Proposed Model: D – log γ

$$D = D_{Masing} * [\, b * (G/G_{max})^{c} \,] + D_{min}$$



G_{max} Degradation with γ: "c" Parameter



Relationships Between Five Parameters and Soil Type and Loading Conditions: Plastic Soils

- γ_r = f (PI, OCR, σ_o')
- a = constant = 0.92
- D_{min} = f (PI, OCR, σ_o', f)
- b = f (N)
- c = constant = 0.10

Bayesian Approach

Bayesian Approach is a systematic way of combining information based on experience (or intuition) with observational data.

- The problem is structured analytically.
- Unknown parameters are modeled as random variables.
- Expected values based on experience and confidence intervals associated with these estimates are determined.
- These values are updated such that the likelihood of occurrence of the observational data is maximized.

Recommended Values: Plastic Soils

$$\gamma_r = (\phi_1 + \phi_2 * PI * OCR^{\phi_3}) * \sigma_o'^{\phi_4}$$

$$a = \phi_5$$

where: σ_o' = mean effective confining pressure (atm),

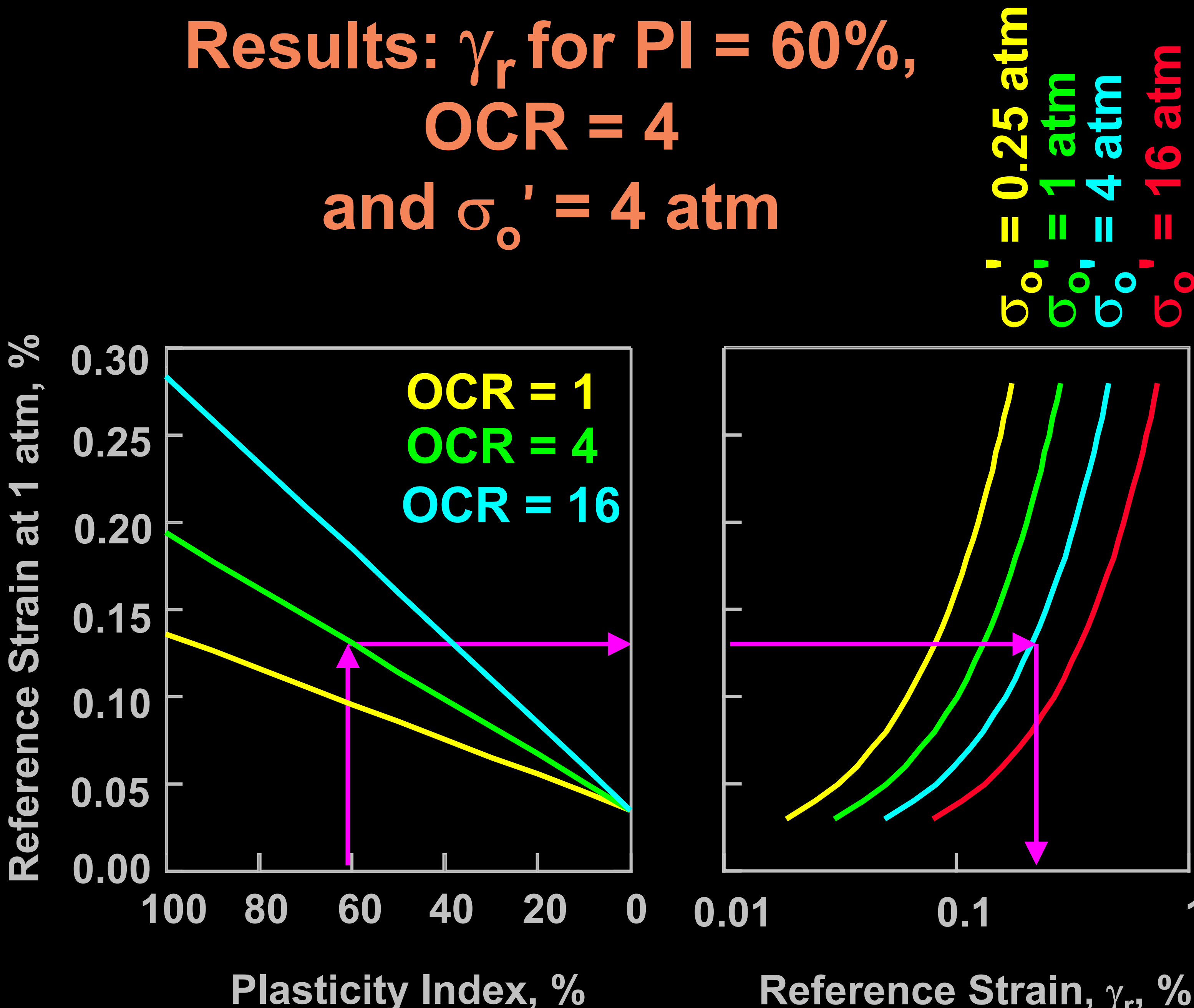
PI = soil plasticity (%),

OCR = overconsolidation ratio,

and

ϕ_1 = 0.0352, ϕ_2 = 0.0010, ϕ_3 = 0.3246,
ϕ_4 = 0.3483, ϕ_5 = 0.9190

Results: γ_r for PI = 60%, OCR = 4 and σ_o' = 4 atm



Recommended Values: Plastic Soils

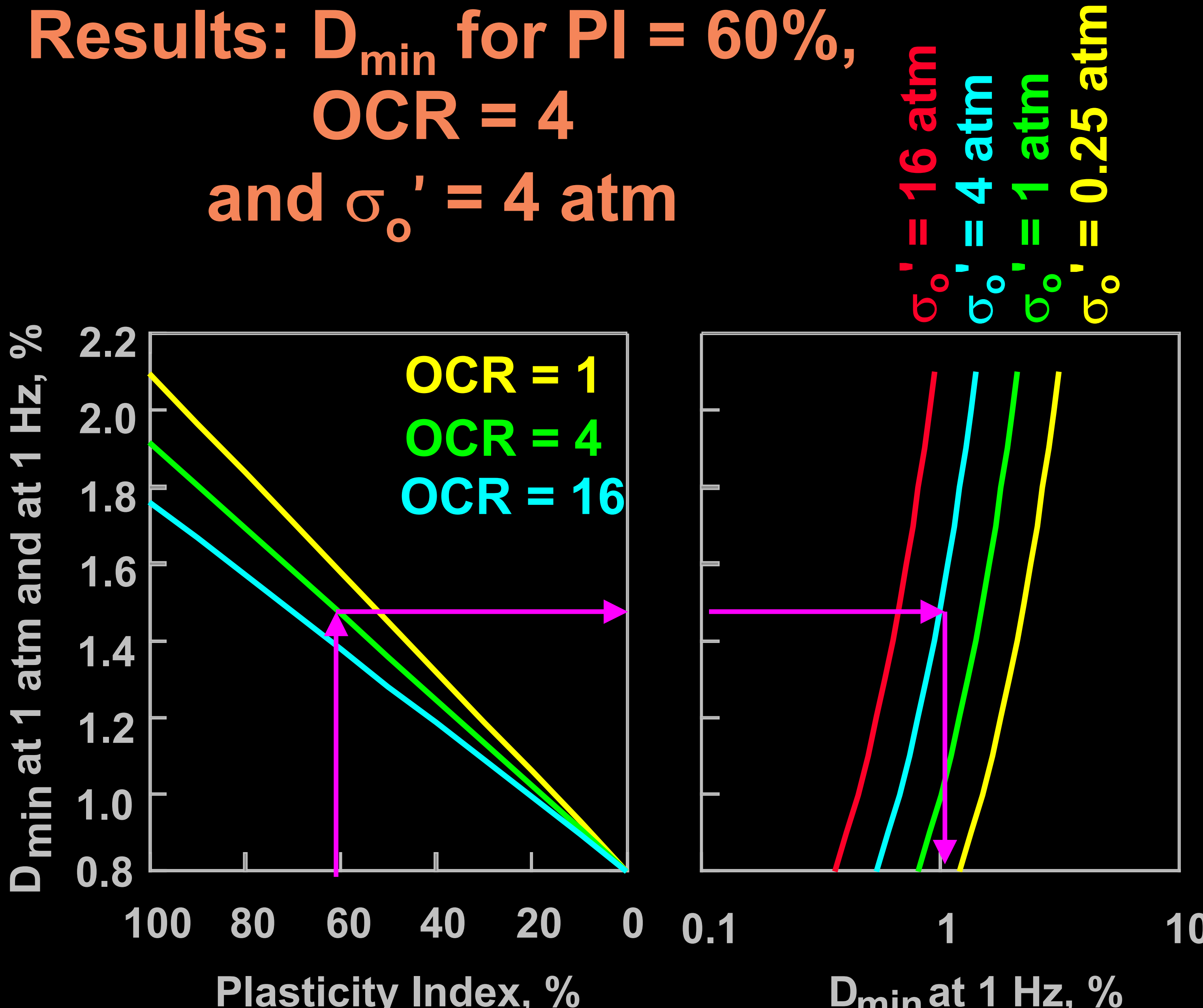
$$D_{min} = (\phi_6 + \phi_7 * PI * OCR^{\phi_8}) * \sigma_o'^{\phi_9} * [1 + \phi_{10} * \ln(f)]$$

$$b = \phi_{11} + \phi_{12} * \ln(N)$$

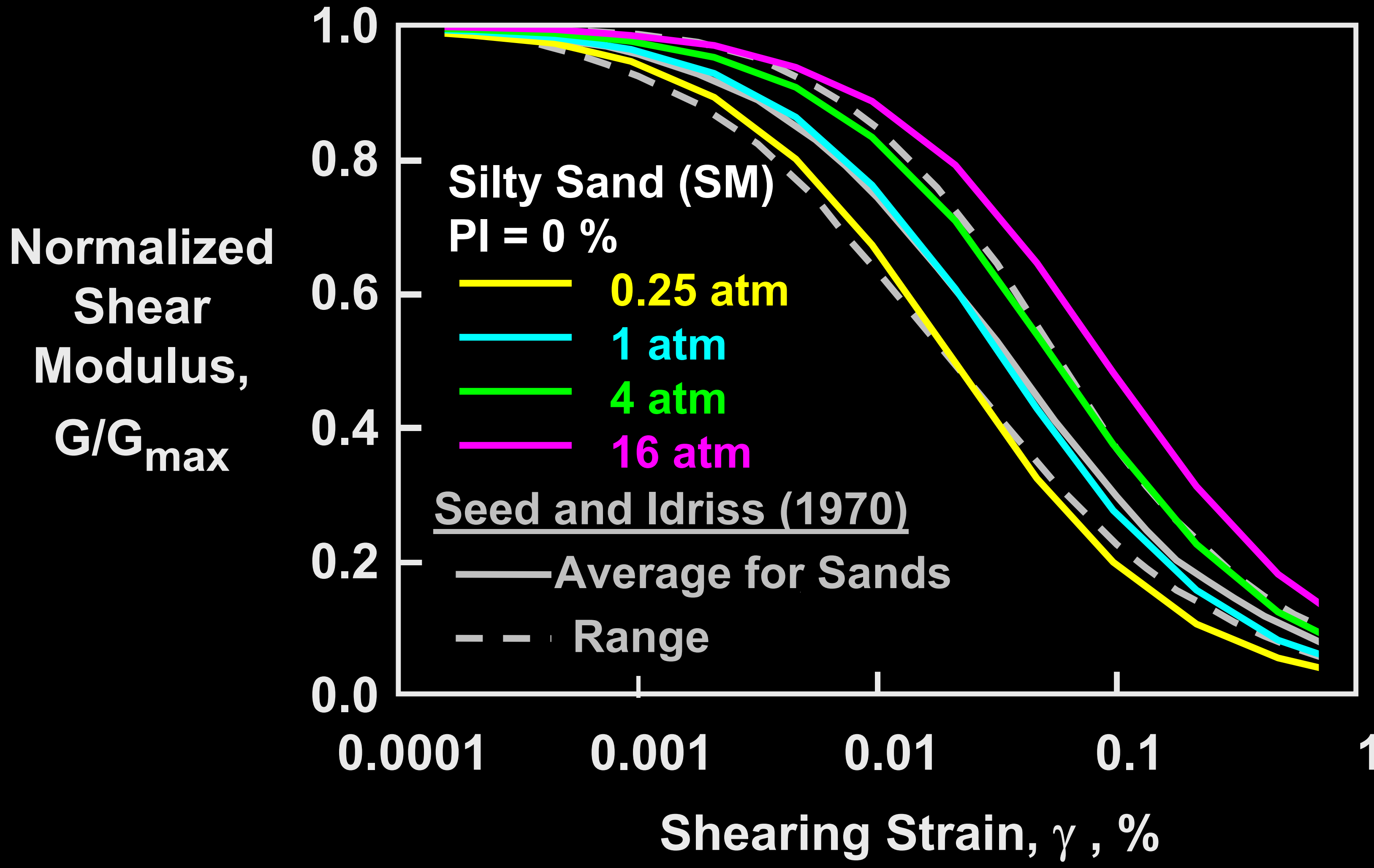
where: σ_o' = mean effective confining pressure (atm),
PI = soil plasticity (%),
OCR = overconsolidation ratio,
f = loading frequency,
N = number of loading cycles,

