Florida Department of Transport APT and Instrumentation Workshop

Granular base/subbase layers:

Combining laboratory and HVS data

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Structure of presentation

- Background and general comments
- Modeling the behaviour of granular pavement layers
  - Non-linear resilient modulus
  - Shear strength
  - Plastic deformation
- A comparison between laboratory and HVS permanent deformation models

Background and general comments

Granular base/subbase layers:
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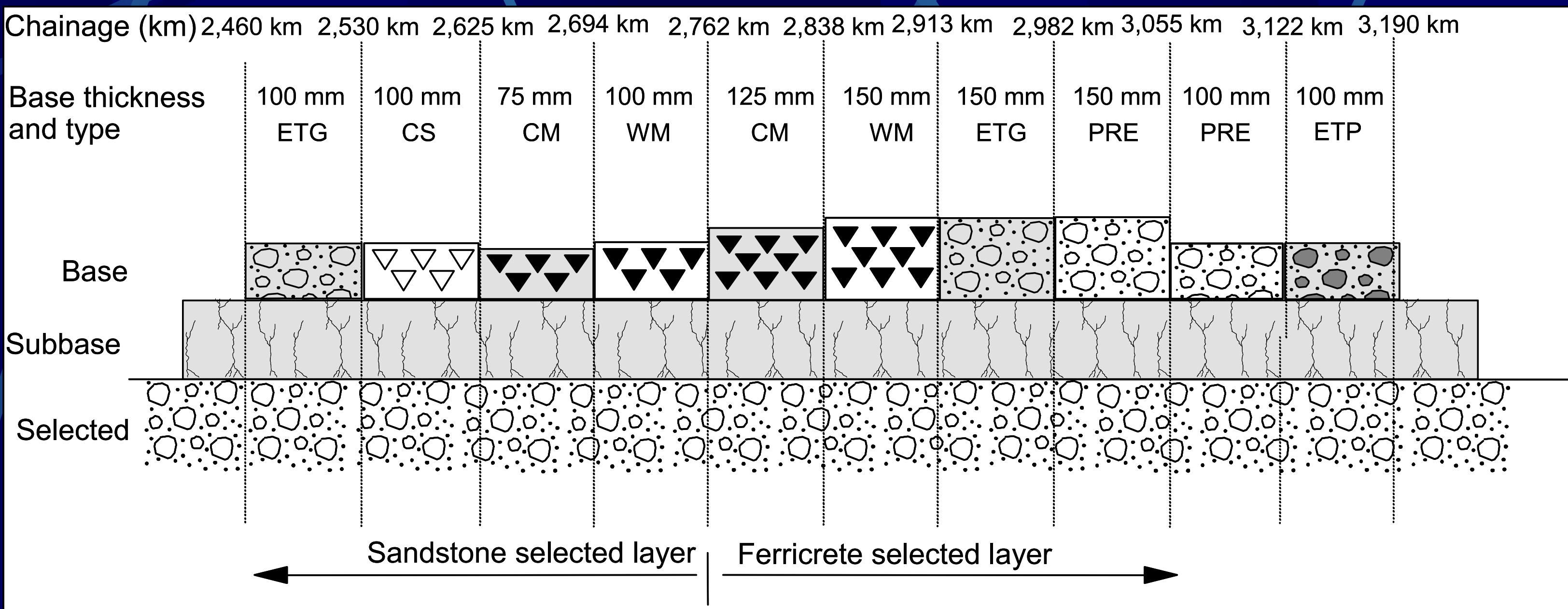
Why permanent deformation of unbound material?

- Thin (25 – 50 mm) AC on unbound base layers
- 40 – 60 % of rut from permanent deformation of unbound base layers
- All pavement materials and layers deform permanently under repeated loading

Background

- Labour-intensive road construction to create employment
  - "Unconventional" material
- Process applied to
  - Waterbound macadam
  - Clinker ash waste product
  - Natural gravel
  - Crushed stone

Layout of experimental sections



CS Crushed stone

ETG Emulsion Treated Gravel

ETP Emulsion Treated Premamix

PRE Premamix (ash)

WM Waterbound Macadam

CM Composite Macadam

ROAD D2388 EXPERIMENTAL SECTIONS

Resilient response

Granular base/subbase layers:
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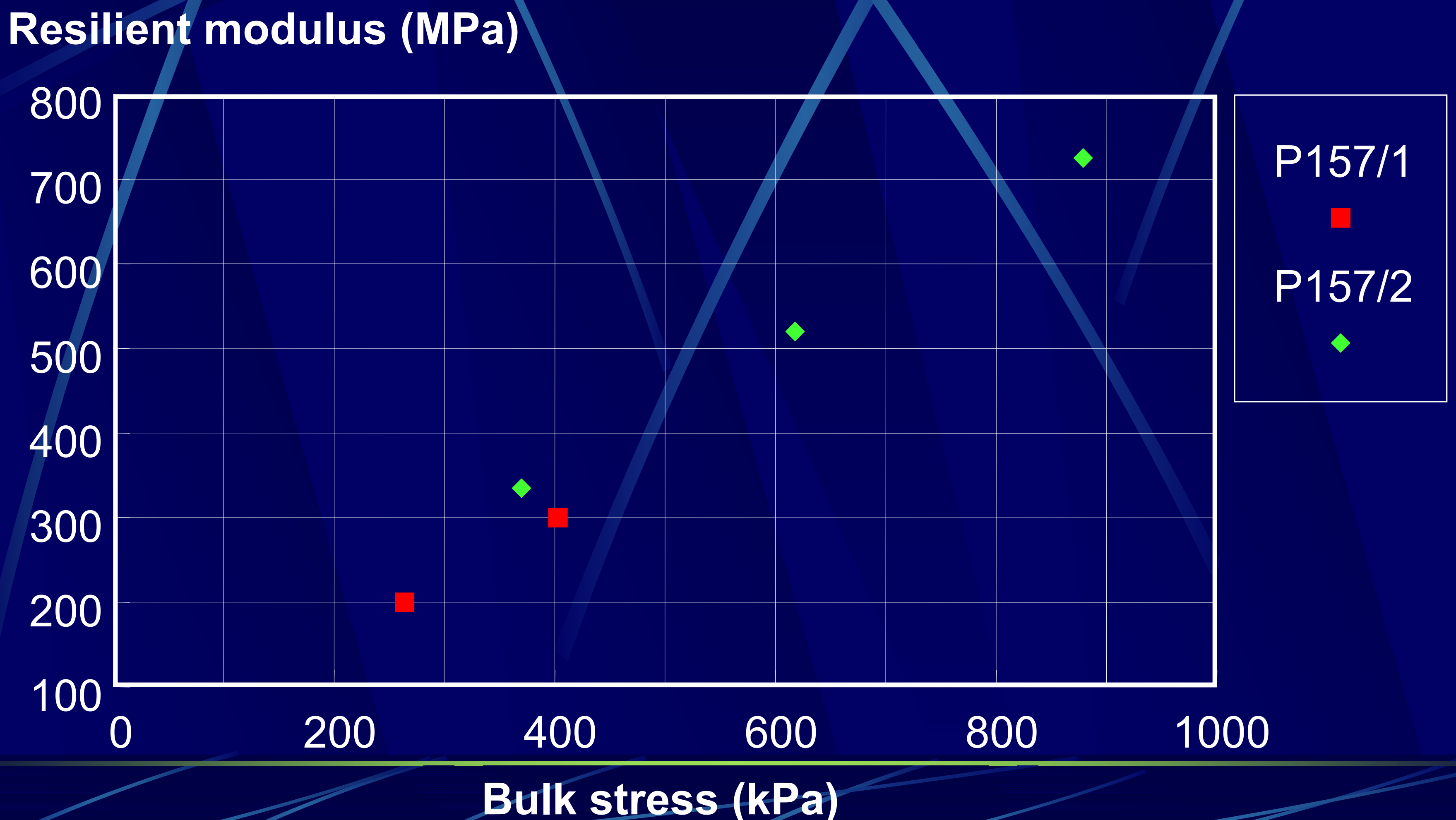
Non-linear resilient modulus models

