Perpetual Pavement Design

Southeast Pavement Management
and Design Conference
June 21, 2005
Savannah, Georgia

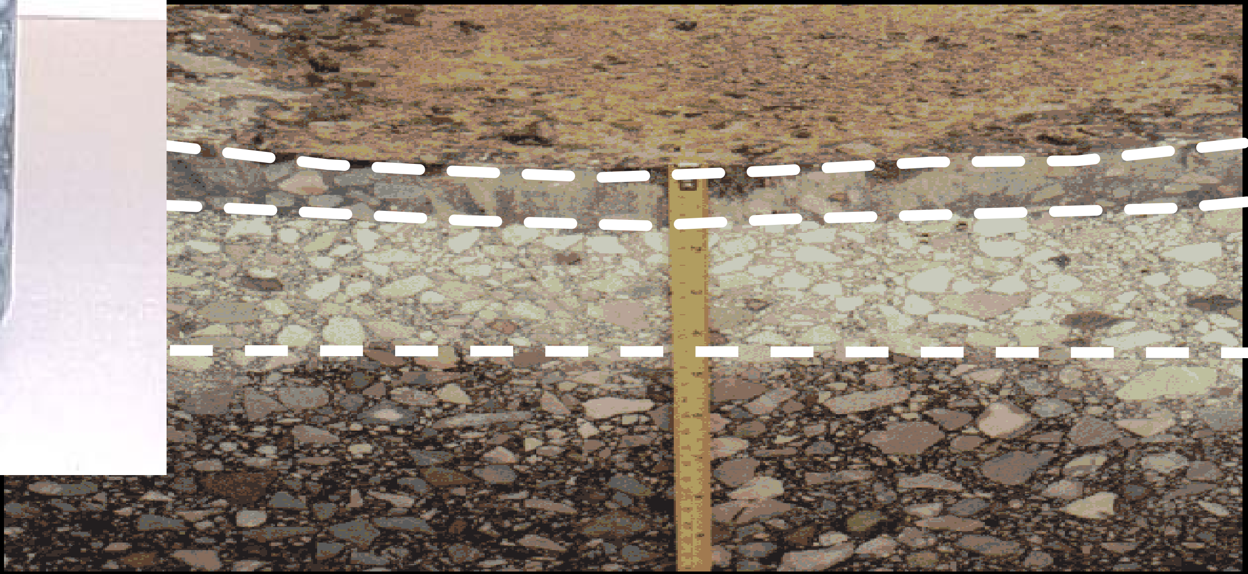
Goal of Perpetual Pavement Design

- Design the structure such that there are no deep structural distresses
  - Bottom up fatigue cracking
  - Structural rutting
- All distresses can be quickly remedied from surface
- Result in a structure with ‘Perpetual’ or ‘Long Life’

Surface Distresses Only

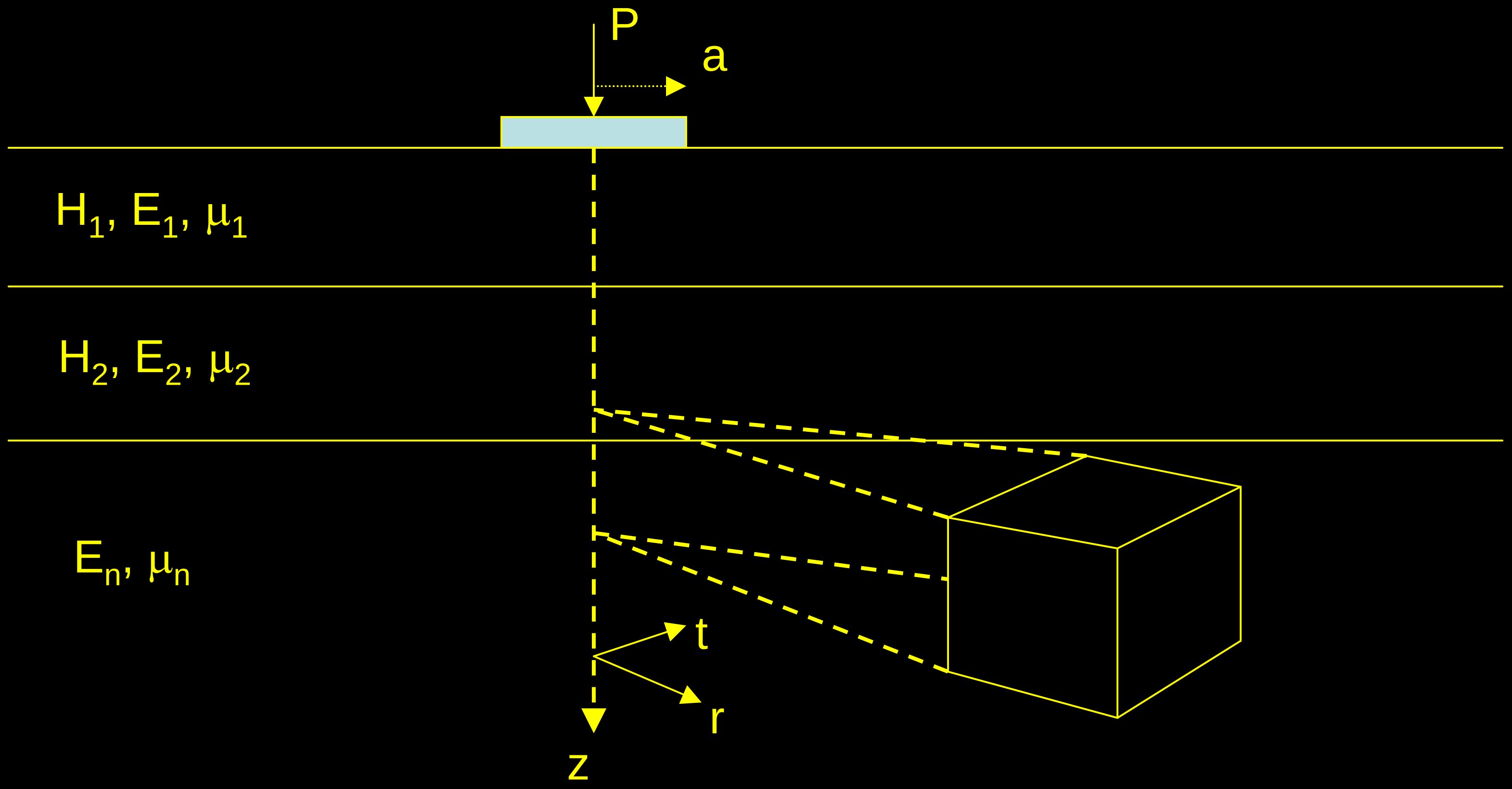
Top Down Cracking

Non-Structural Rutting



How do you compute pavement response?

- Flexible pavements consist of multiple layers
- Using physical principles, we can calculate stresses beneath loads

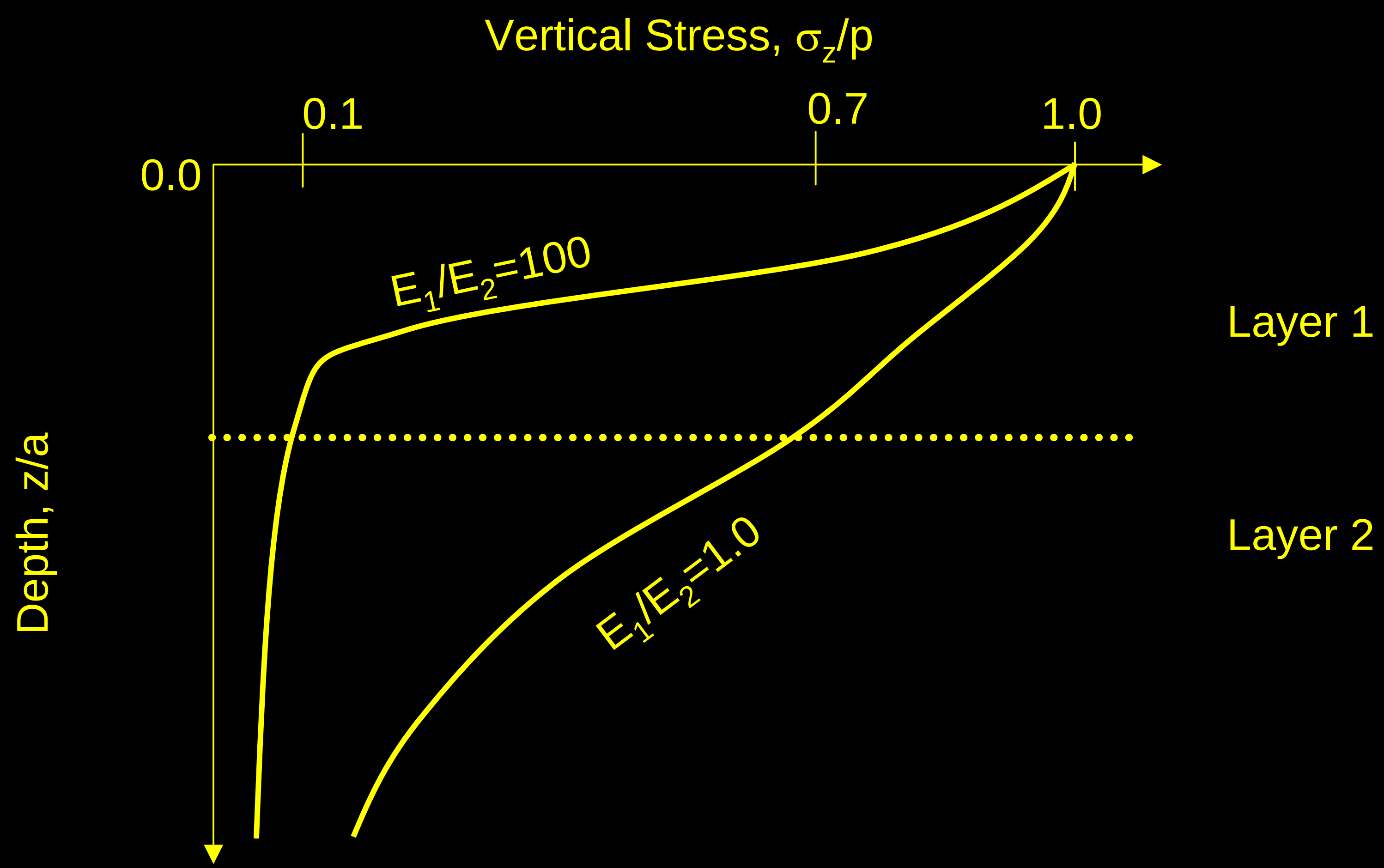


Linear Elastic System Assumptions

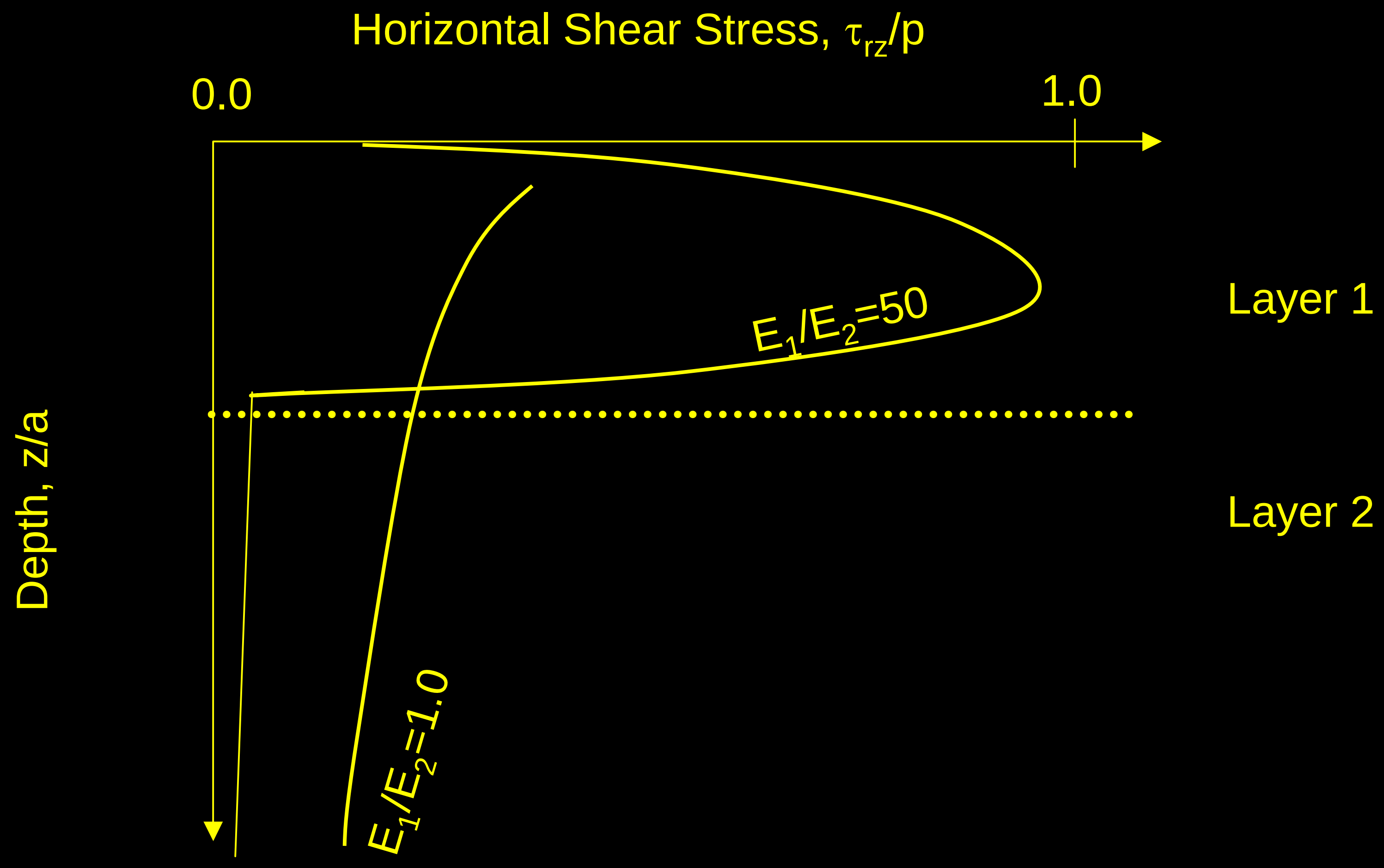
- Many constitutive models available
- Linear Elastic Most Common
- Assumptions
  - Homogeneity
  - Finite thickness
  - Infinite in horizontal direction
  - Isotropic
  - Full friction between layers
  - No surface shear forces