and ϕ_6 = 0.8005, ϕ_7 = 0.0129, ϕ_8 = -0.1069,
ϕ_9 = -0.2889, ϕ_{10} = 0.2919, ϕ_{11} = 0.6329,
ϕ_{12} = -0.0057

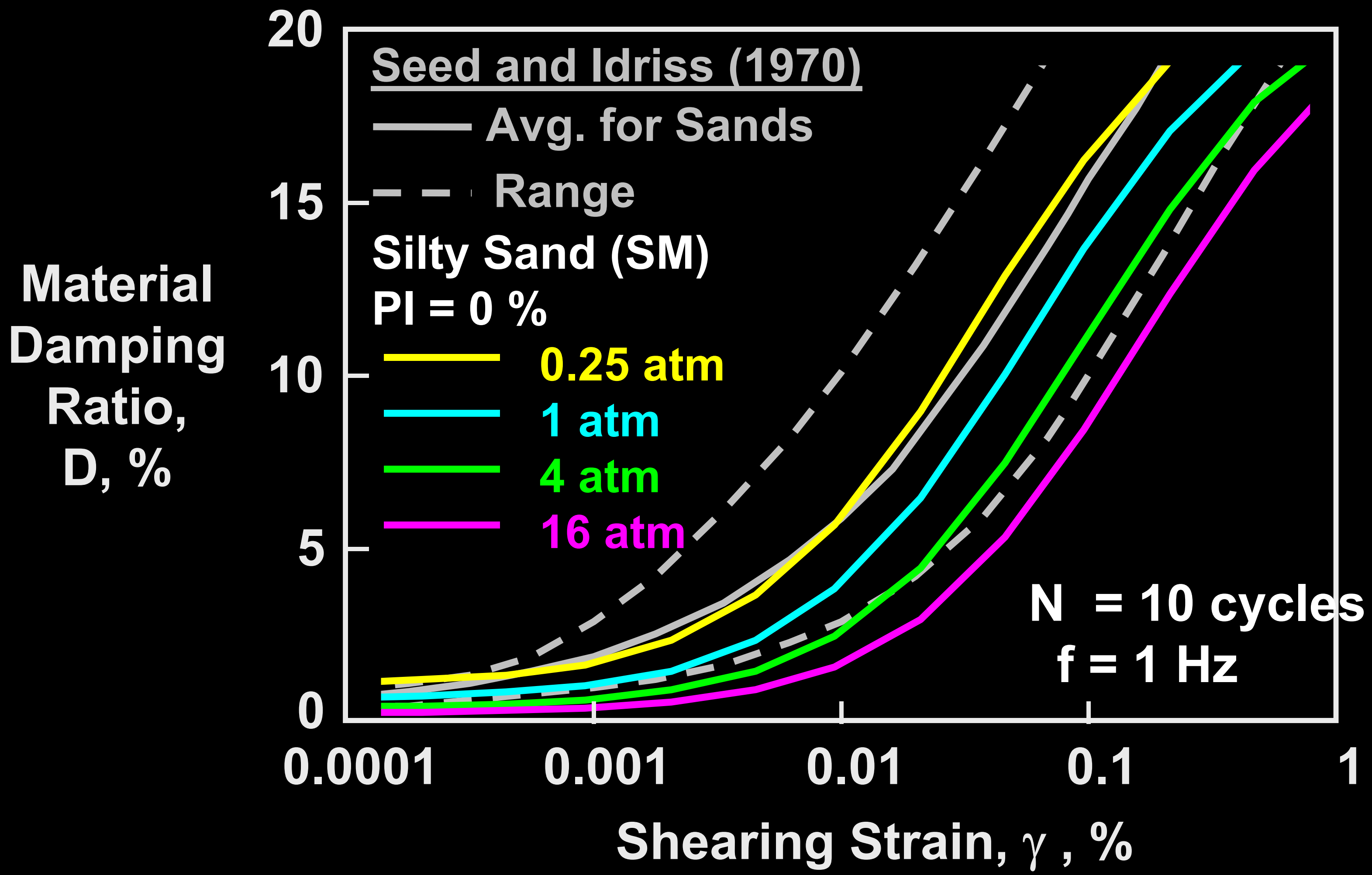
Results: D_{min} for PI = 60%, OCR = 4 and σ_o' = 4 atm



