U.S. – New Zealand – Japan International Workshop
Liquefaction-Induced Ground Movements Effects
The Faculty Club, UC Berkeley, California

Session I

Liquefaction-induced flow slides that are governed by the residual shear strength of liquefied soil

Session I Schedule

9:15	Invited Presentations	
	Steve Kramer	*University of Washington*
	Roland Orense	*University of Auckland*
	Y. Tsukamoto	*Tokyo University of Science*
	Ross Boulanger	*U.C. Davis*
10:15	Additional Presentations	
	Scott Olson	*University of Illinois*
	Gabriele Chiaro	*University of Canterbury*
	Adda Athanasopoulos-Zekkos	*University of Michigan*
	Akihiro Takahashi	*Tokyo Institute of Technology*
	Bruce Kutter	*U.C. Davis*
	Les Harder	*HDR, Inc.*
10:45	Break	
11:15	Discussions of identified key challenges/issues	
12:45	Lunch	

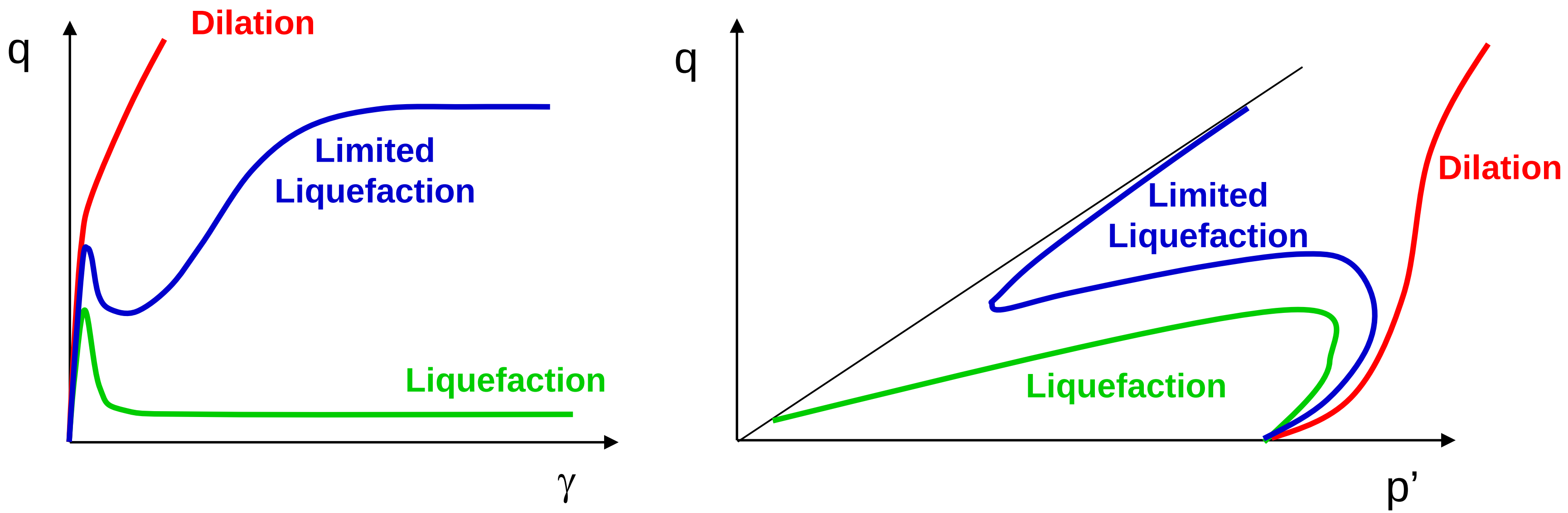
Residual Strength of Liquefied Soil

Steve Kramer

University of Washington

Seattle, Washington

Stress-strain and stress path behavior - Castro (1969)