Two-Layer Systems

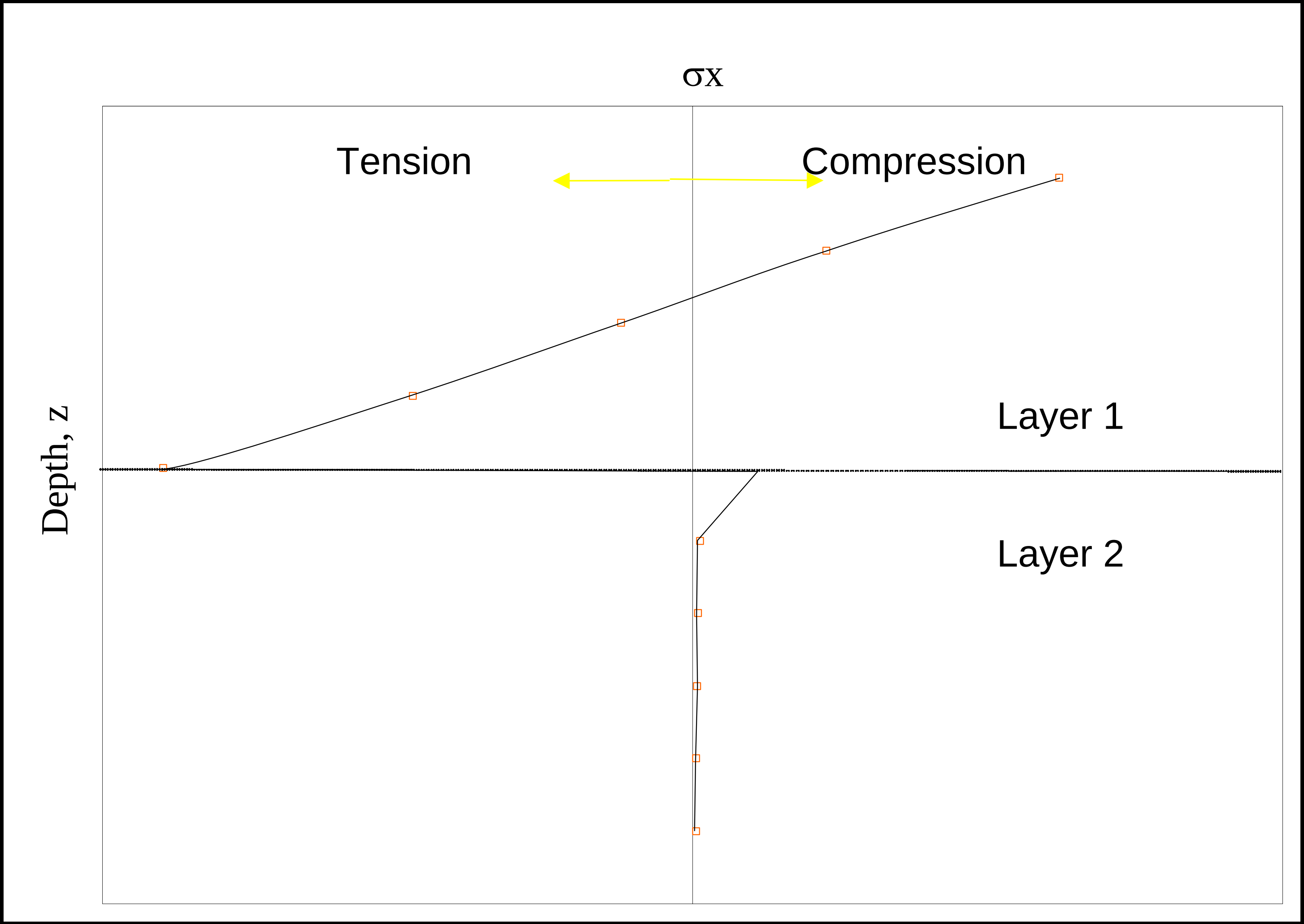
- Analytical solution derived by Burmister (1940's)
- Importance of stiffness ratio (E_1/E_2)



Two Layer System – Shear Stress

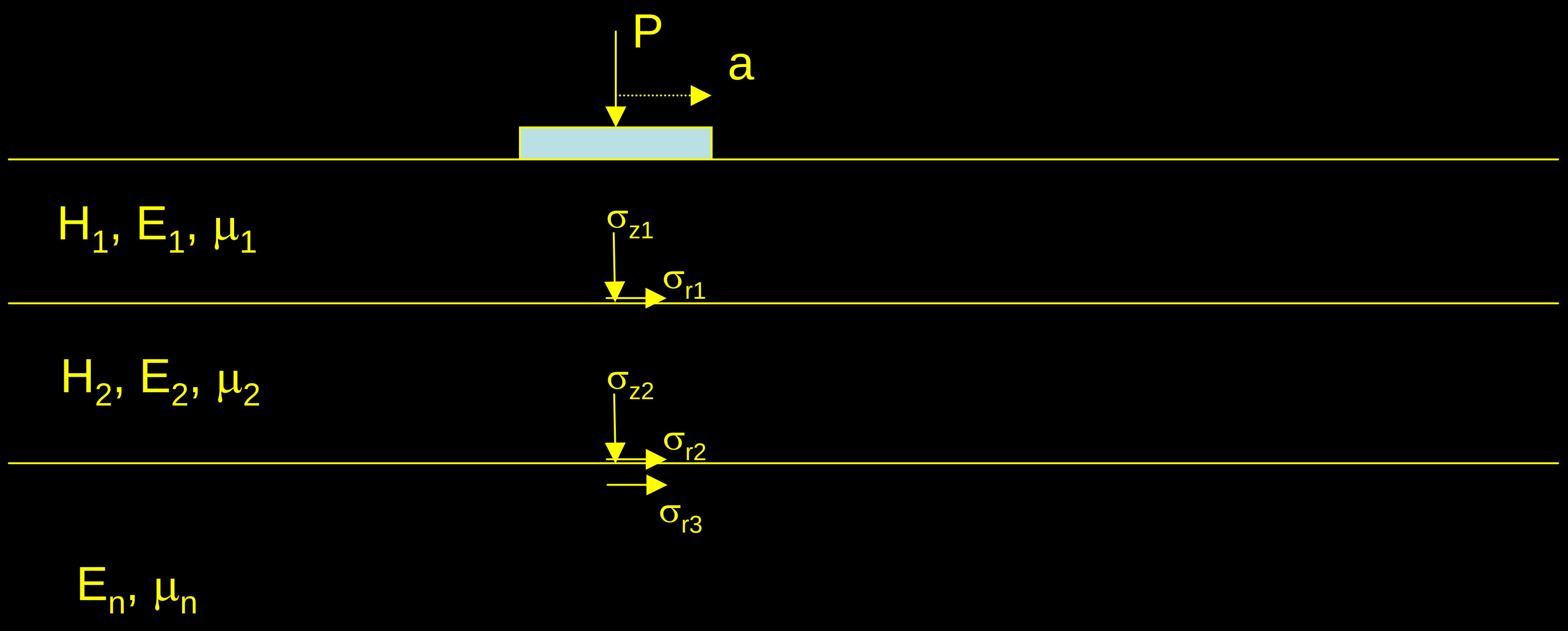


Two-Layer System – Tensile Stresses



Three Layer Systems

- Much more complicated system!
- Initially solved for a limited set of parameters due to computational limitations
  - $\mu = 0.5$
- Limited number of locations



Materials

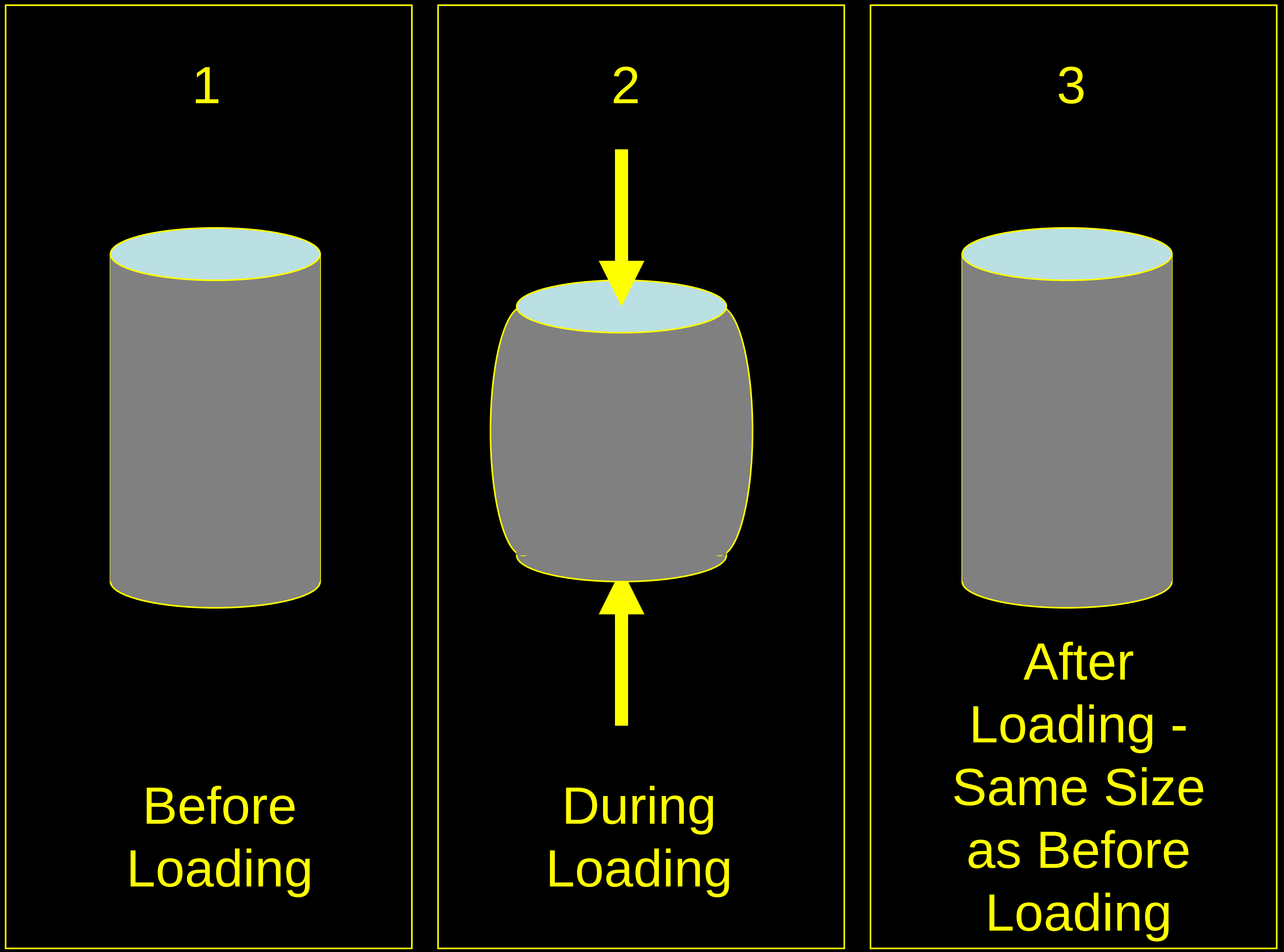
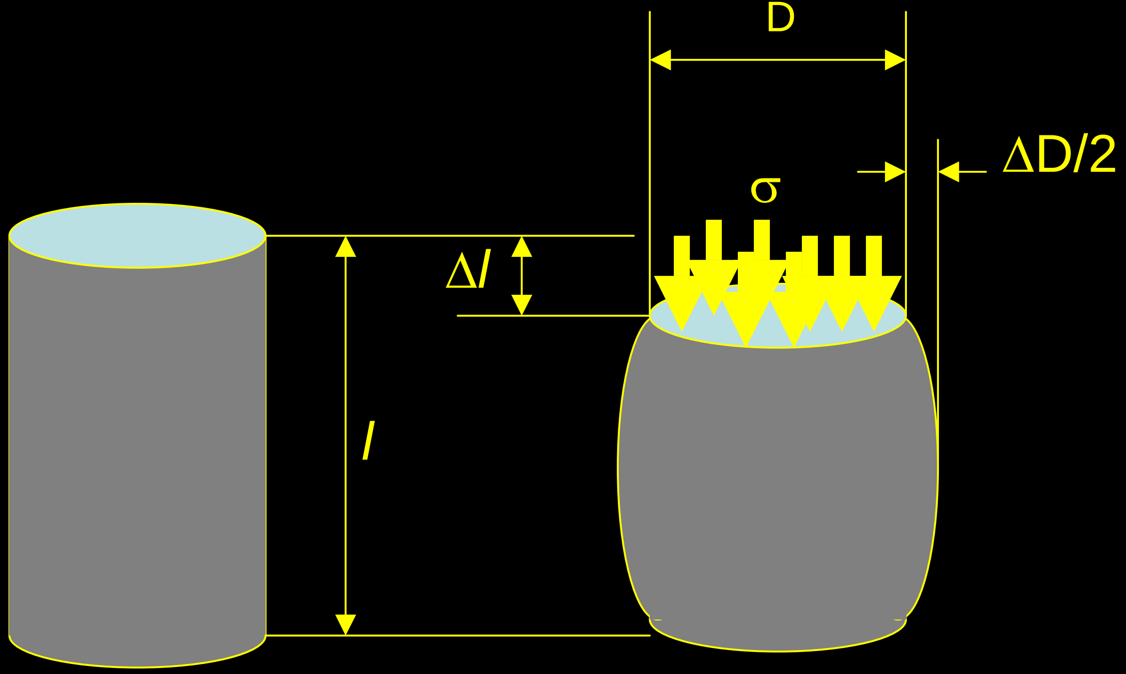


Figure 1. How an Elastic Material Behaves.