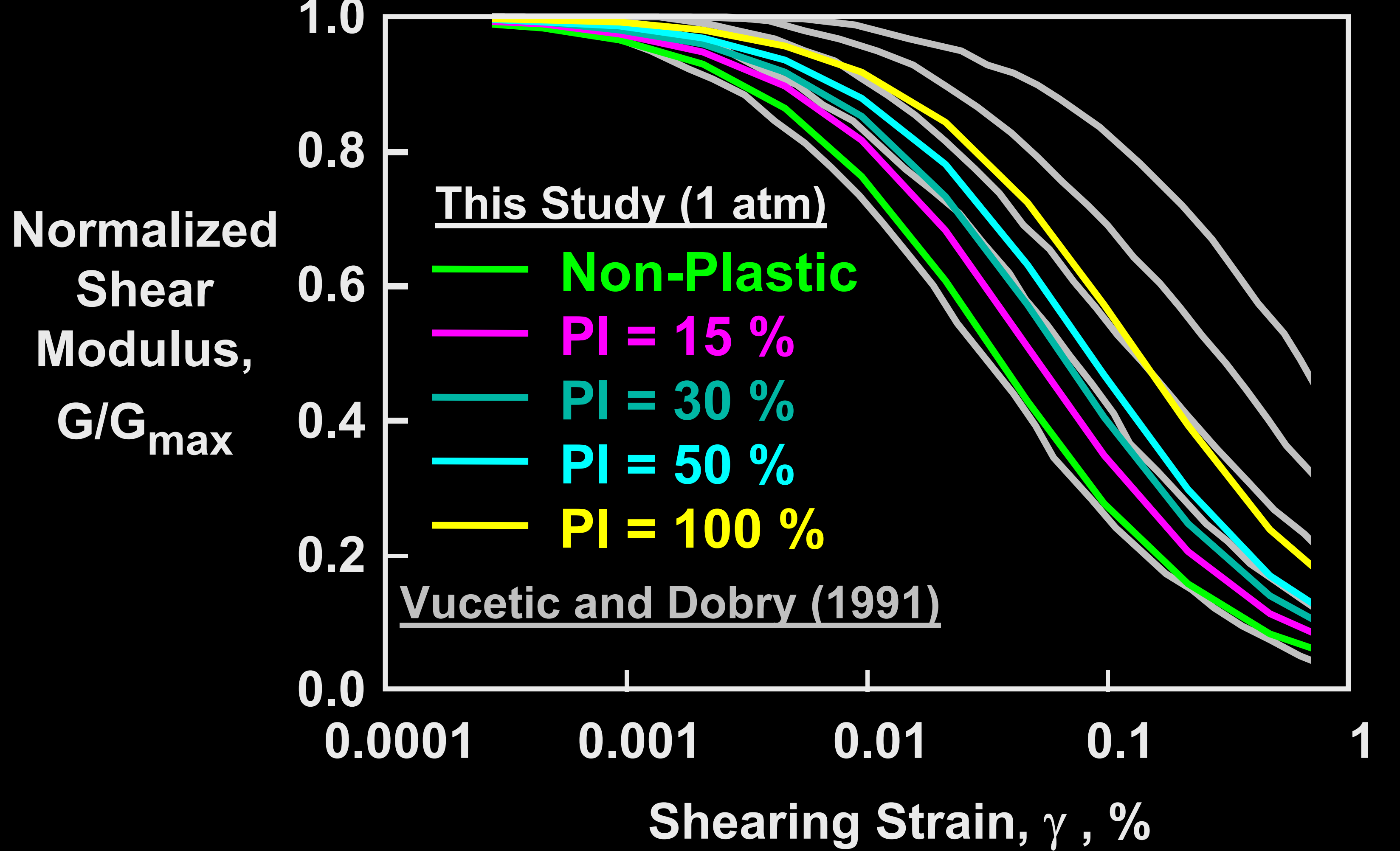
Effect of σ´o on the Nonlinear Behavior of Sands