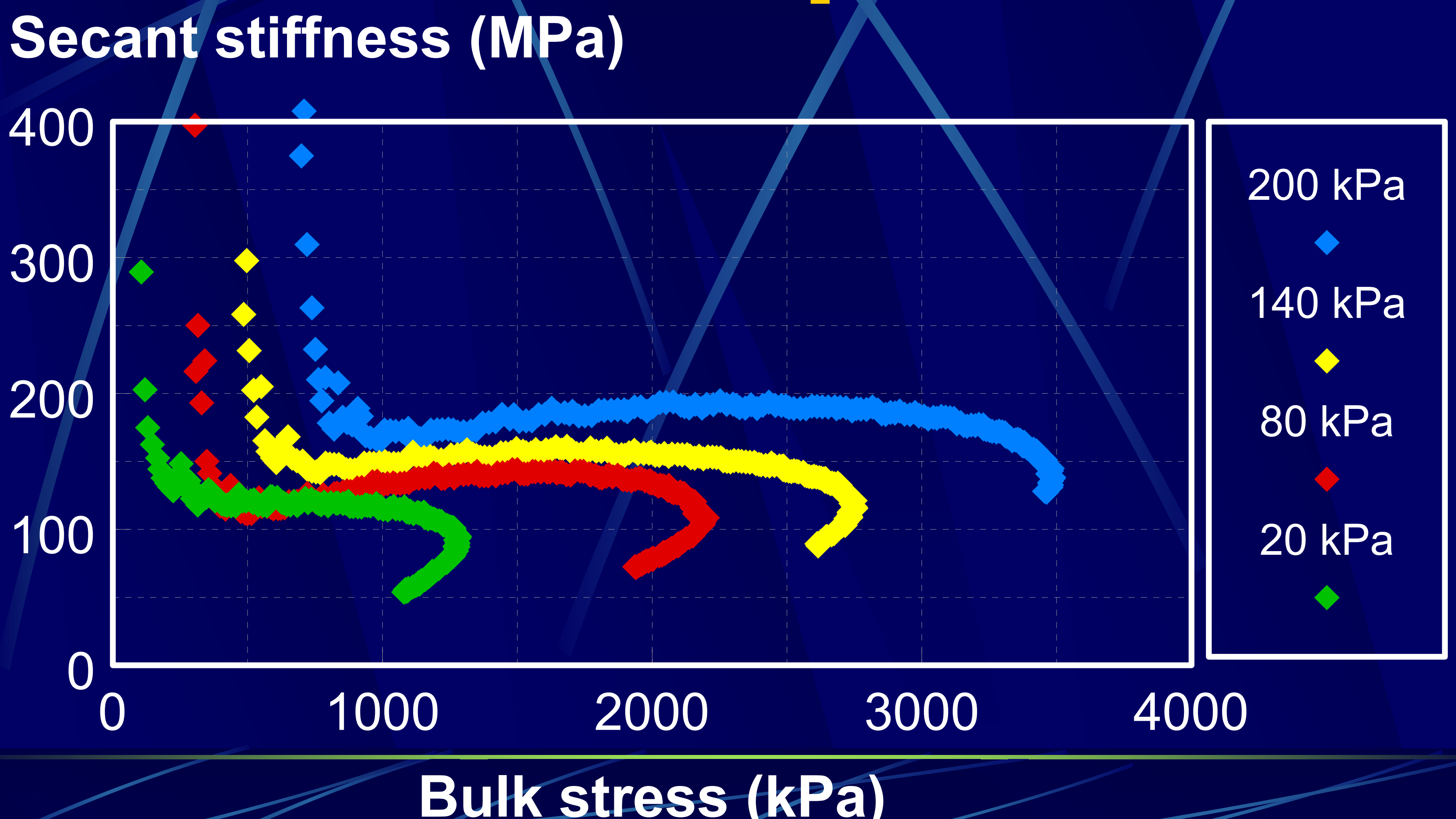
$$M_r = k\theta^n$$

$$M_r = k_0 \left(\frac{\theta}{P_a} \right)^{k_1} \left(\frac{\sigma_d}{P_a} \right)^{k_2}$$

Stress stiffening from MDD back-calculation

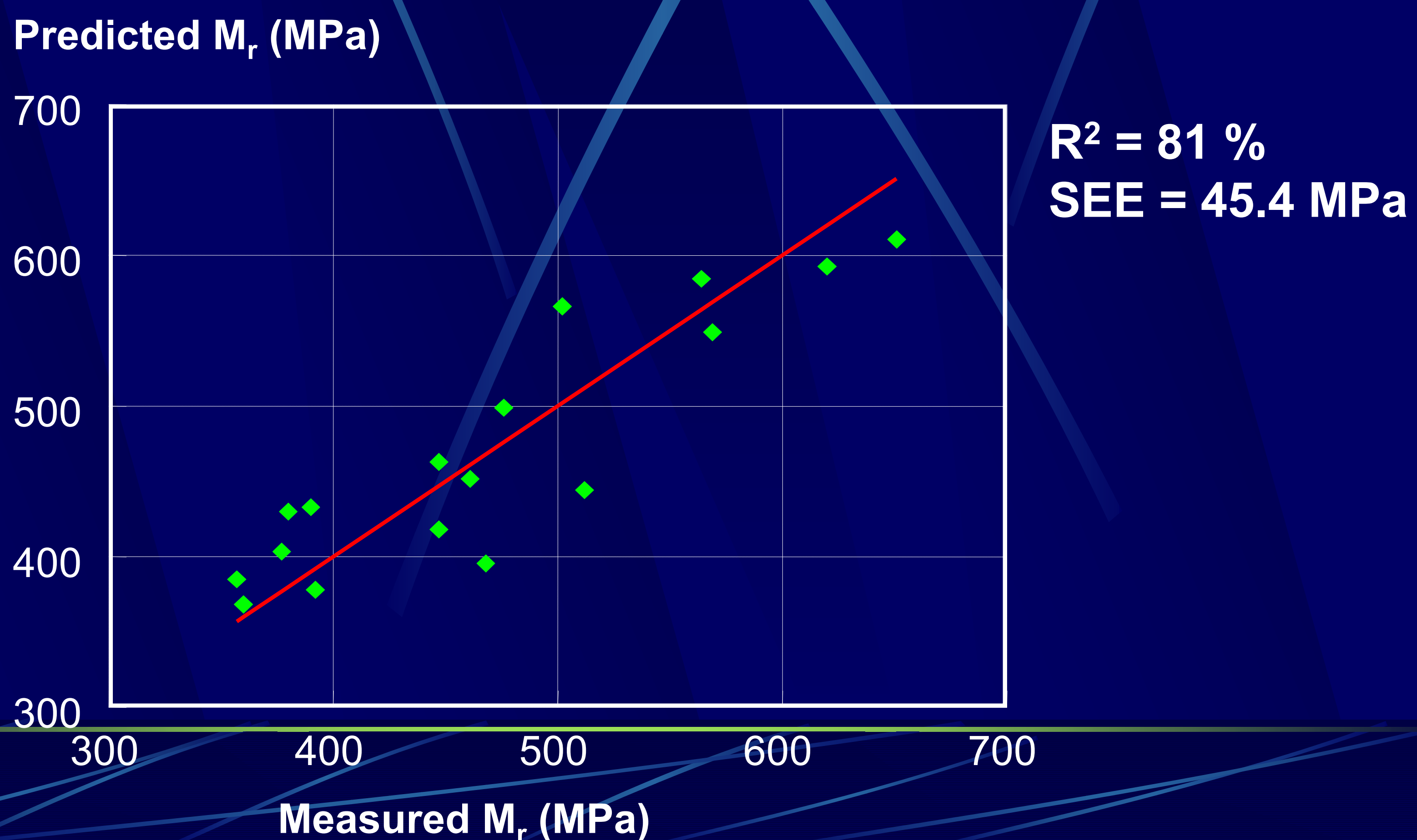


Appropriate confinement parameter



MDD depth deflection data: Deflection profile

- Dynamic triaxial results
- $M_R = -528 + 14.0\ RD - 2.7\ S + 0.83\ \rho_3 - 0.87\ SR$



Conclusions: Resilient modulus

- Conclusions from laboratory results
  - Stress stiffening **and** softening behaviour
    - Important for modeling, no stress concentration
  - Relative density and degree of saturation largely determines resilient modulus
  - Typical dynamic resilient modulus values for crushed stone
    - 350 to 650 MPa depending on confinement, shear stress, relative density and degree of saturation
    - Compares well with HVS (300 - 700 MPa)