$\varepsilon_l = \Delta l / l$

$E = \sigma / \varepsilon$

$\varepsilon_t = \Delta D / D$

$\mu = \varepsilon_l / \varepsilon_t$

Figure 1. Definitions of E and μ.

Dynamic Modulus Test

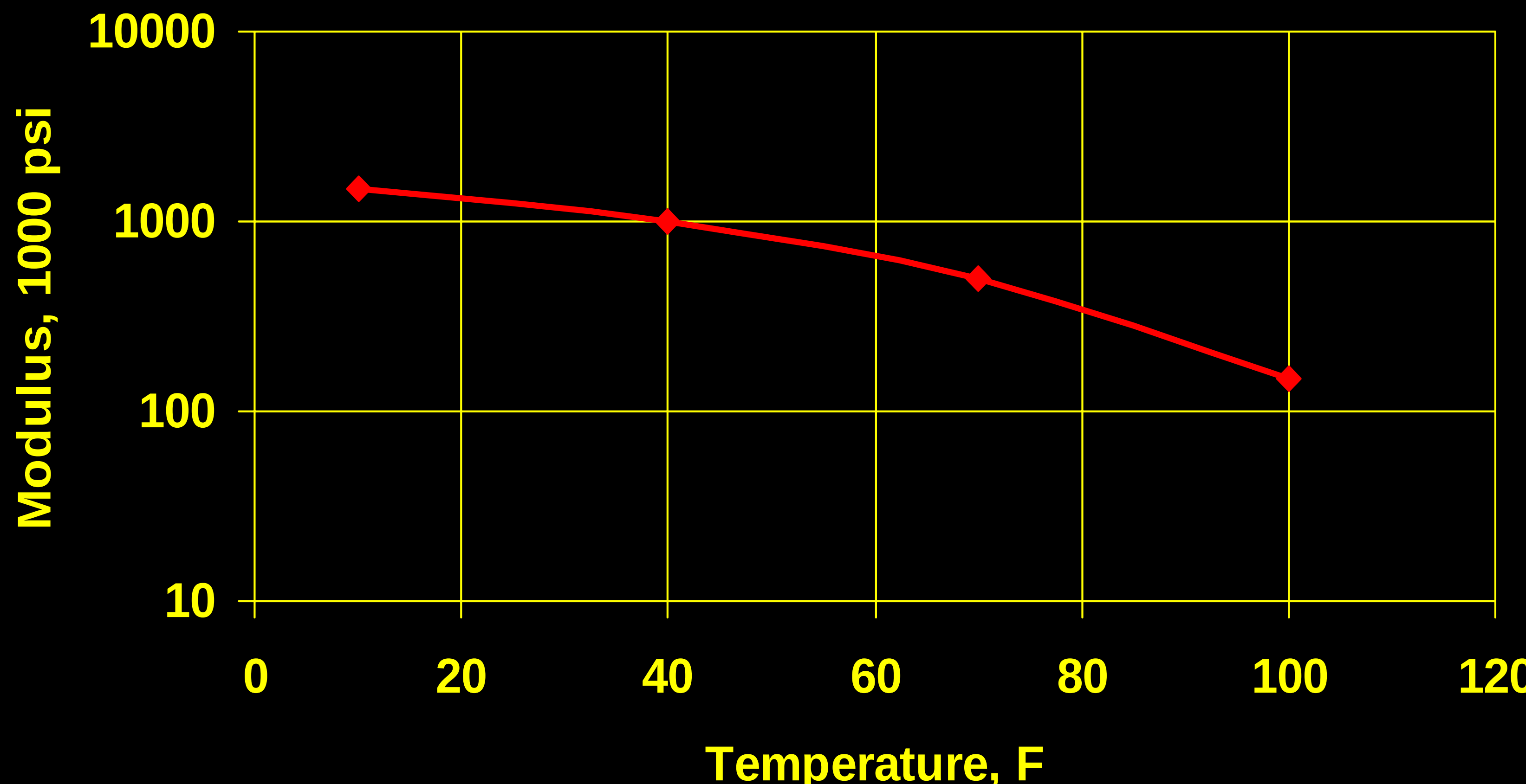
Witczak Equation for E*

$$\log E = -1.249937 + 0.29232\rho_{200} - 0.001767(\rho_{200})^2 - 0.002841\rho_4 - 0.058097V_a$$

$$-0.802208\left(\frac{V_{beff}}{V_{beff} + V_a}\right) + \frac{3.871977 - 0.0021\rho_4 + 0.003958\rho_{38} - 0.000017(\rho_{38})^2 + 0.005470\rho_{34}}{1 + e^{(-0.6033`3 - 0.313351\log(f) - 0.393532\log(\eta))}}$$

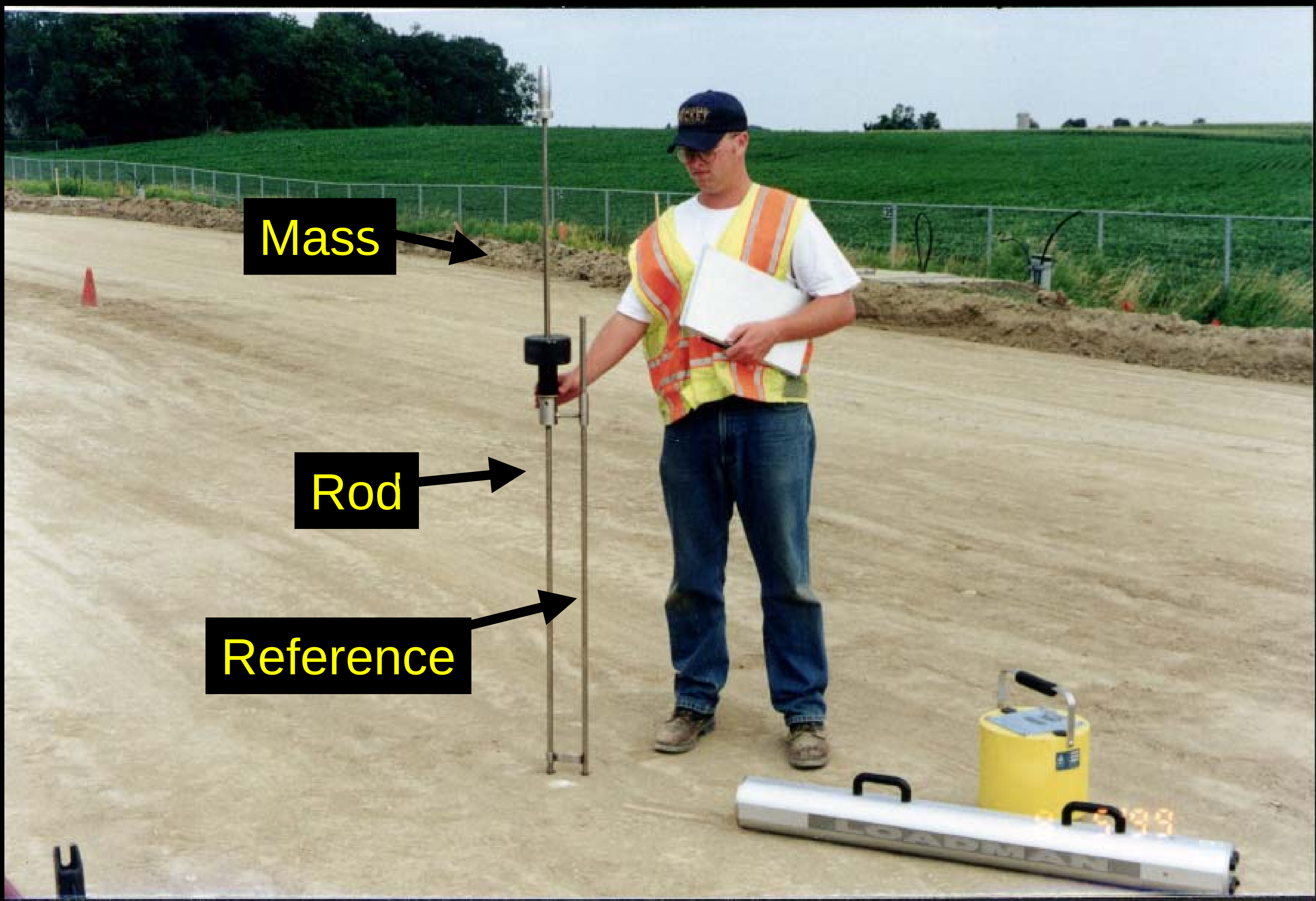
- bitumen viscosity (dynamic shear rheometer)
- loading frequency
- air voids
- effective bitumen content
- cum. % retained on 19-mm sieve
- cum. % retained on 9.5-mm sieve
- cum. % retained on 4.76-mm sieve
- % passing the 0.075-mm sieve