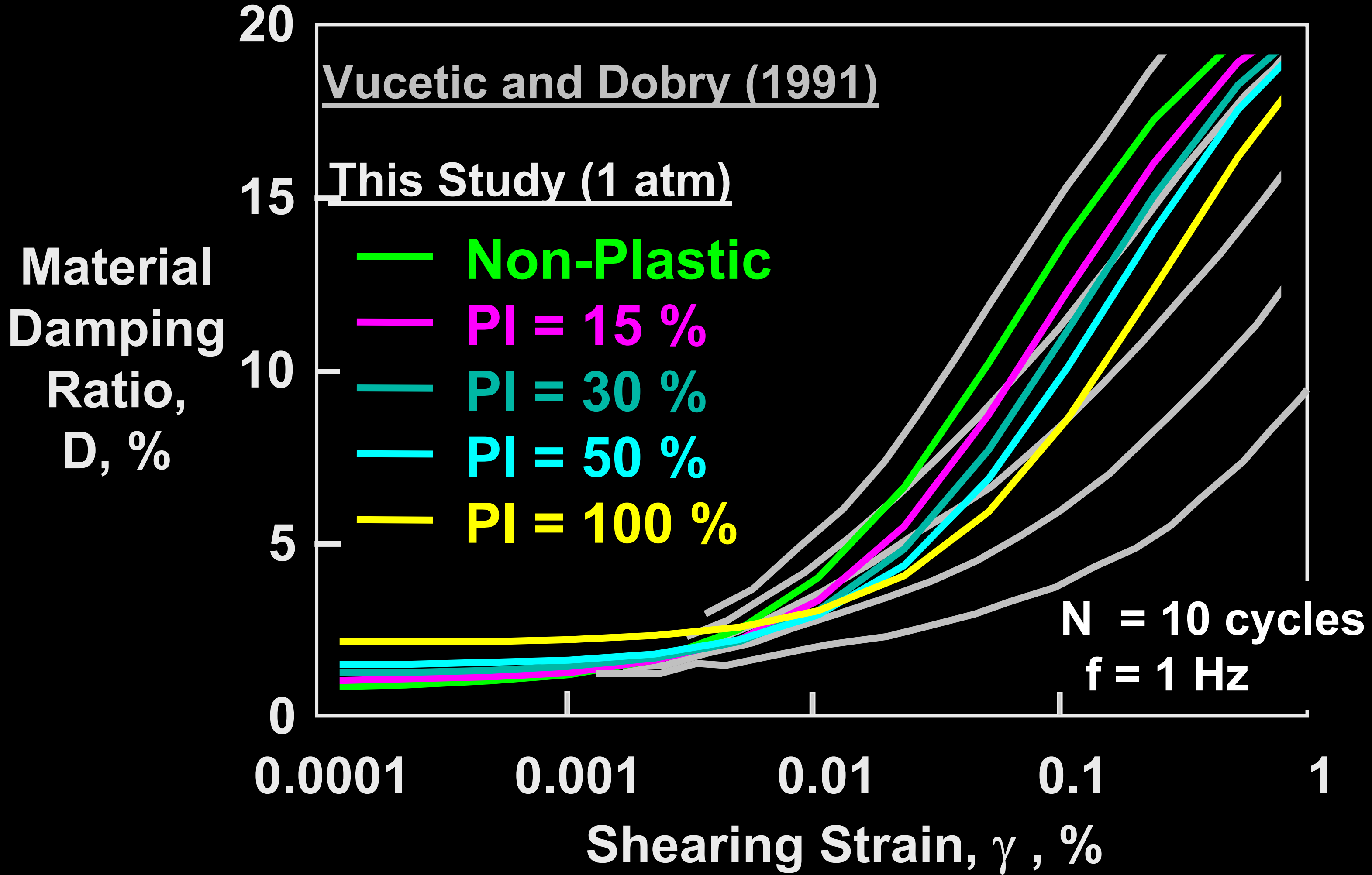
Effect of σ'_o on the Nonlinear Behavior of Sands



Effect of Plasticity on Nonlinear Soil Behavior



Effect of Plasticity on Nonlinear Soil Behavior



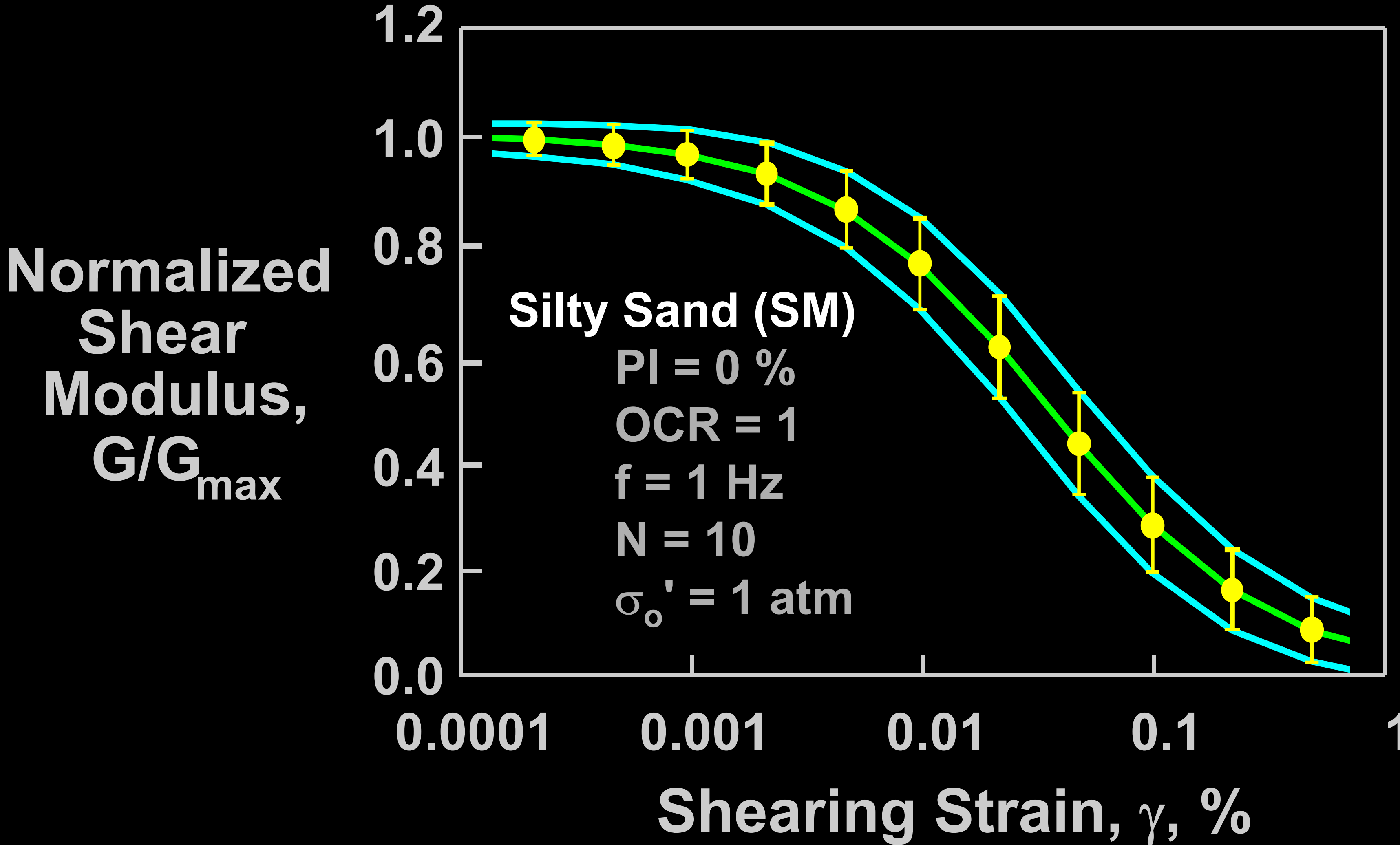
Standard Deviations for G/G_{max} – log γ