Shear strength

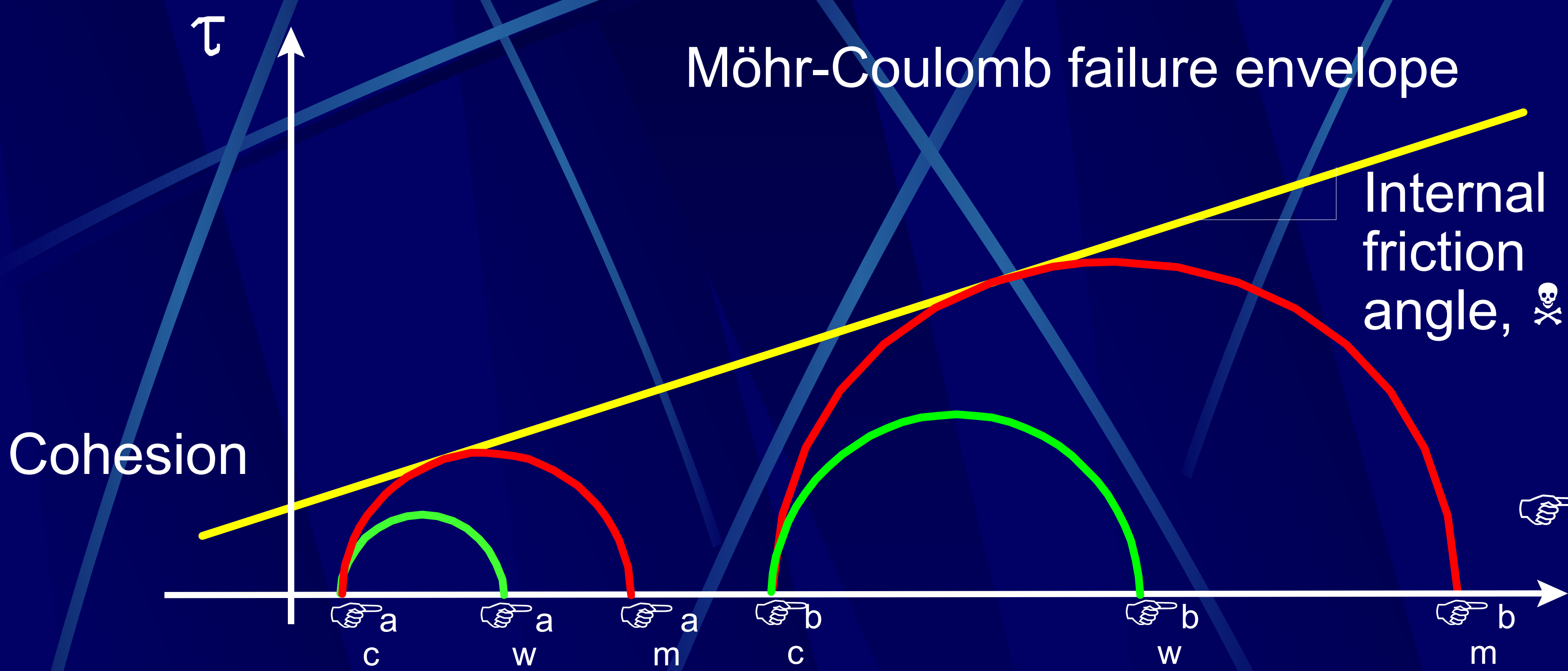
Granular base/subbase layers:
Combining laboratory and HVS data

Appropriate stress parameter

$$SR = \frac{\sigma_1{}^a - \sigma_3}{\sigma_1{}^m - \sigma_3} = \frac{\sigma_1{}^a - \sigma_3}{\sigma_3\left(\tan^2\left(45^\circ + \frac{\phi}{2}\right) - 1\right) + 2C\tan\left(45^\circ + \frac{\phi}{2}\right)}$$

Shear strength parameters required

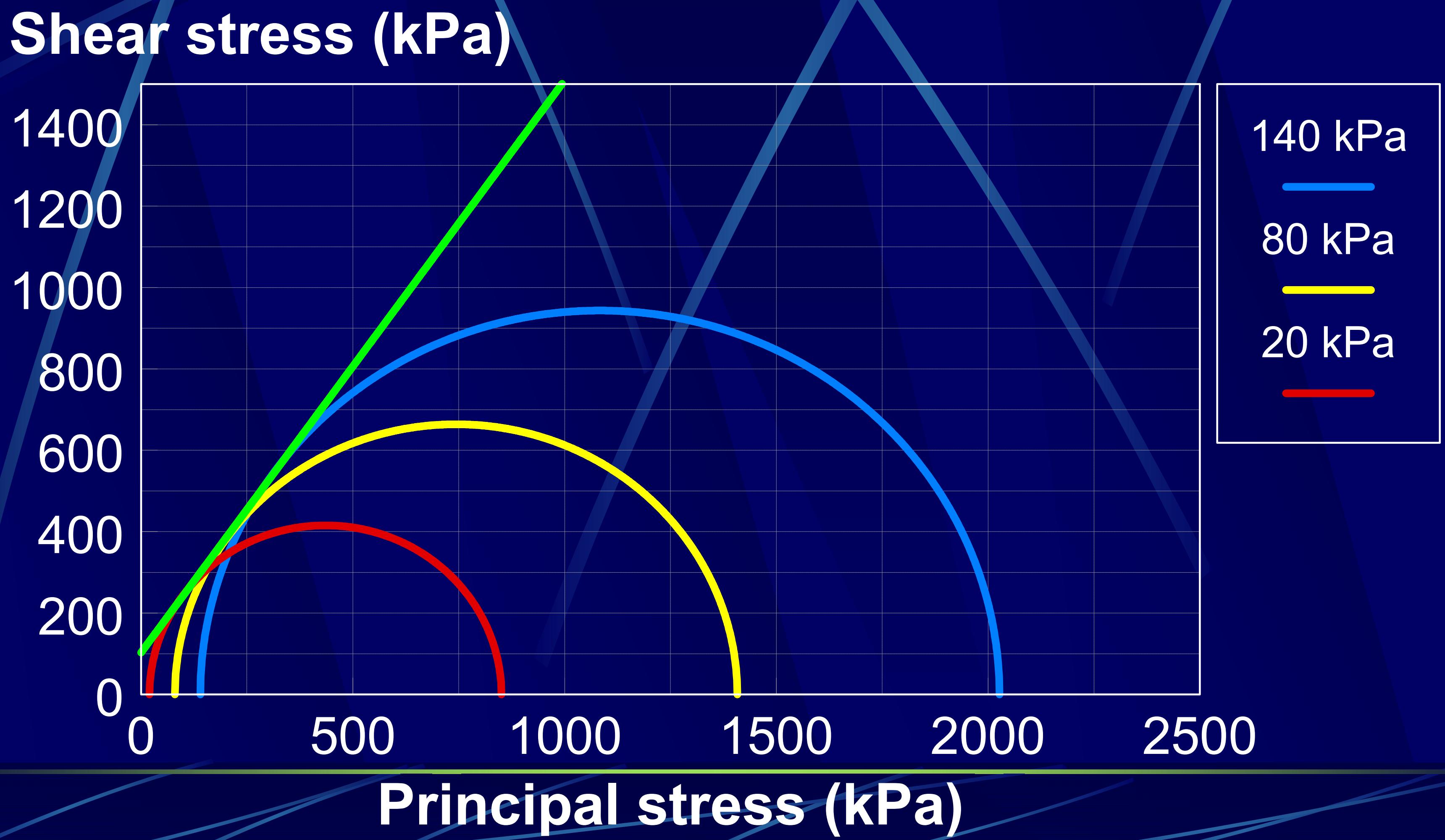
Stress ratio



Stress ratio R = (☞a w – ☞a c) / (☞a m – ☞a c) = (☞b w – ☞b c) / (☞b m – ☞b c)