HMA Modulus
Versus
Temperature

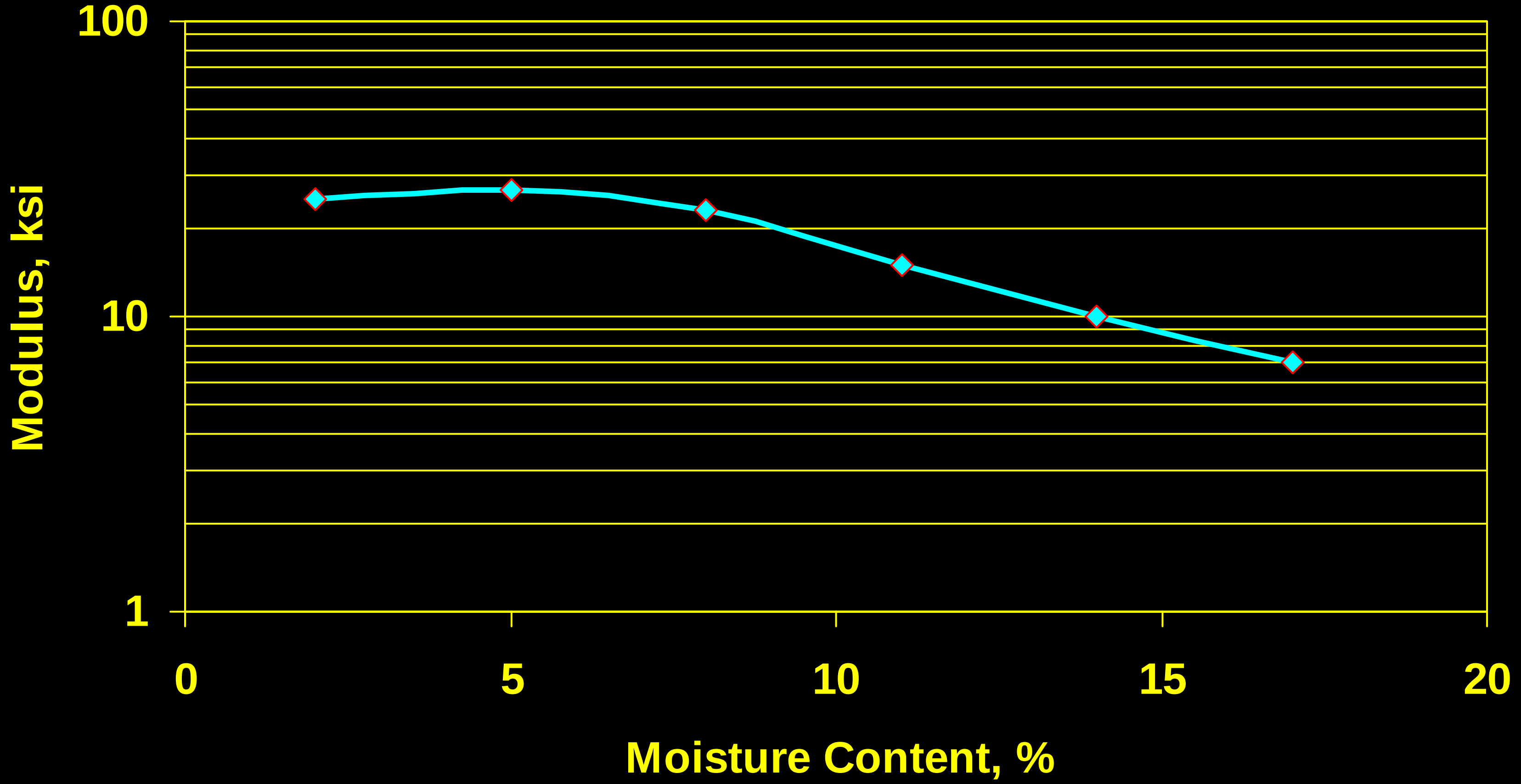


Soil Modulus Testing

Dynamic Cone Penetration

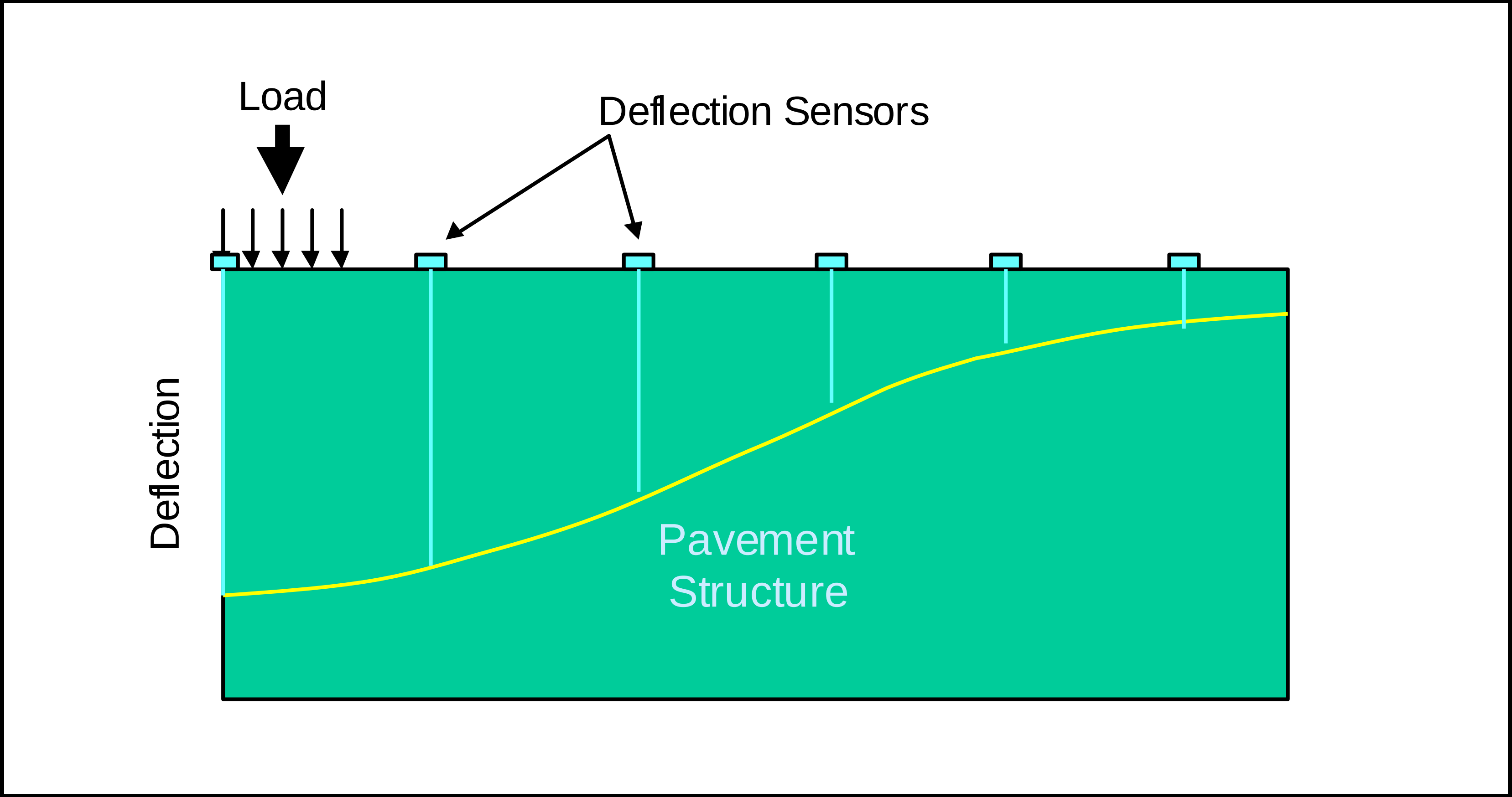


Effect of Moisture Content



FWD Testing

Backcalculation



E = f(Load, Pressure, Deflection, Distance)


Traffic
EXIT
15

AASHO Road Test Trucks

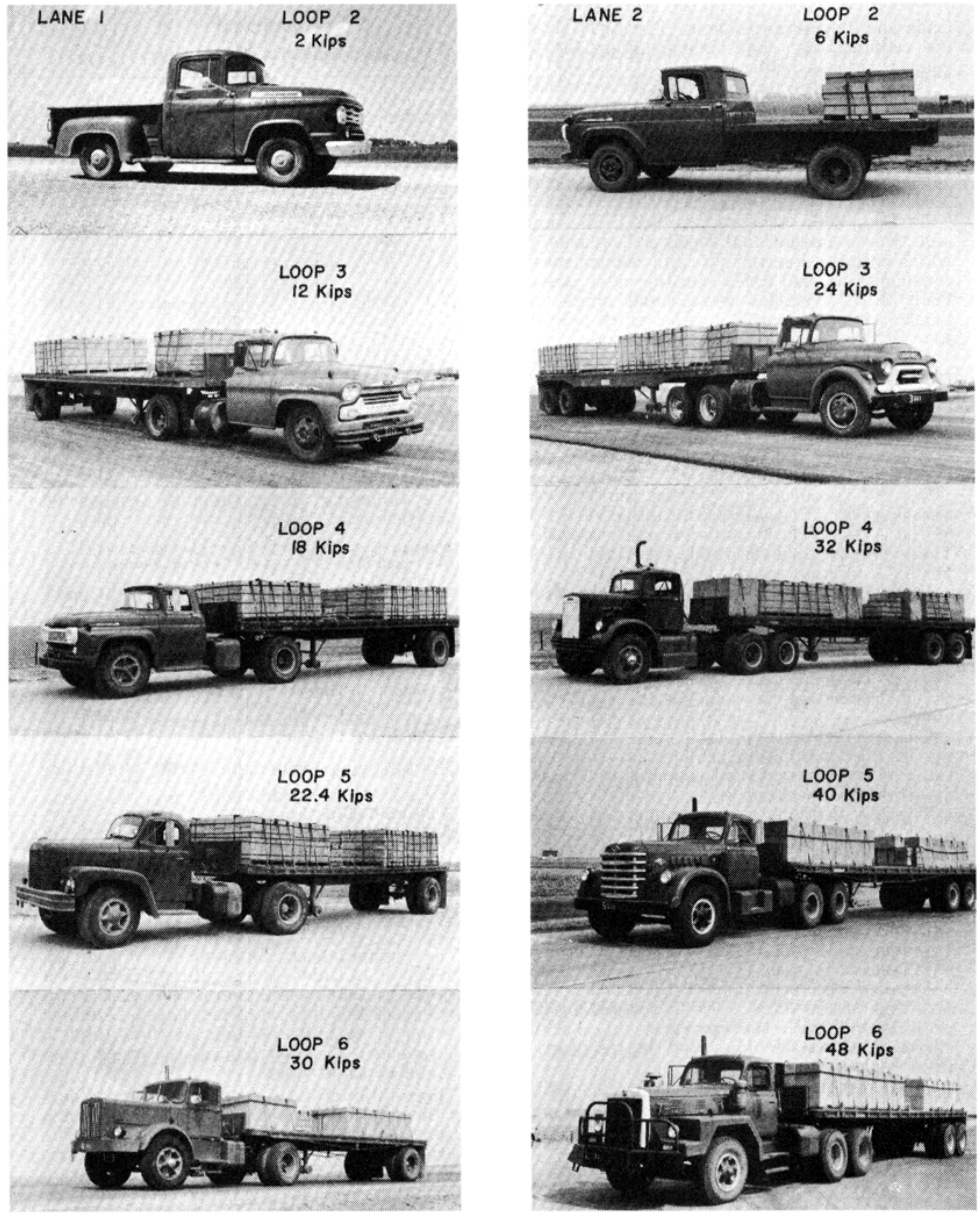
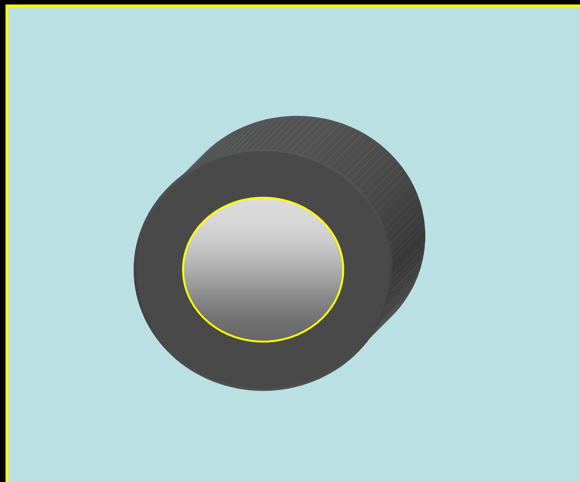
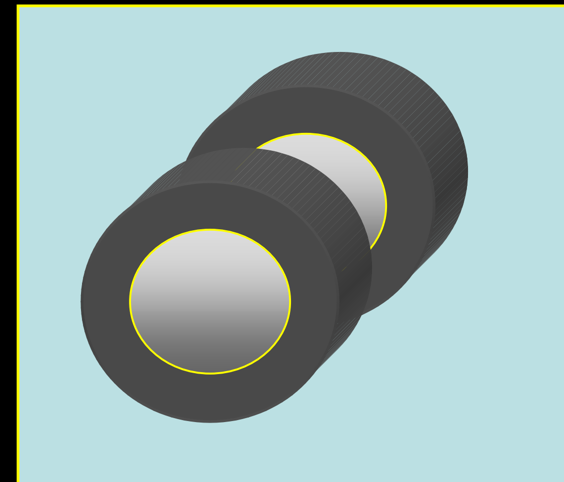


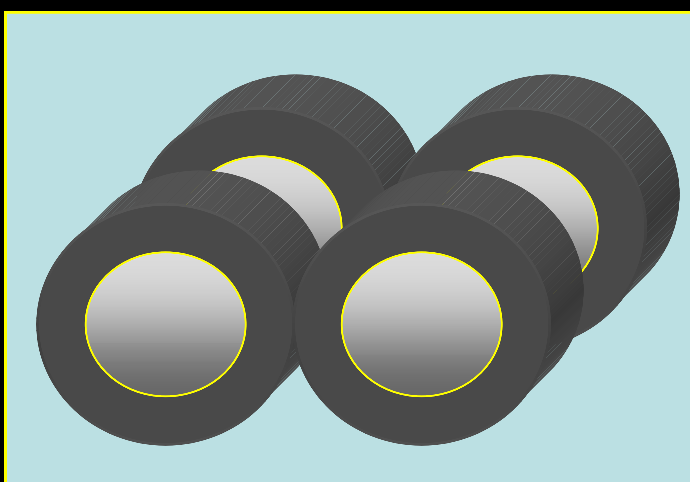
FIGURE 3 AASHO Road Test truck traffic.