$$\sigma_{NG} = \exp(\phi_{13}) + \sqrt{\frac{0.25}{\exp(\phi_{14})} - \frac{(G/G_{max} - 0.5)^2}{\exp(\phi_{14})}}$$

where:

- **σ_{NG} = standard deviation for normalized modulus reduction curve**
- **G/G_{max} = estimated normalized shear modulus, and**
- **ϕ_{13} and ϕ_{14} = parameters that relate standard deviation to mean estimate of normalized shear modulus**

Uncertainty Associated with the Predicted G/G_{max} – log γ Curves



Standard Deviations for D – log γ

$$\sigma_D = \exp(\phi_{15}) + \exp(\phi_{16}) * \sqrt{D}$$

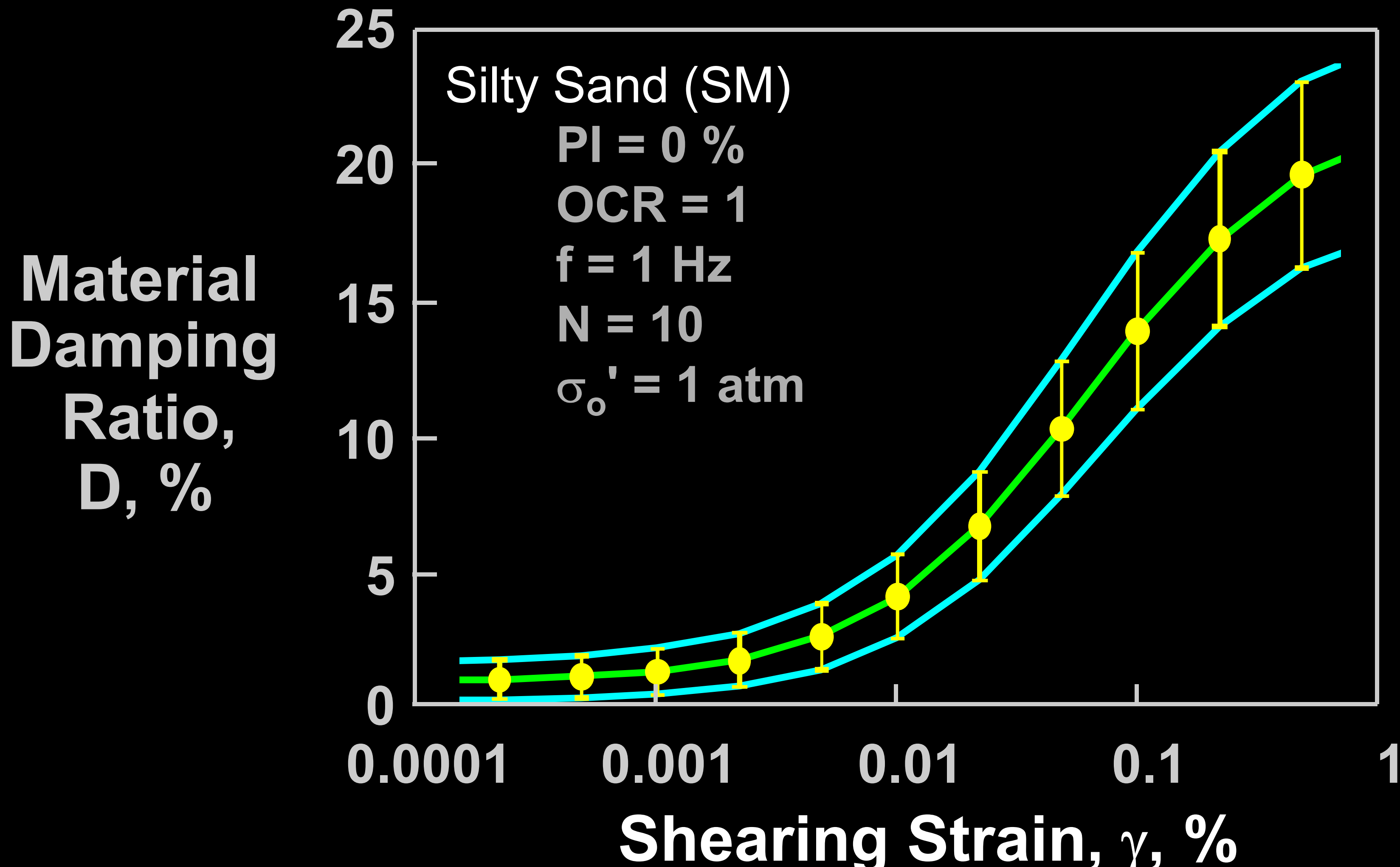
where:

σ_D = standard deviation for material damping curve,

D = estimated material damping ratio, and

ϕ_{15} and ϕ_{16} = parameters that relate standard deviation to the mean estimate of material damping ratio