Shear strength parameters

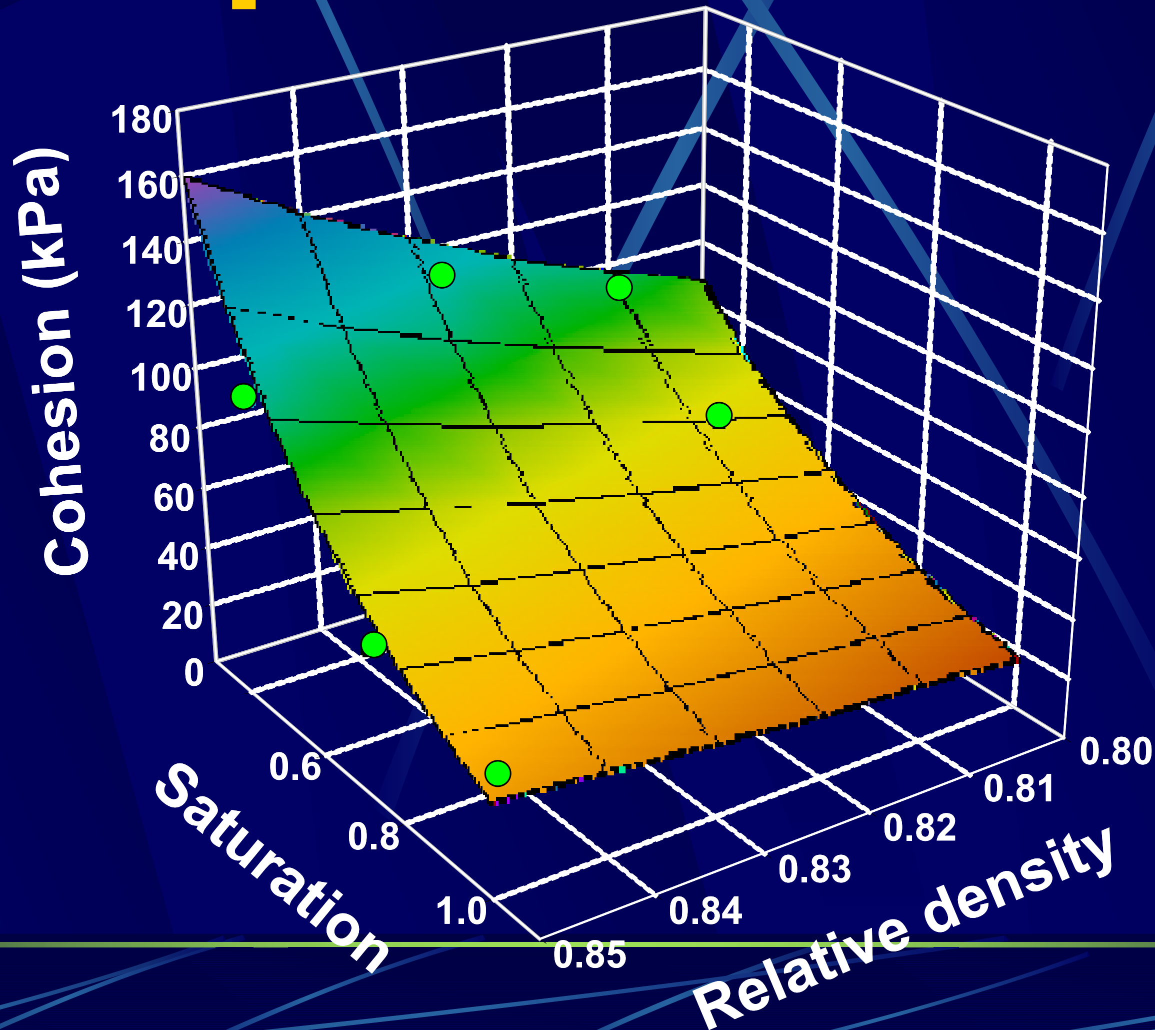
- Typical laboratory result



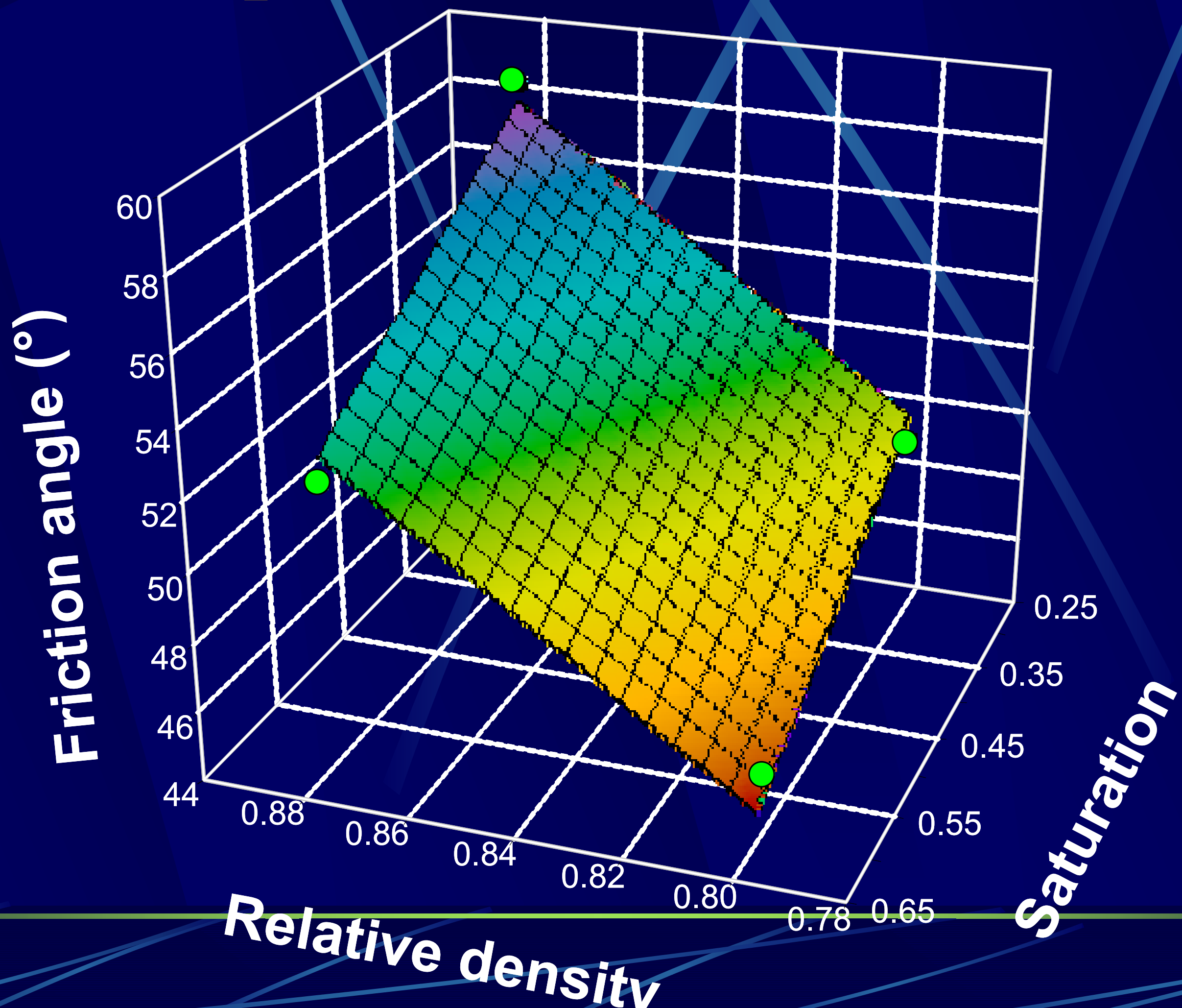
Shear strength parameters

- Laboratory results - Maree 1982
  - Degree of saturation
    - Reduction in S
      - Significant increase in cohesion
      - No significant effect on friction angle
      - Significant increase in shear strength
  - Density
    - Increase in RD
      - No significant increase in cohesion
      - Significant increase in friction angle
      - Significant increase in shear strength
  - Grading and properties of course and fine fractions