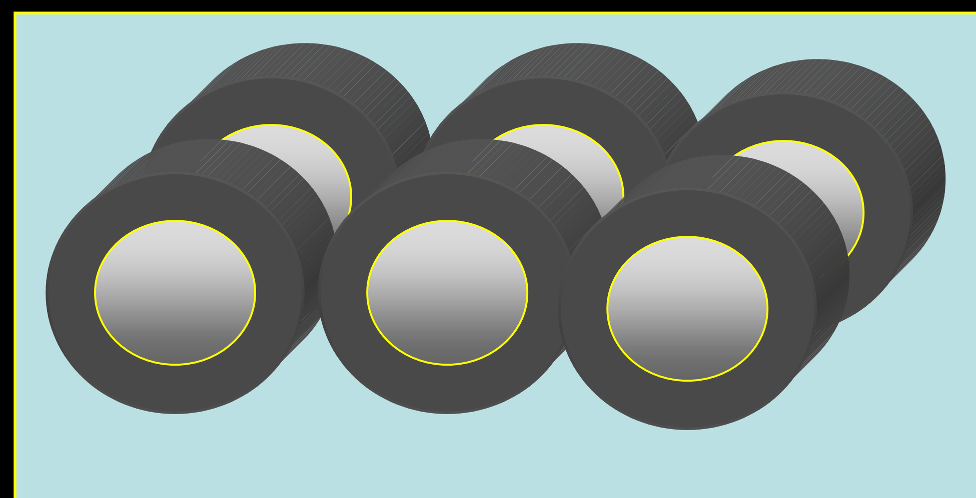
Single Tire



Dual Tire



Tandem



Tridem

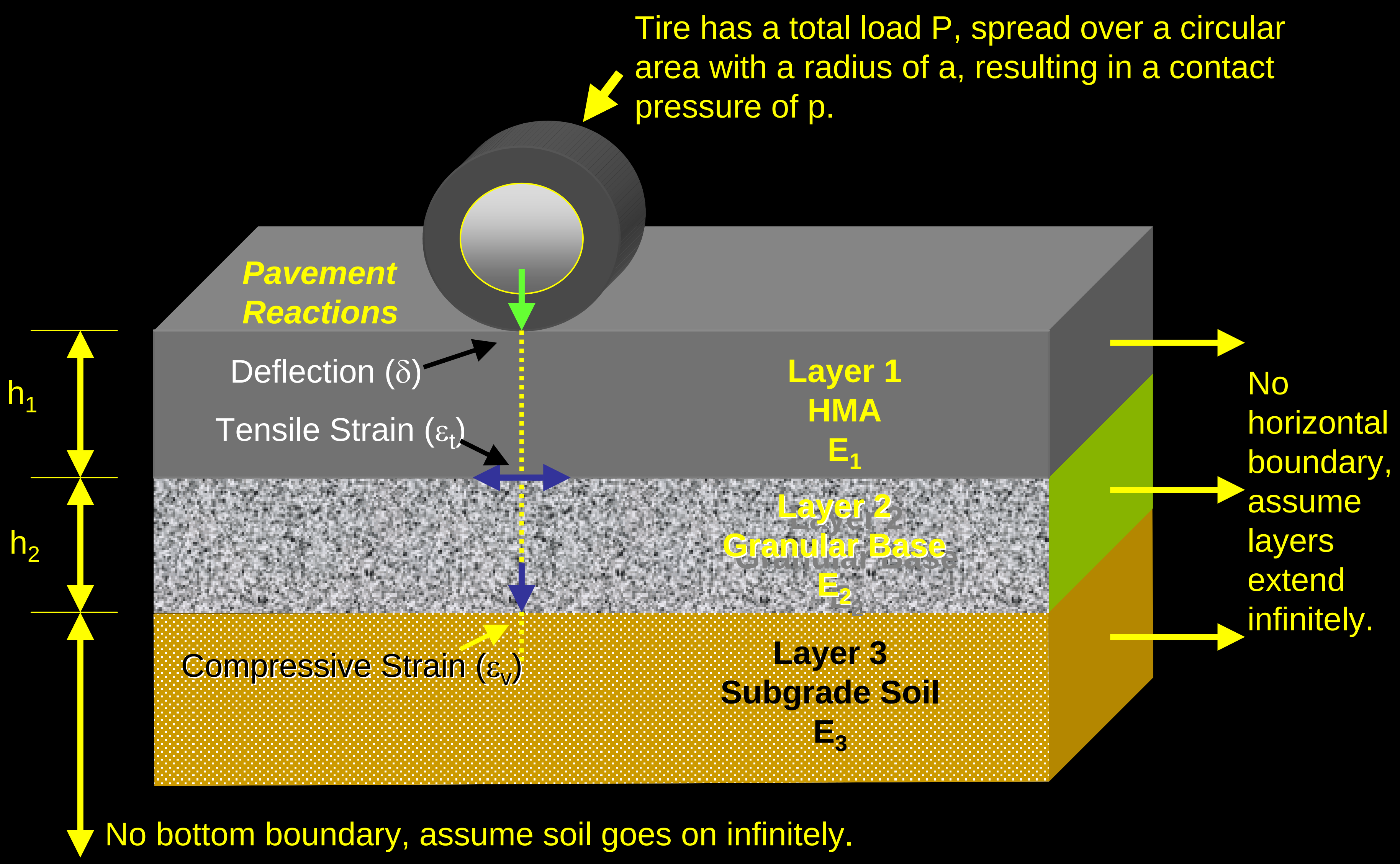


Figure 2. Layered Elastic Model Representation of a Pavement.

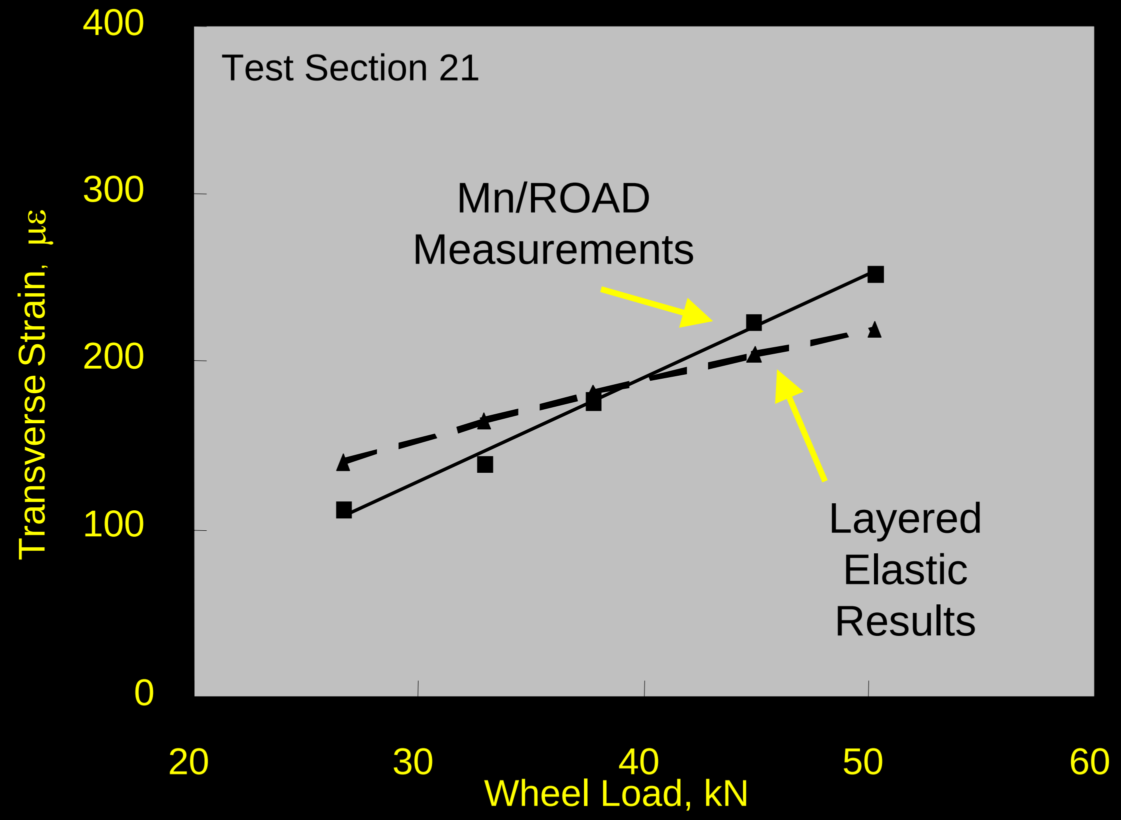
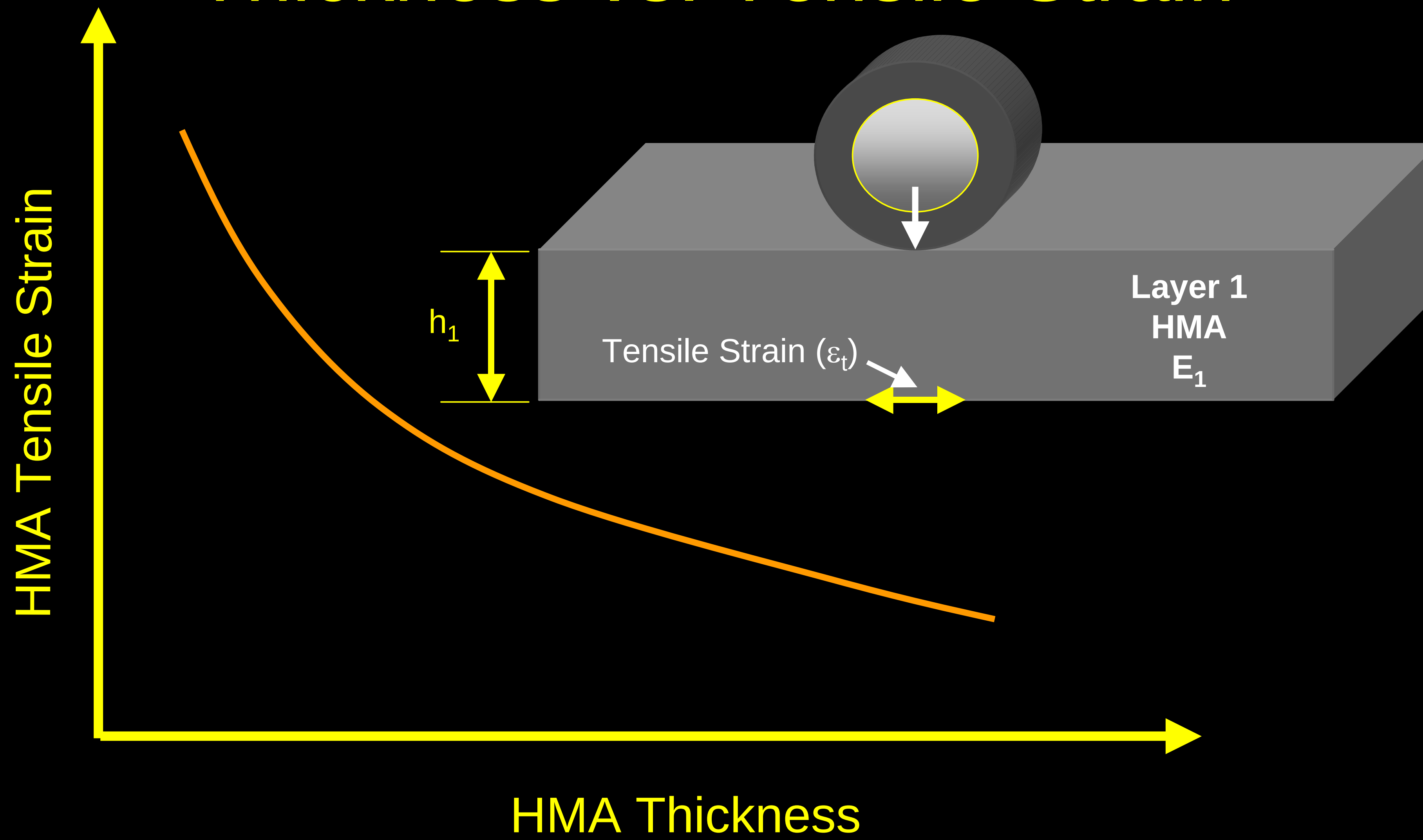
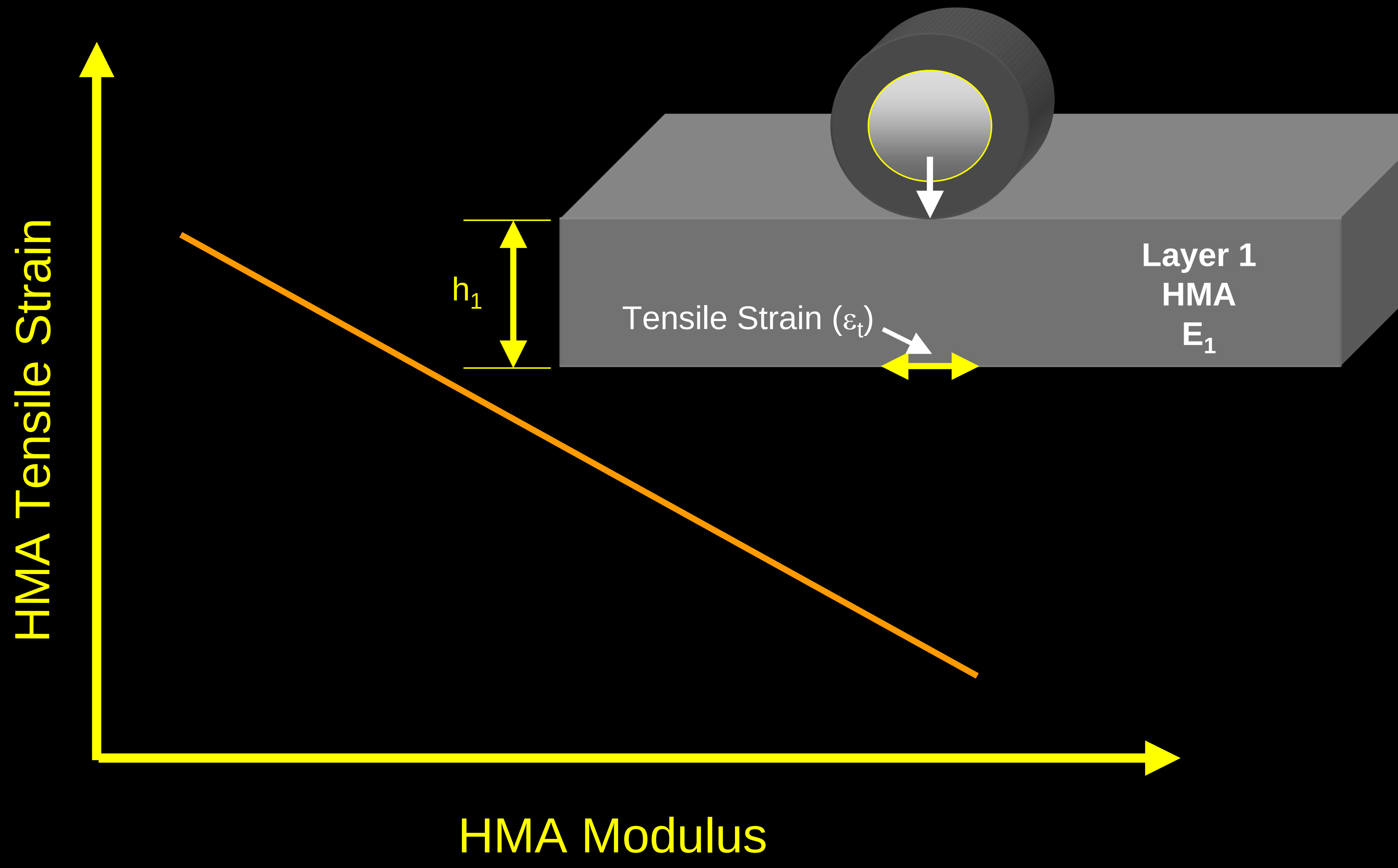


Figure 4. A Comparison of Measured Strains and Computed Strains at Mn/ROAD. (After Timm et al., 1998, Development of Mechanistic-Empirical Pavement Design, *Transportation Research Record No. 1629*, Transportation Research Board, Washington, DC.)