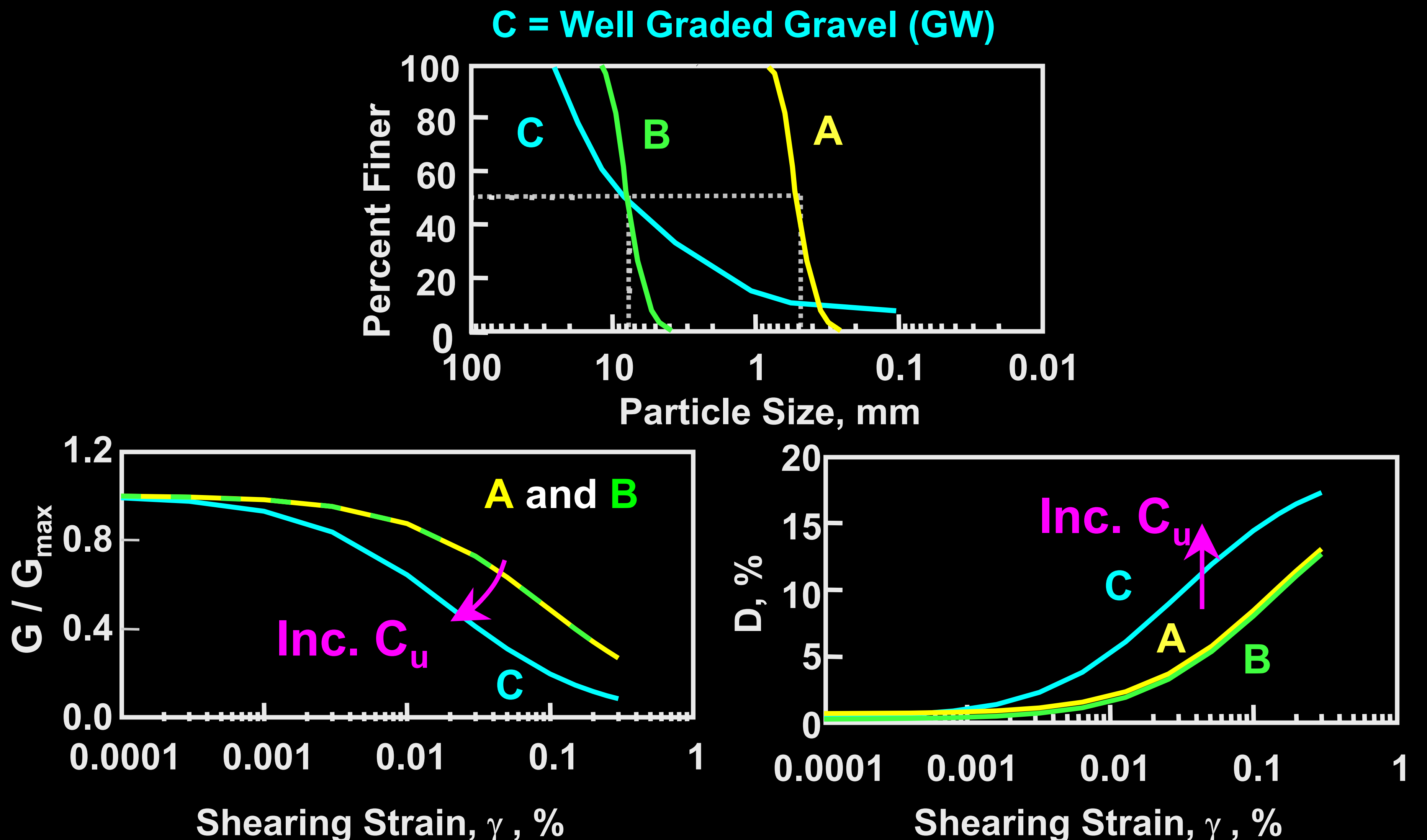
Uncertainty Associated with the Predicted D – log γ Curves