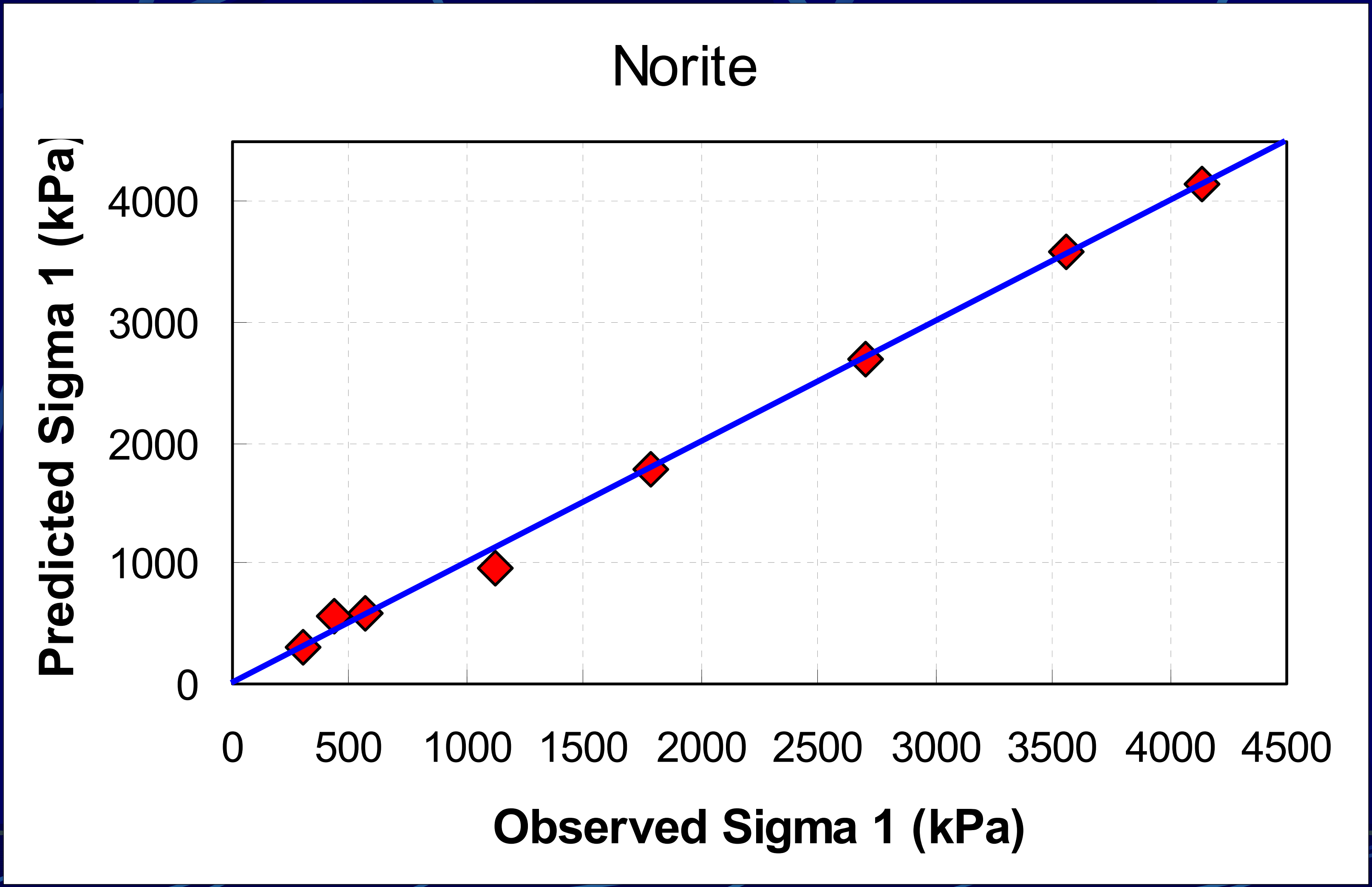
Shear strength parameters



Shear strength parameters



Shear strength



Shear strength parameters

- Conclusions from laboratory results
  - Correlation between
    - Friction angle and cohesion
    - Relative density (RD) degree of saturation (S)
  - Often interaction between shear strength parameters
    - Simple regression models for shear strength
  - Need to investigate predictive models
    - Particle size distribution
    - Properties of course and fine fractions