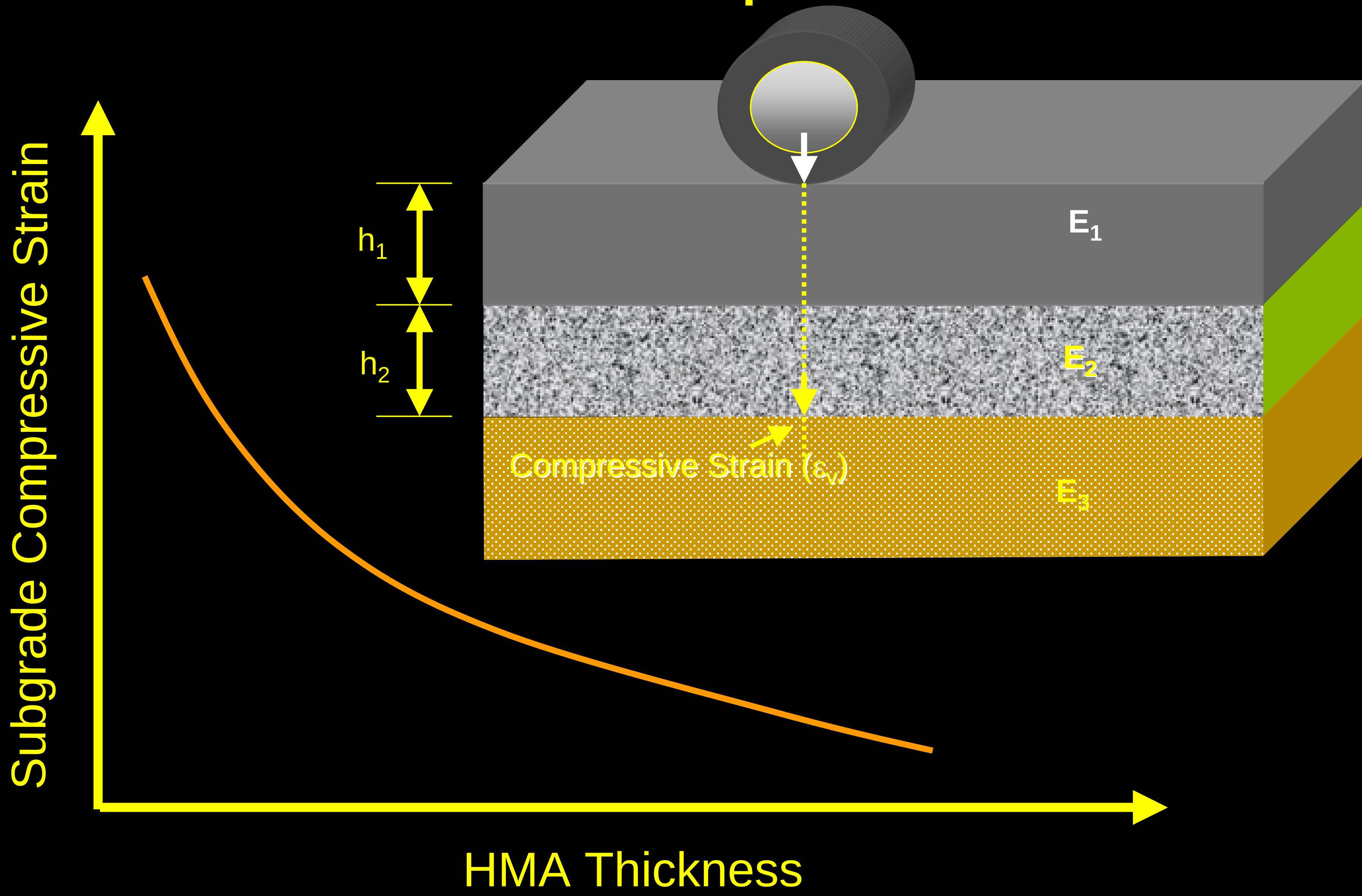
Thickness vs. Tensile Strain



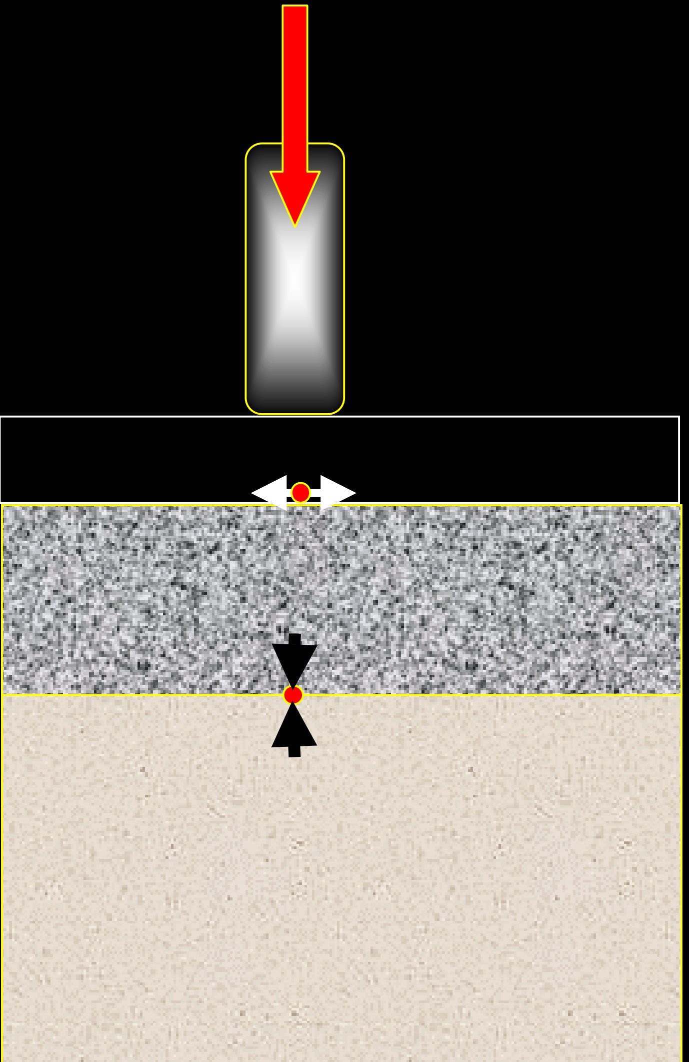
Modulus vs. Tensile Strain

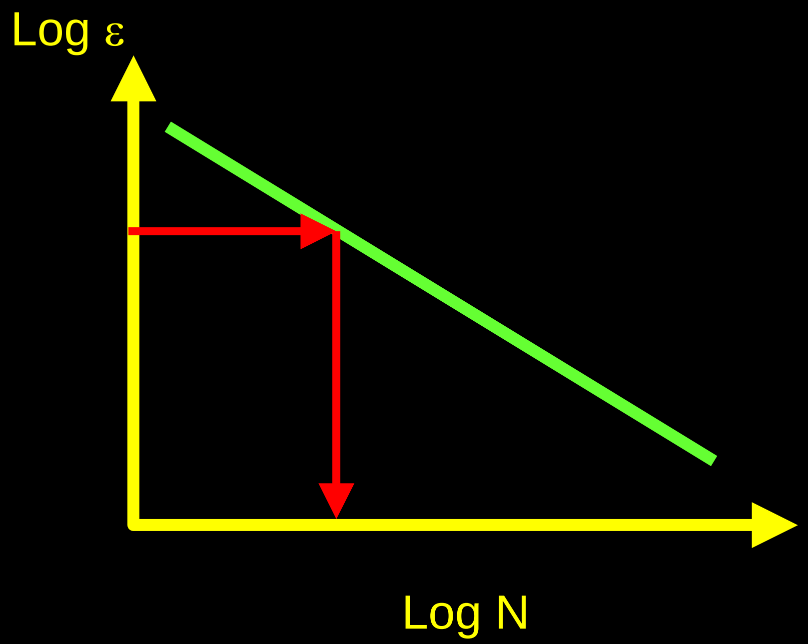


Thickness vs. Compressive Strain

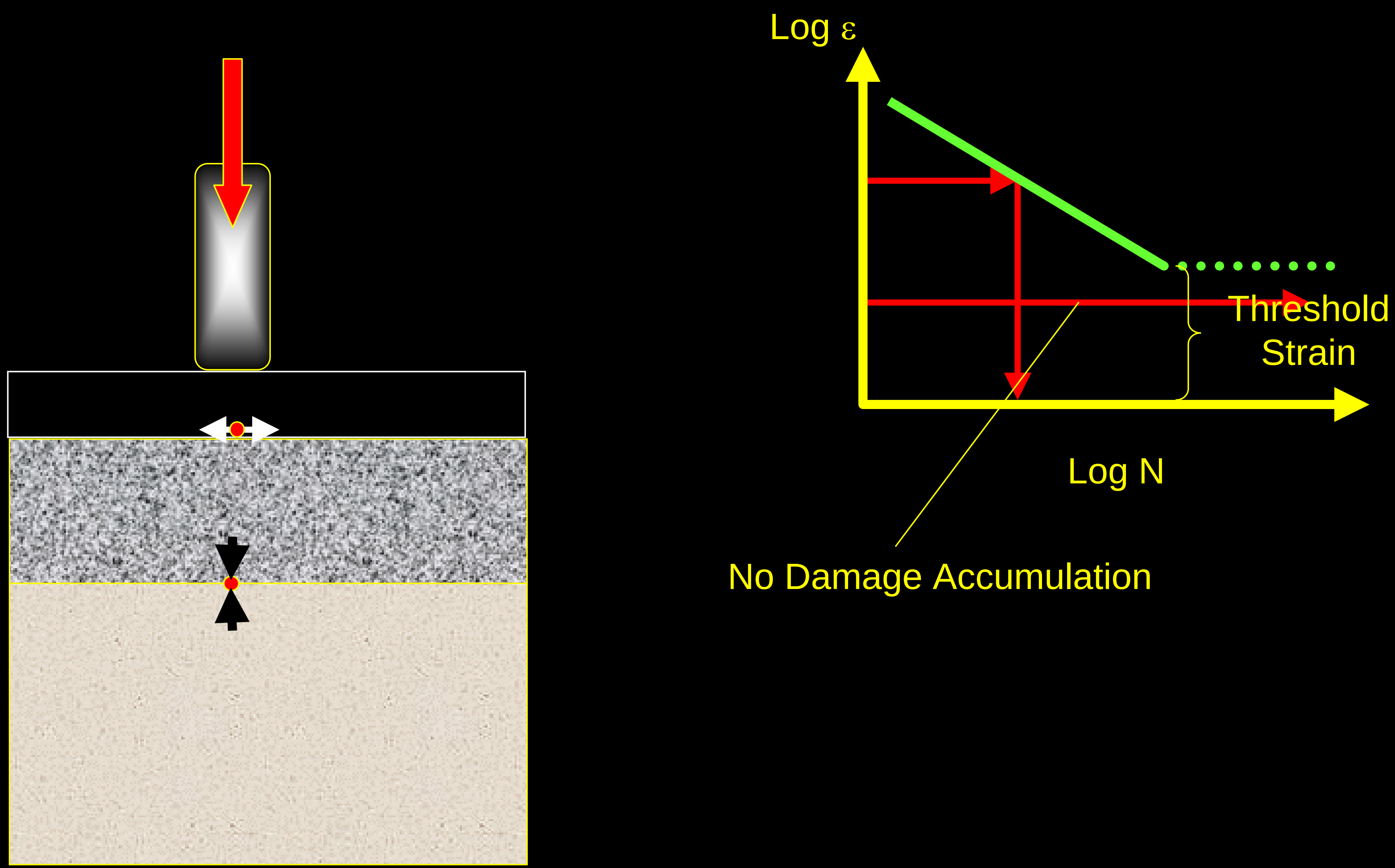


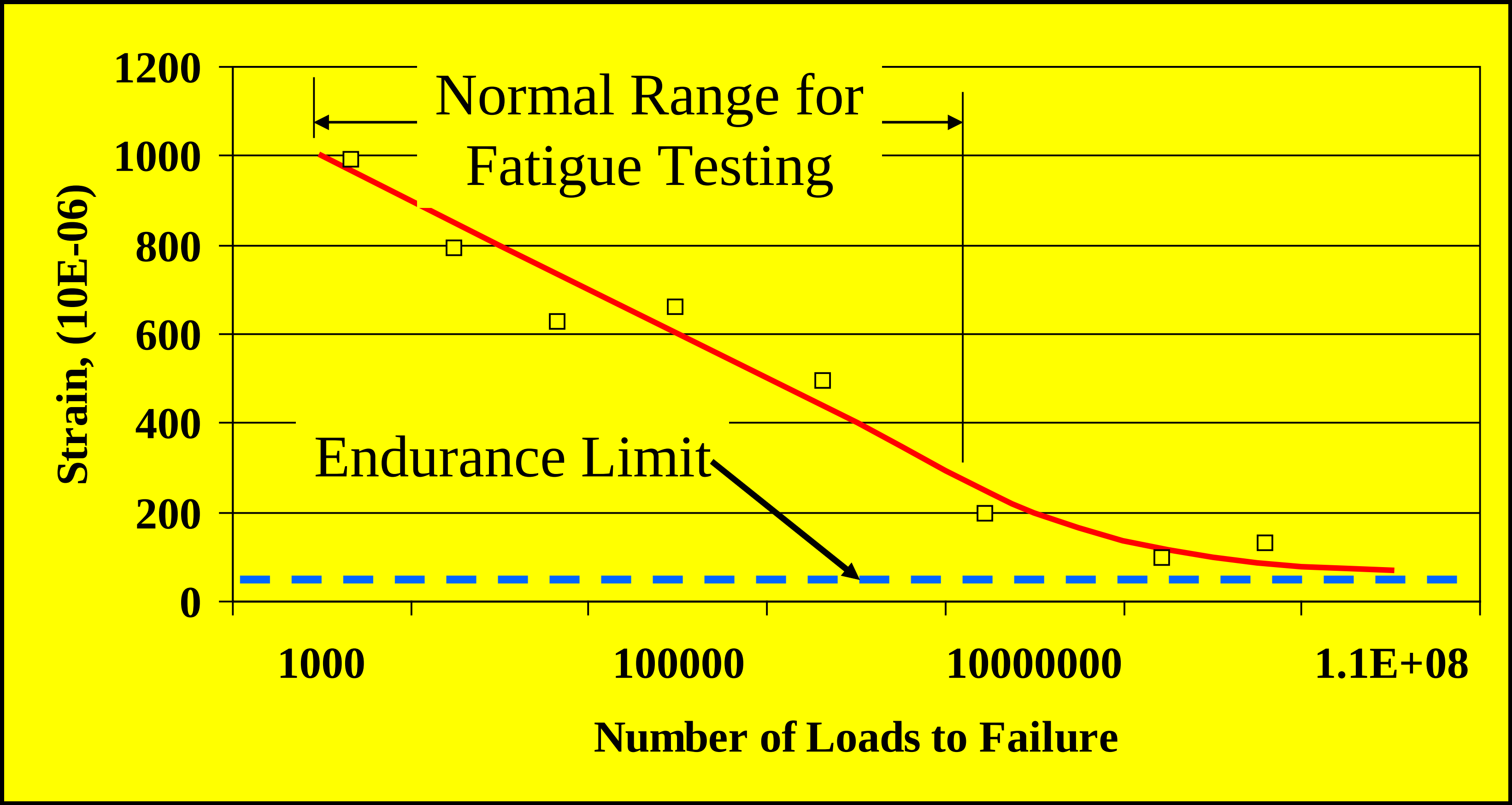
Traditional M-E Design





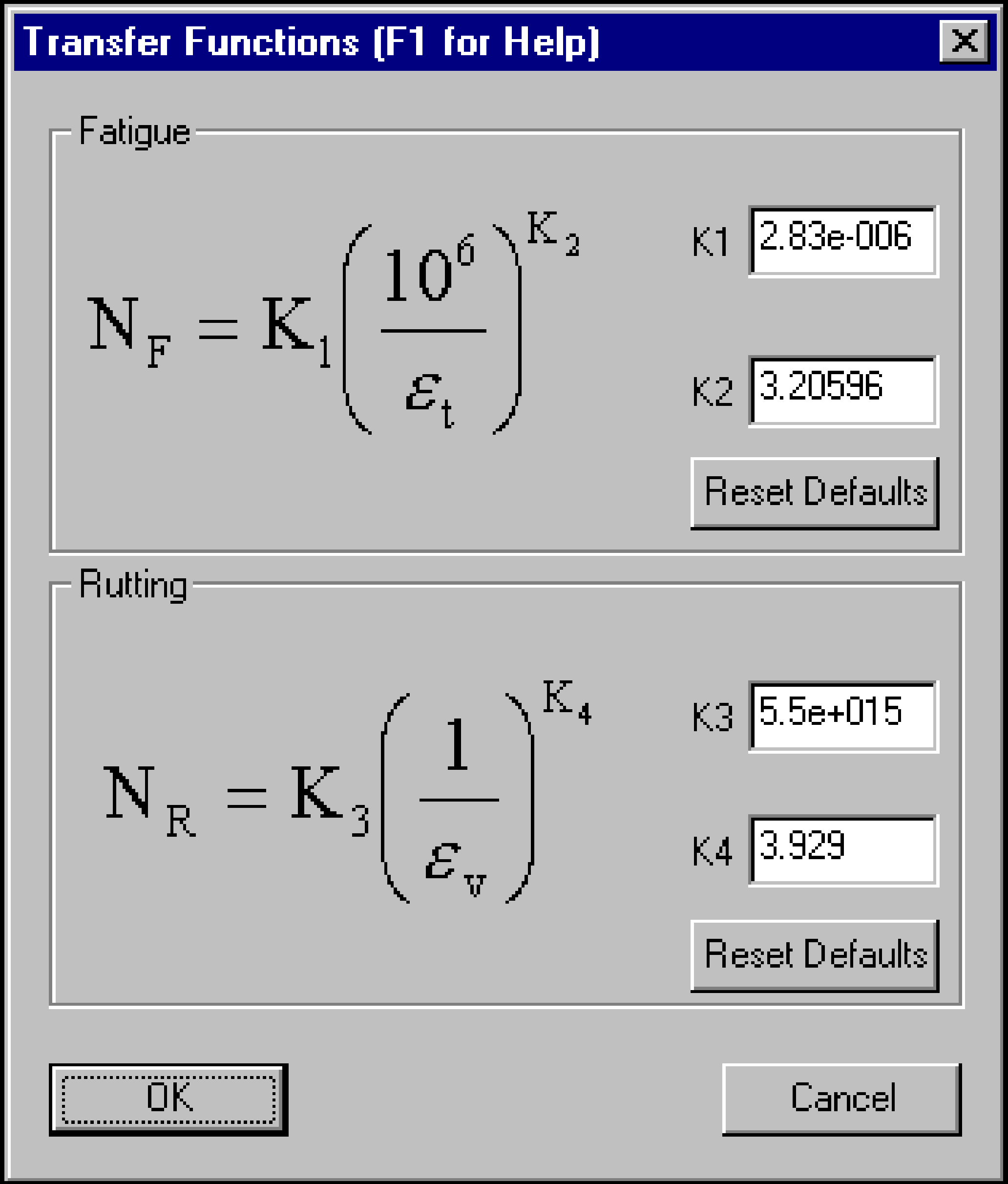
Perpetual Pavement Design

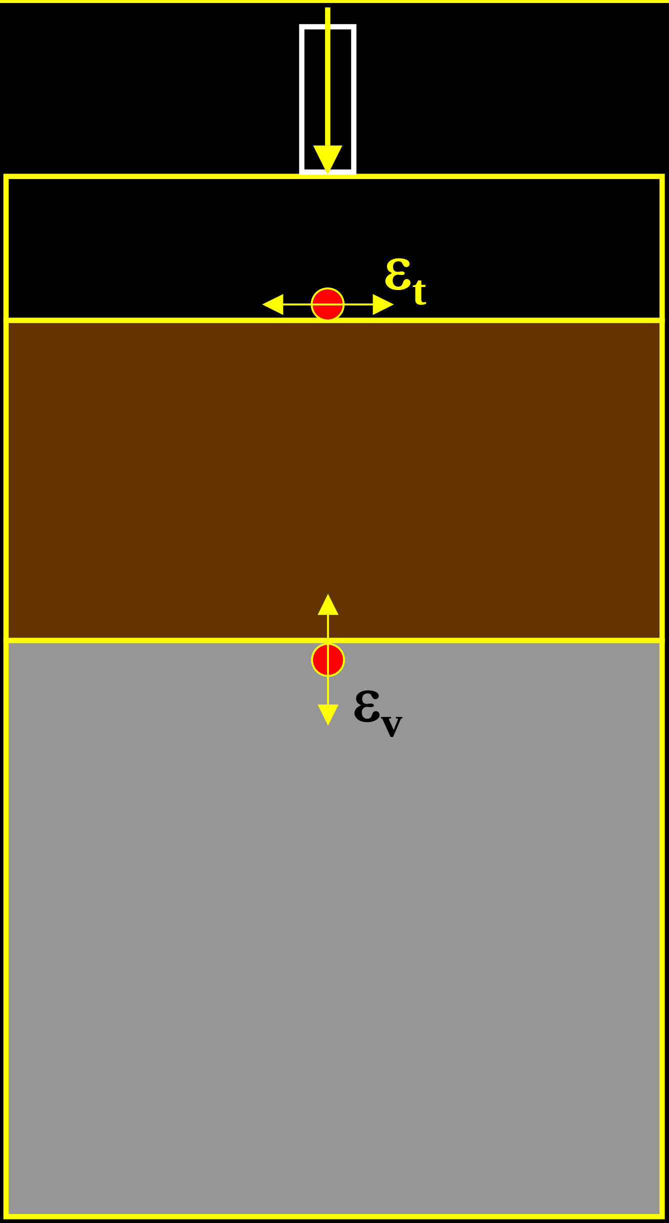




Normal Fatigue Testing Results Versus
Endurance Limit Testing

Transfer Functions



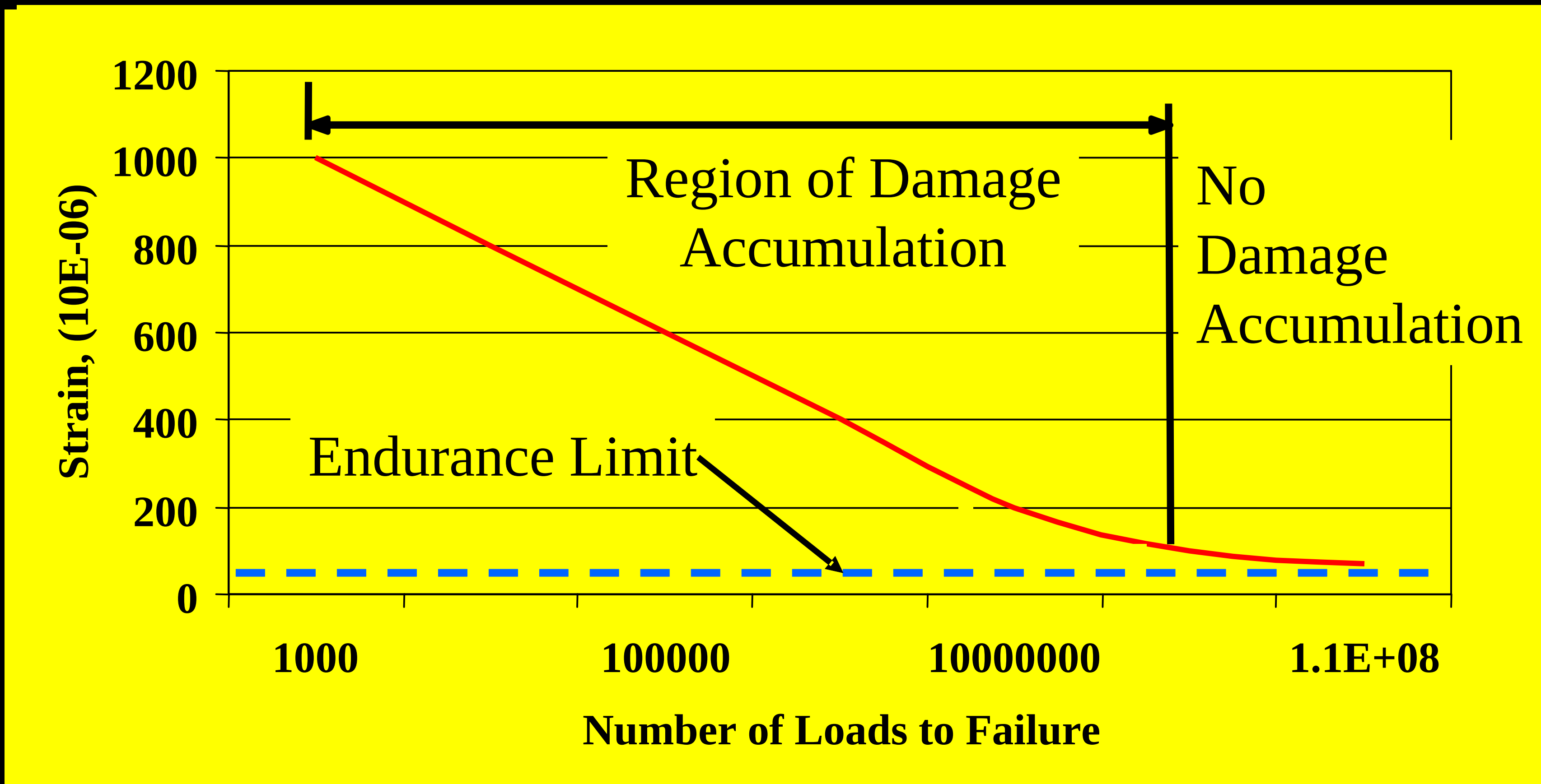


Miner’s Hypothesis

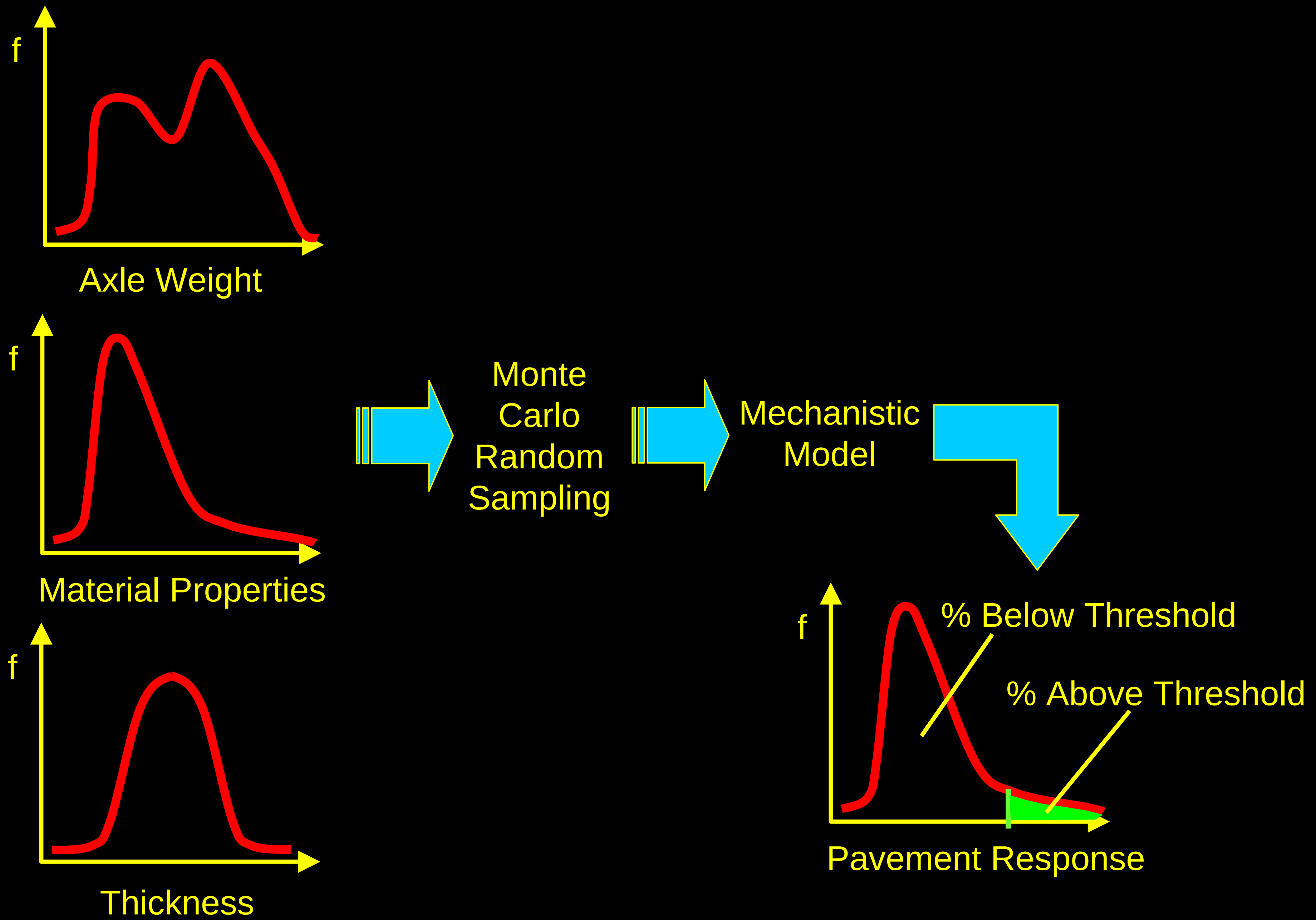