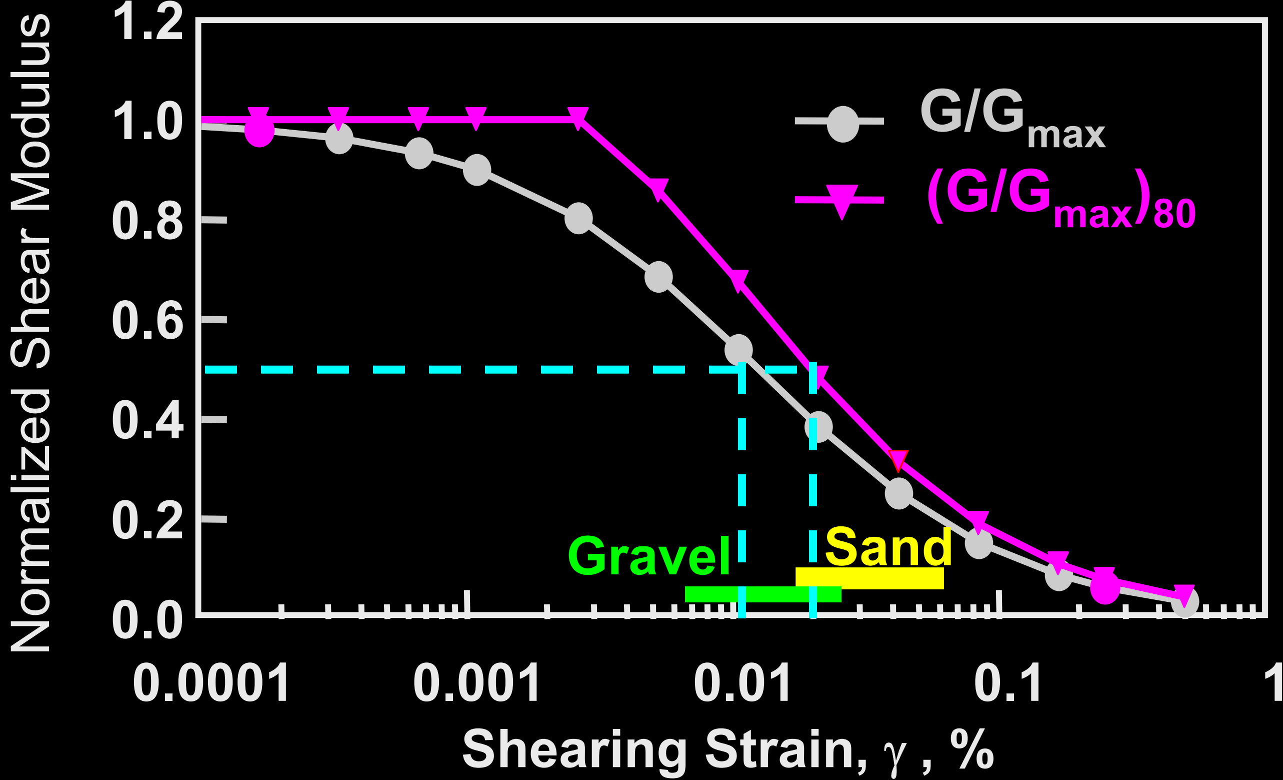
Accomplishments

- An empirical formulation to estimate G/G_{max} – log γ and D – log γ curves for different soils under various loading conditions was generated.
- This formulation was calibrated using data collected at UT over the past decade (with significant input from ROSRINE/PEER).
- G/G_{max} – log γ and D – log γ curves predicted using the formulation were observed to be consistent with the general trends reported in the literature and observed during the course of this study.
- The uncertainties associated with the predicted curves were also evaluated within the formulation.

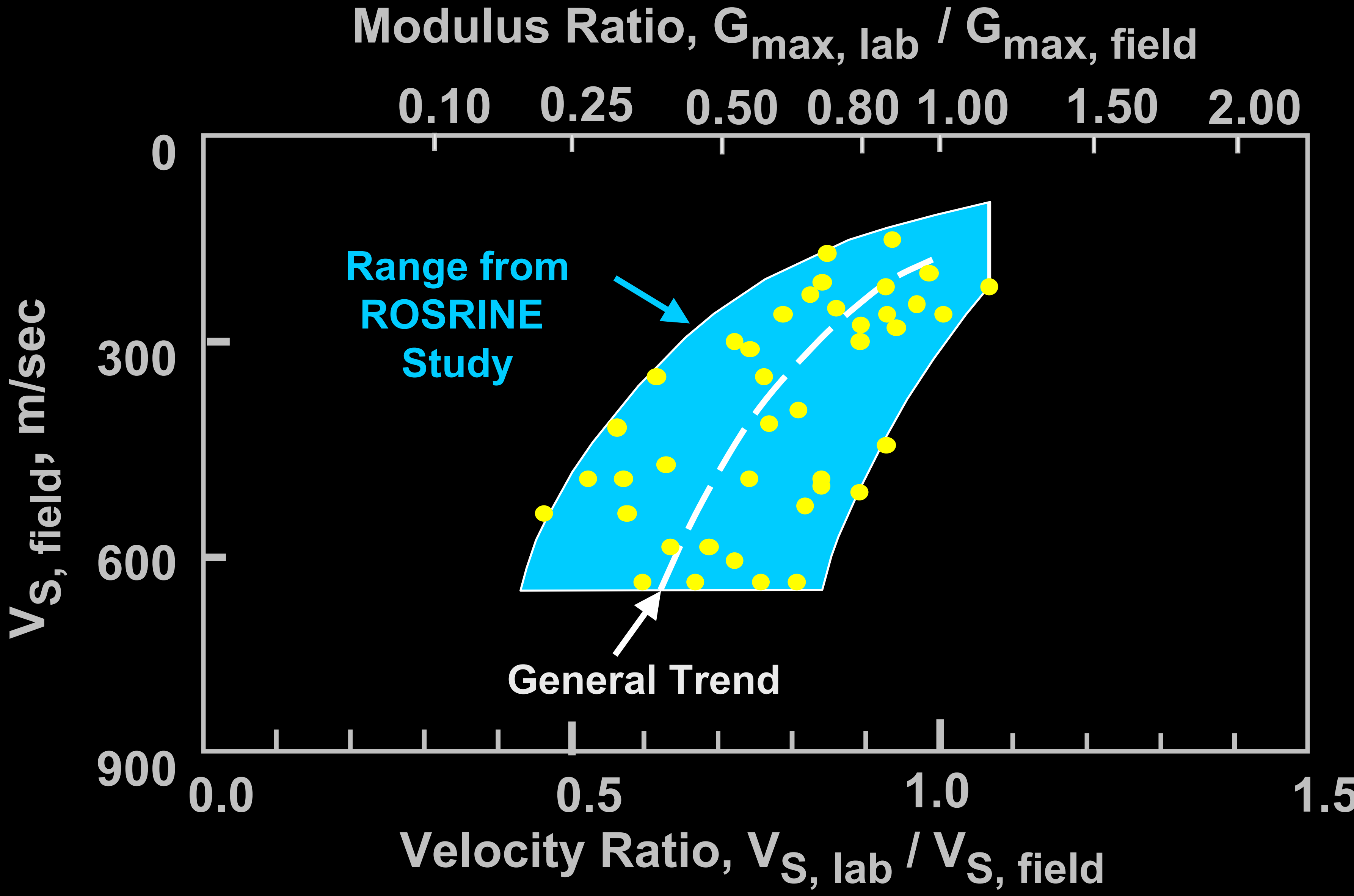
Comparison Between SP, GP, and GW



Problem with Using the Wrong G_{max}



Effect of Sampling on V_S Values



Thank You

- Don Anderson, CH2MHill
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- Richard Lee, Savannah River
- Robert Pyke, Consultant
- Cliff Roblee, Caltrans
- John Schneider, EPRI
- Walt Silva, Pacific Engineering