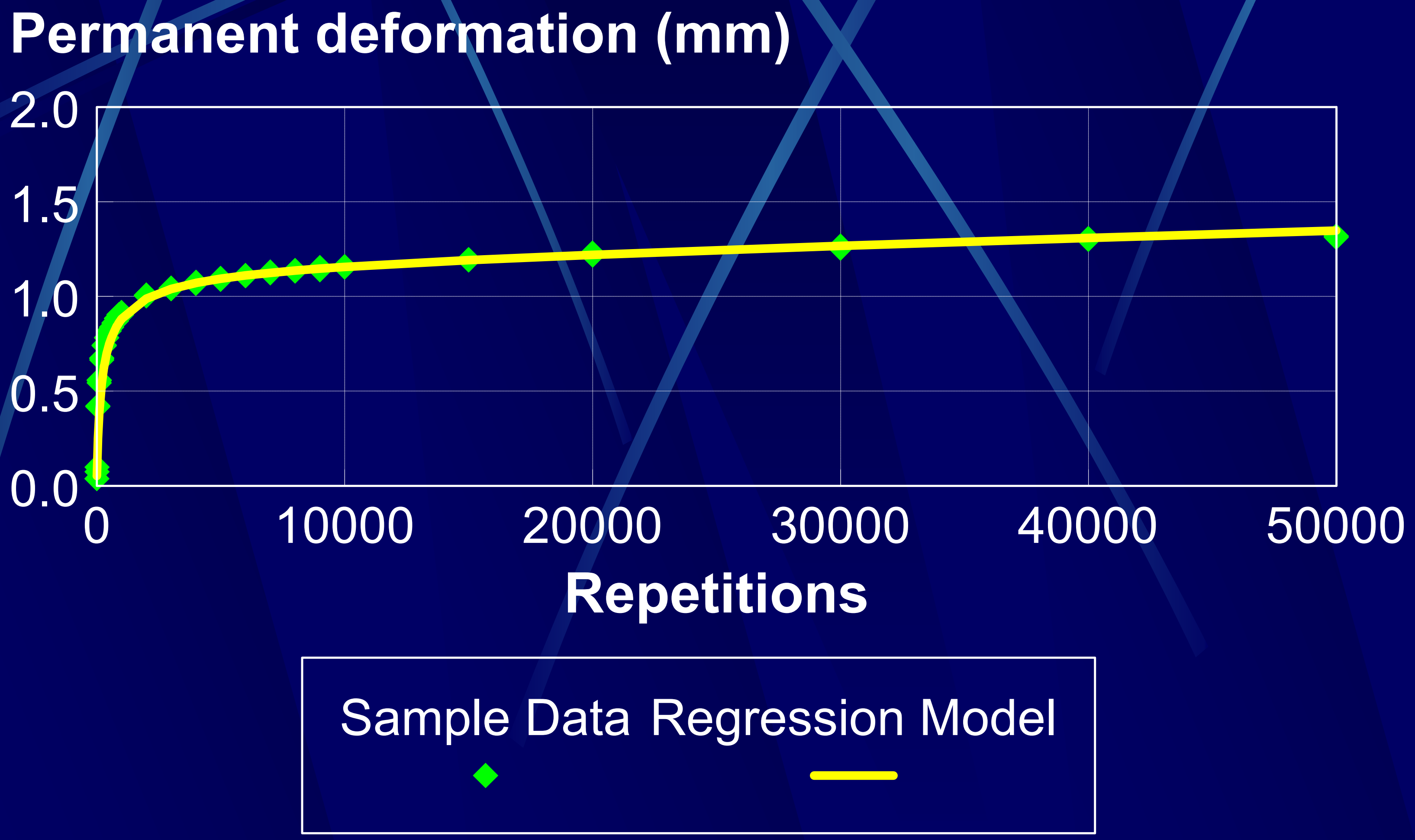
Plastic deformation

Granular base/subbase layers:
Combining laboratory and HVS data

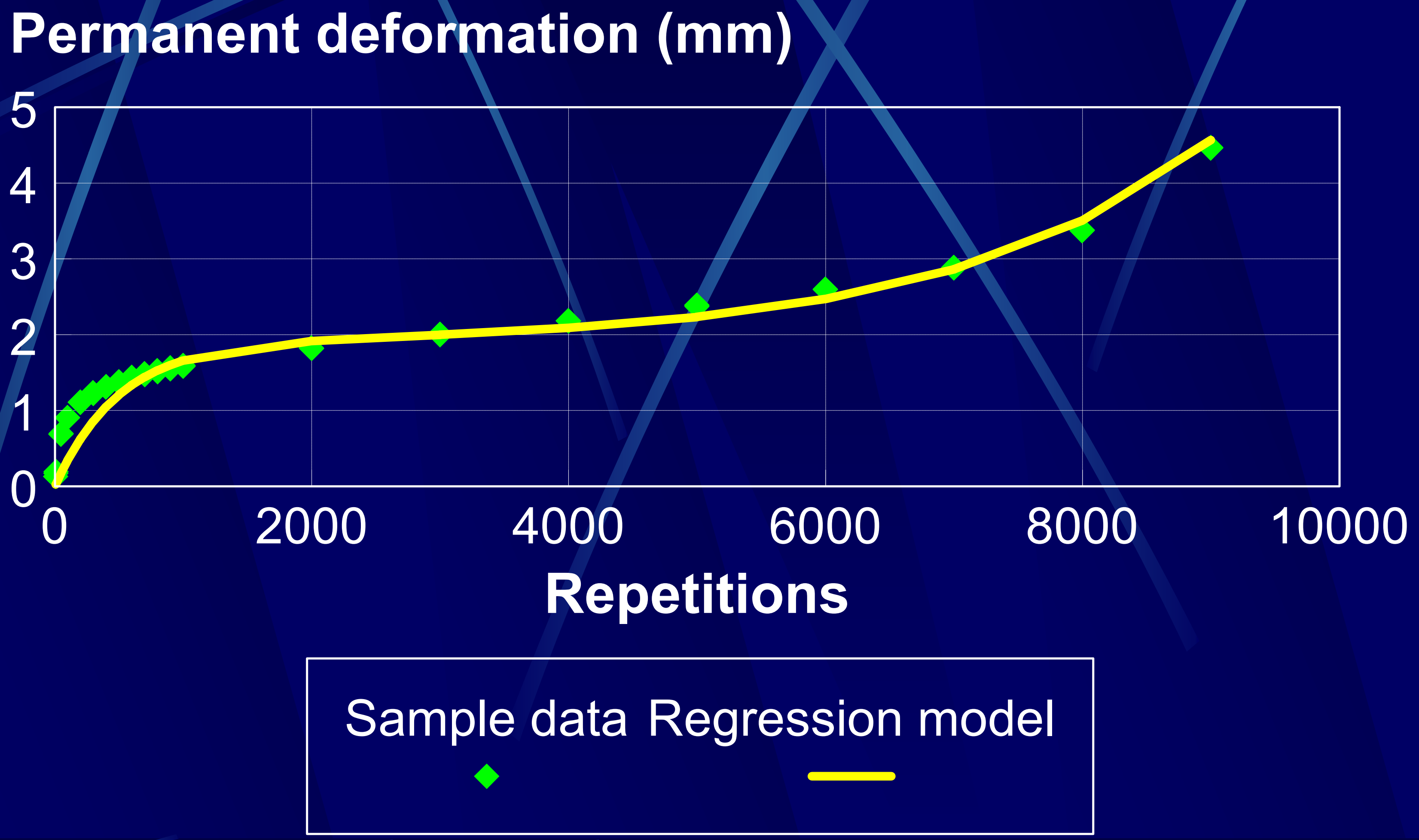
Plastic deformation

- Stable
  - Bedding-in
  - Linear rate of deformation
- Unstable
  - Bedding-in
  - Linear rate of deformation
  - Exponential increase

Stable permanent deformation



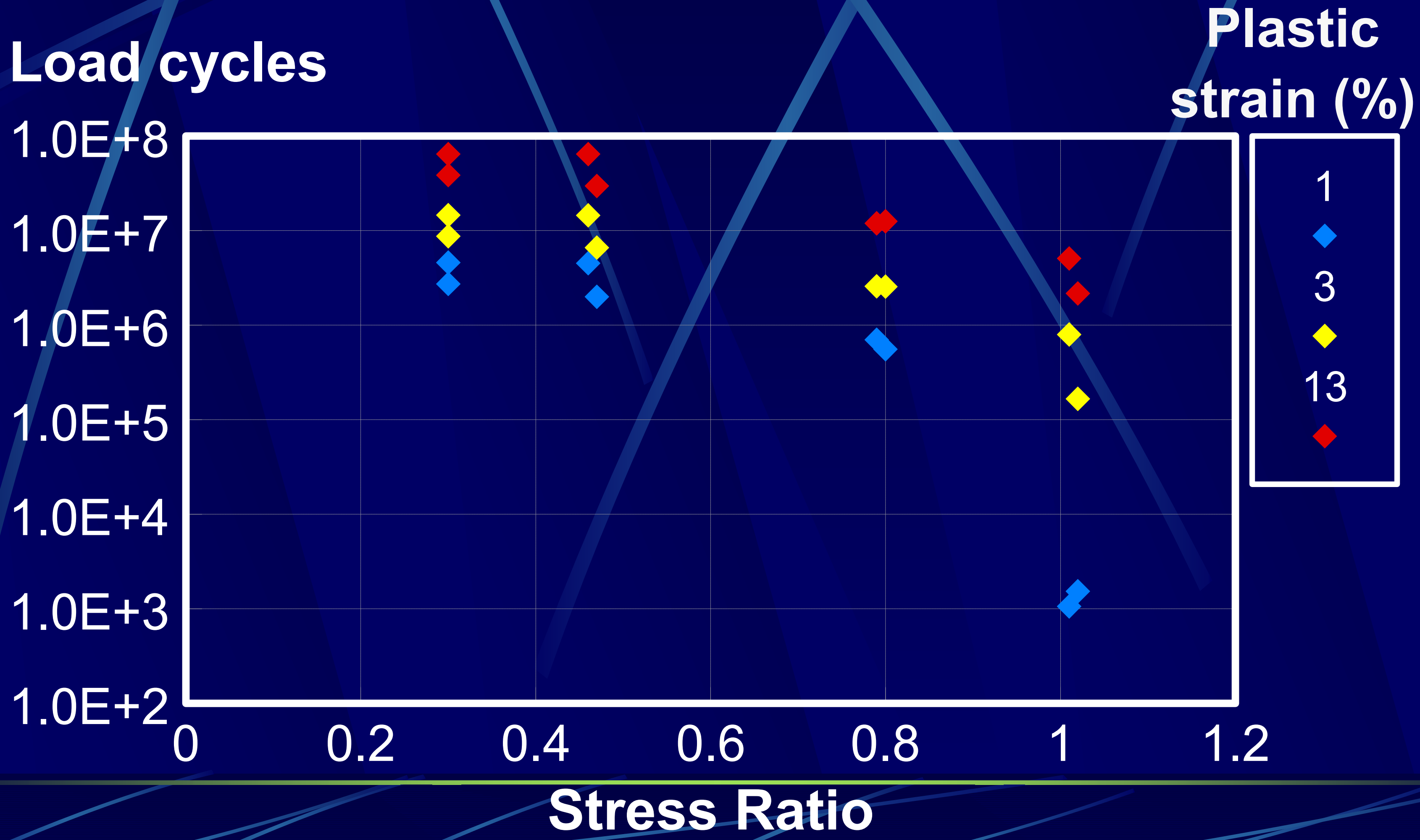
Unstable permanent deformation



Permanent deformation Dynamic triaxial test

- Shear strength parameters known
- Dynamic triaxial tests
  - Two confining pressure levels
  - Three or more stress ratio values
- Non-linear regression analysis
  - PD = f(Number of repetitions, N)
- Determine N for selected levels of PD
- Plot N against stress parameter (S) to generate S-N plot