- Provides the ability to sum damage for a specific distress type
- $D = \Sigma\ n_i/N_i \leq 1.0$

where n_i = actual number of loads during condition i

N_i = allowable number of loads during condition i

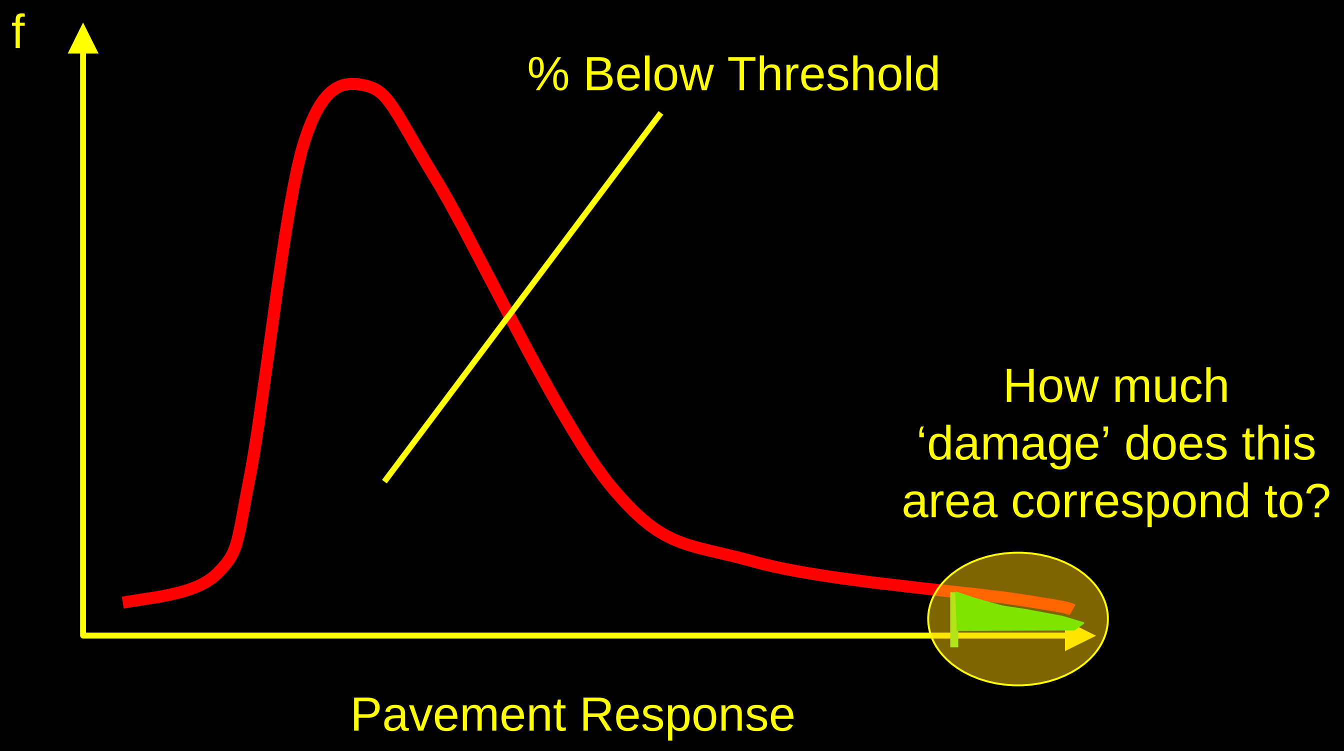

1200
1000
800
600
400
200
0
Strain, (10E-06)
Region of Damage
Accumulation
No
Damage
Accumulation
Endurance Limit
1000
100000
10000000
1.1E+08
Number of Loads to Failure

Probabilistic Design – Monte Carlo Simulation



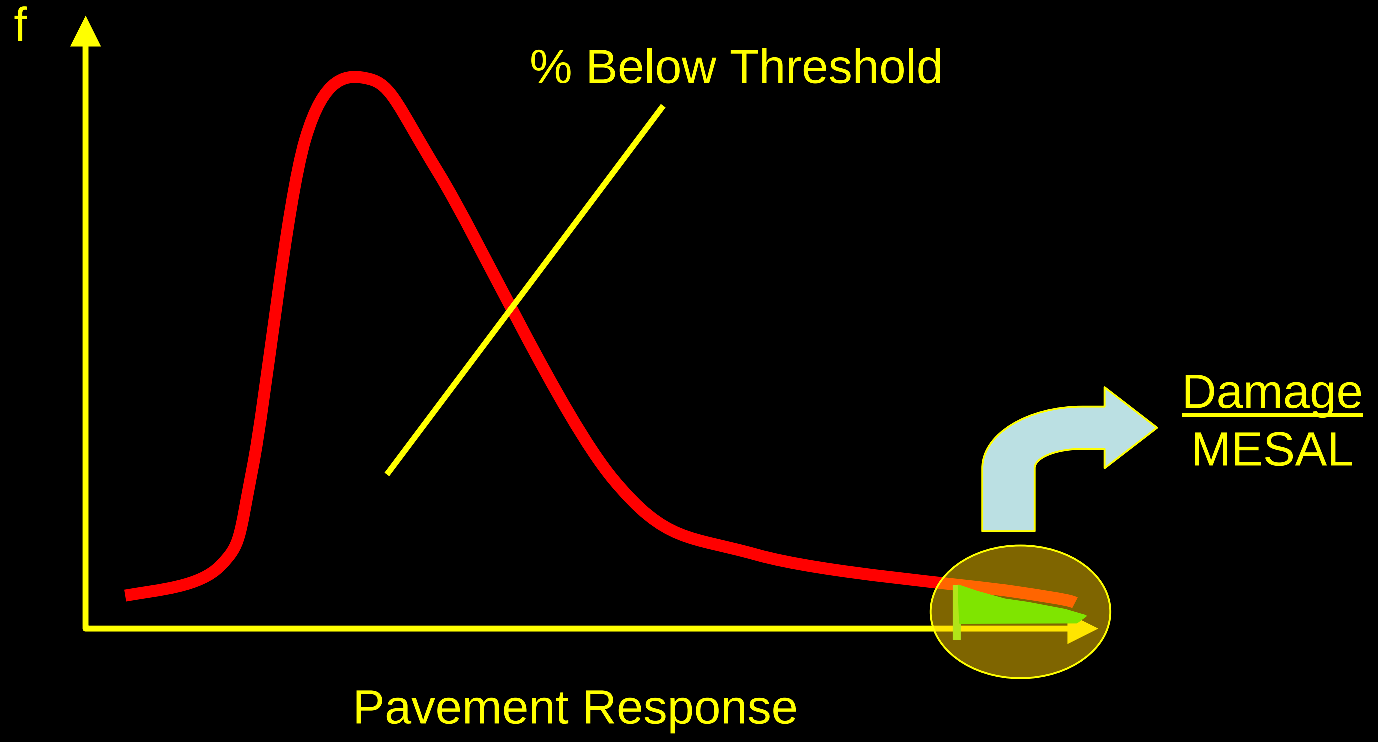
% Below Threshold

- Design should have high % below threshold



‘Damage Computation’

- For responses exceeding threshold, compute N using transfer function
  - User defined
- Calculate damage accumulation rate
  - Damage / MESAL

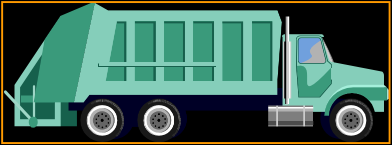


Estimated Long Life

- Convert damage rate into an estimated life
  - Use traffic volume and growth
  - Calculate when damage = 0.1
    - Use for Low Vol. Roads (t ~30 yrs.)

Low Volume Traffic

10 - 20/wk



3 - 5/wk

10 - 20/wk

PerRoad 2.4

- Sponsored by APA
- Developed at Auburn University / NCAT
- M-E Perpetual Pavement Design and Analysis Tool
- Help File is the Users Manual
- Press F1 at Any Time for Help File