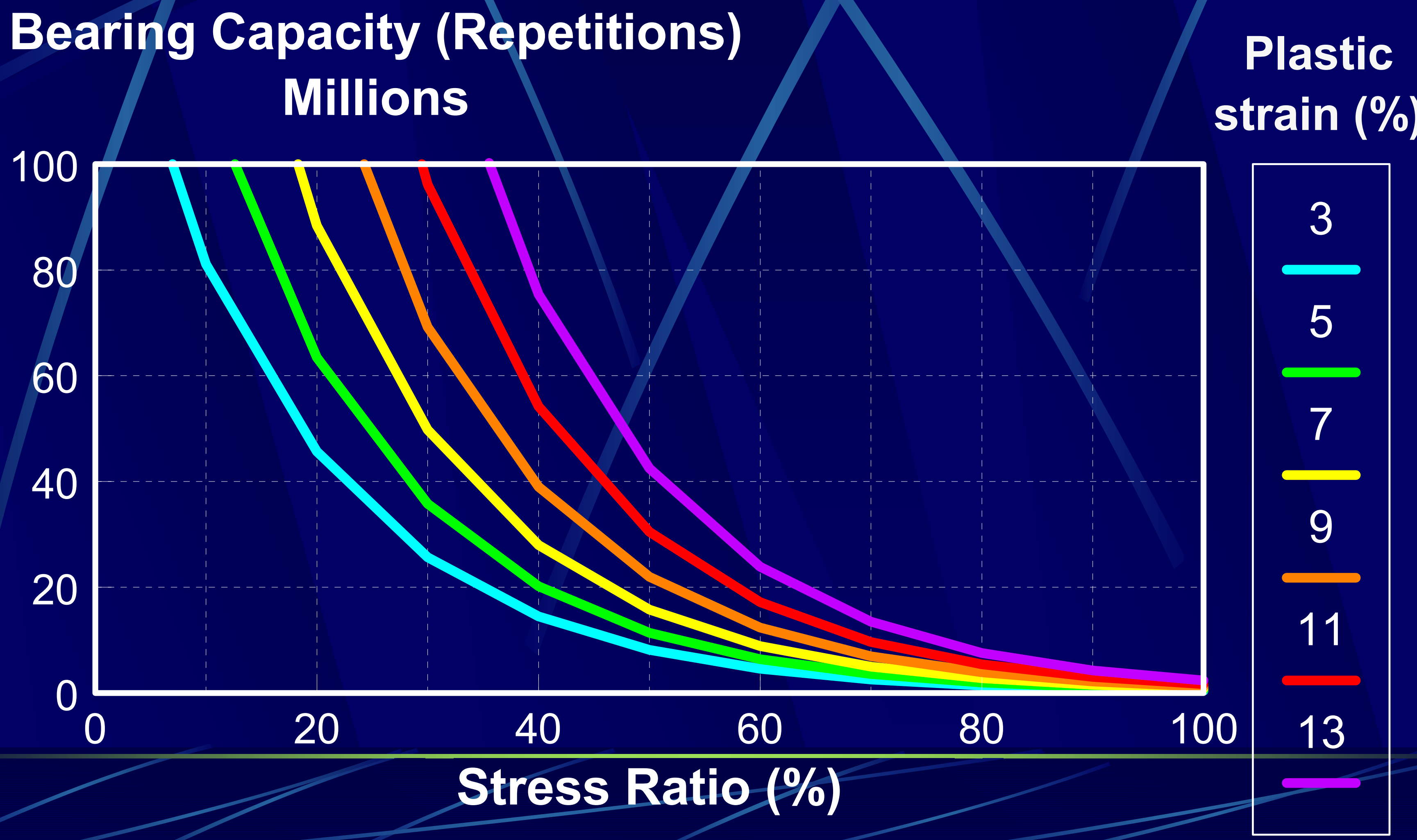
Permanent deformation S-N plot



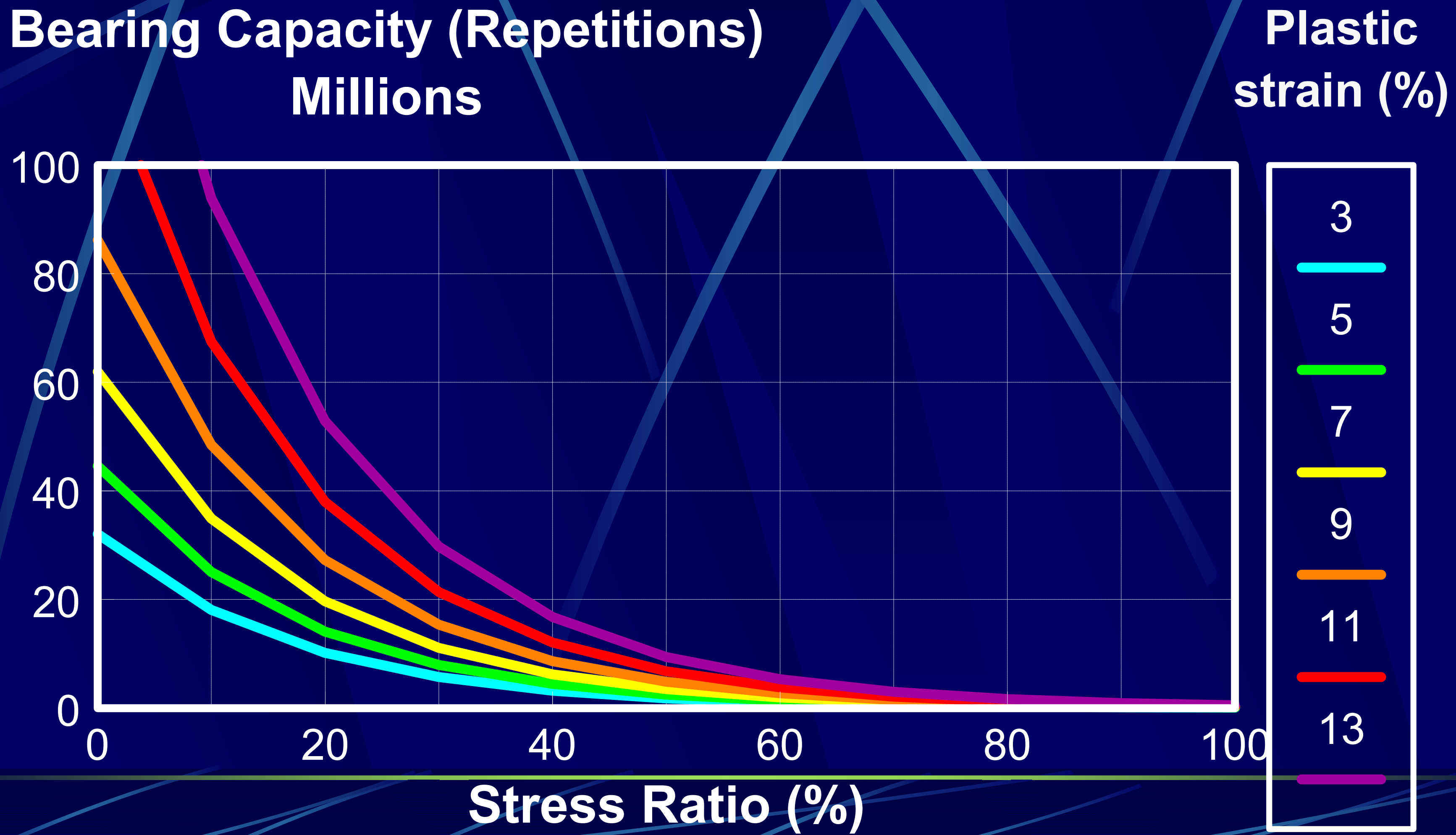
Permanent deformation S-N plot

- Regression modeling of S-N data provides contour plots on 3-dimensional plastic strain model
- Contour plots used as design transfer functions
  - Effects of density and saturation included

S-N design model
84 % AD, 45 % S



S-N design model
84 % AD, 55 % S



Conclusions
Permanent deformation

- Permanent deformation or plastic strain of granular materials
  - Degree of saturation
  - Relative density
  - Combined shear and confinement stress

A comparison between laboratory and HVS permanent deformation models

Granular base/subbase layers:
Combining laboratory and HVS data

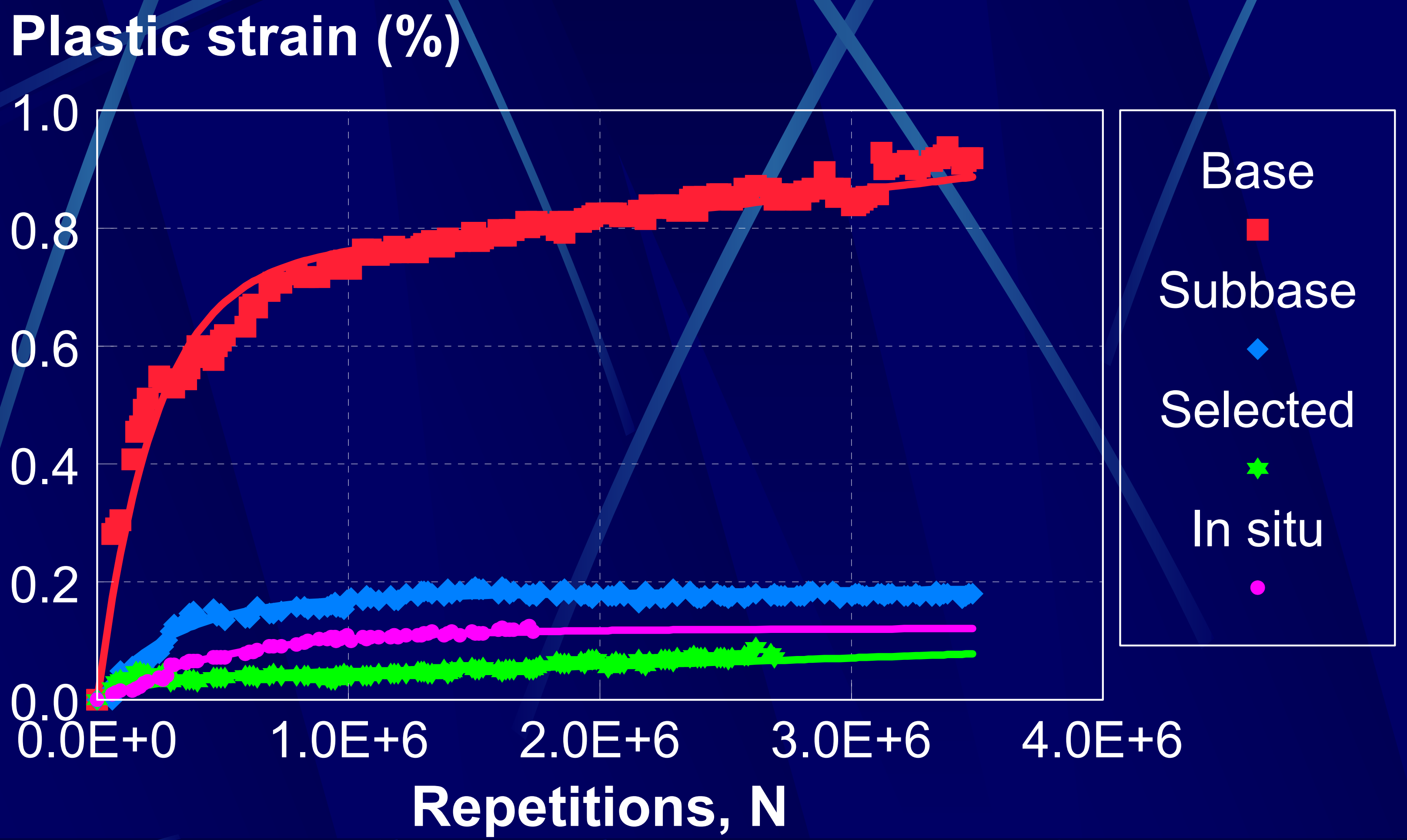
Process

- Determine plastic deformation of base layers from MDD permanent displacement data
  - Subtract permanent displacement of module at bottom of layer from that of the module at the top of the layer
  - Fit non-linear model
  - Solve for “N” that would result in 10 mm base layer permanent deformation
- Back-calculation of MDD deflection data
  - Resilient modulus
  - Calculate stress ratio at mid-depth of layer using shear strength calibrated for density and saturation
- All this data available for two load levels

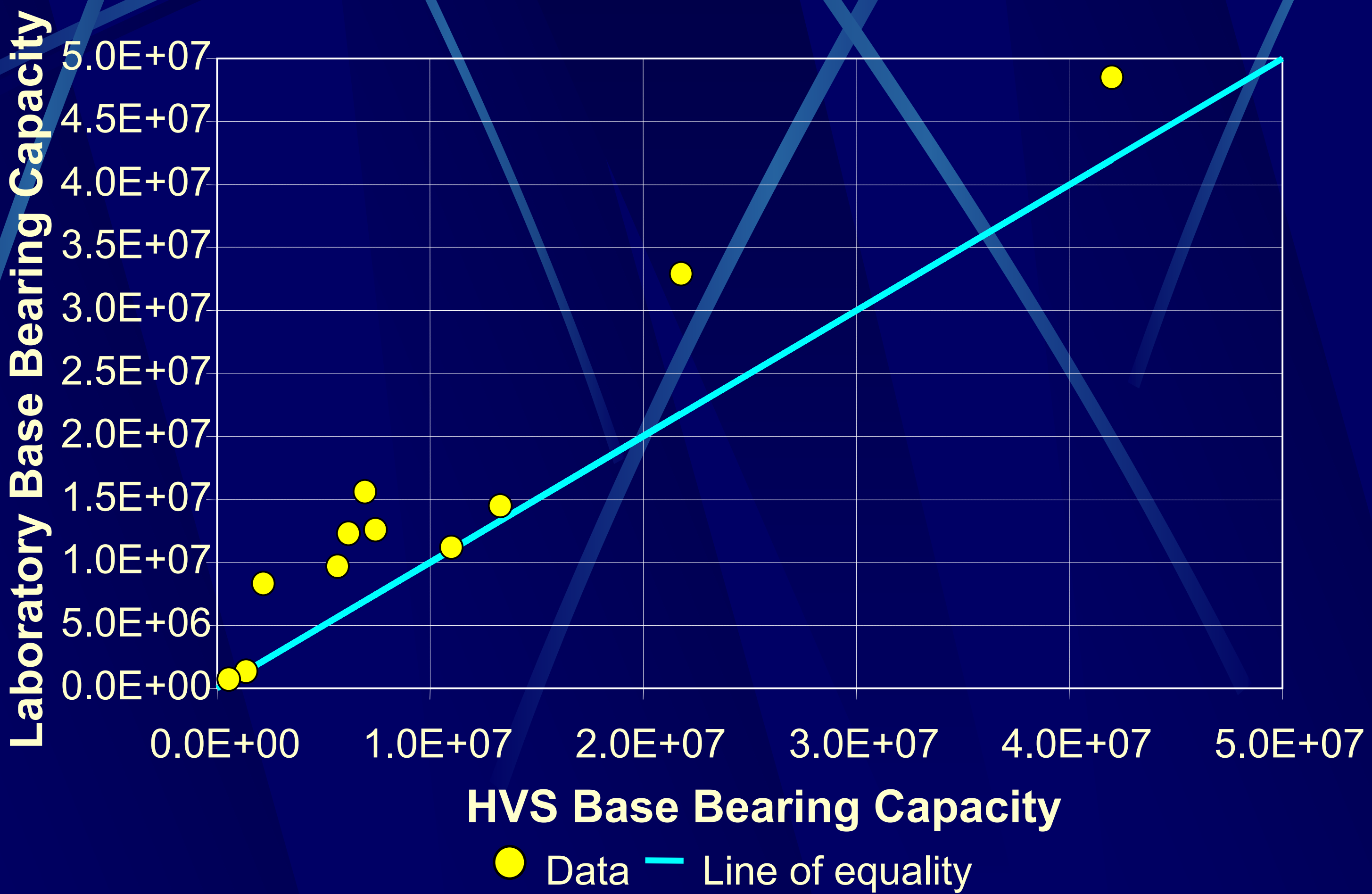
Process (continued)

- Using the known layer thickness, calculate the plastic strain that is equivalent to 10 mm permanent deformation
- Enter stress ratio and plastic strain in the laboratory model
  - Solve for “N”
- Compare “N” from field testing with “N” from laboratory model

Permanent deformation result from field testing



Base bearing capacity: HVS and laboratory



In summary: Granular layers

- Biggest problem
  - Calculation of correct stress ratio in pavement base/subbase layers
  - Non-linear, stress-dependent model calibrated for density and saturation
- Separate elastic and plastic response
- Move away from linear Möhr-Coulomb shear strength parameters
  - Shear strength calibrated for density and saturation
- Established concepts need to develop and refine
  - “Surrogate” resilient modulus and shear strength models