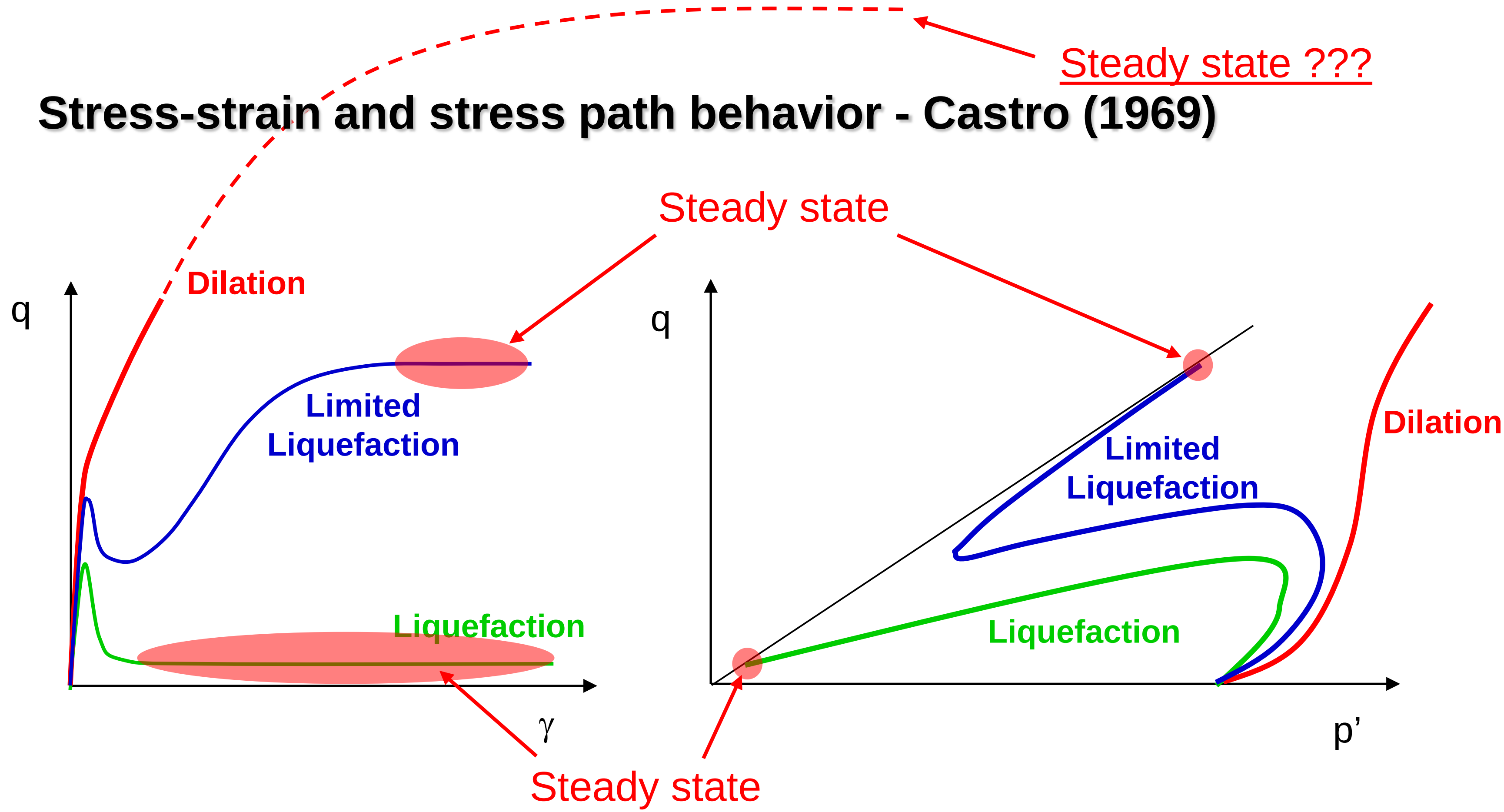
Steady state of deformation - Constant volume

Constant effective stress

Constant shearing resistance

Constant velocity

Stress-strain and stress path behavior - Castro (1969)



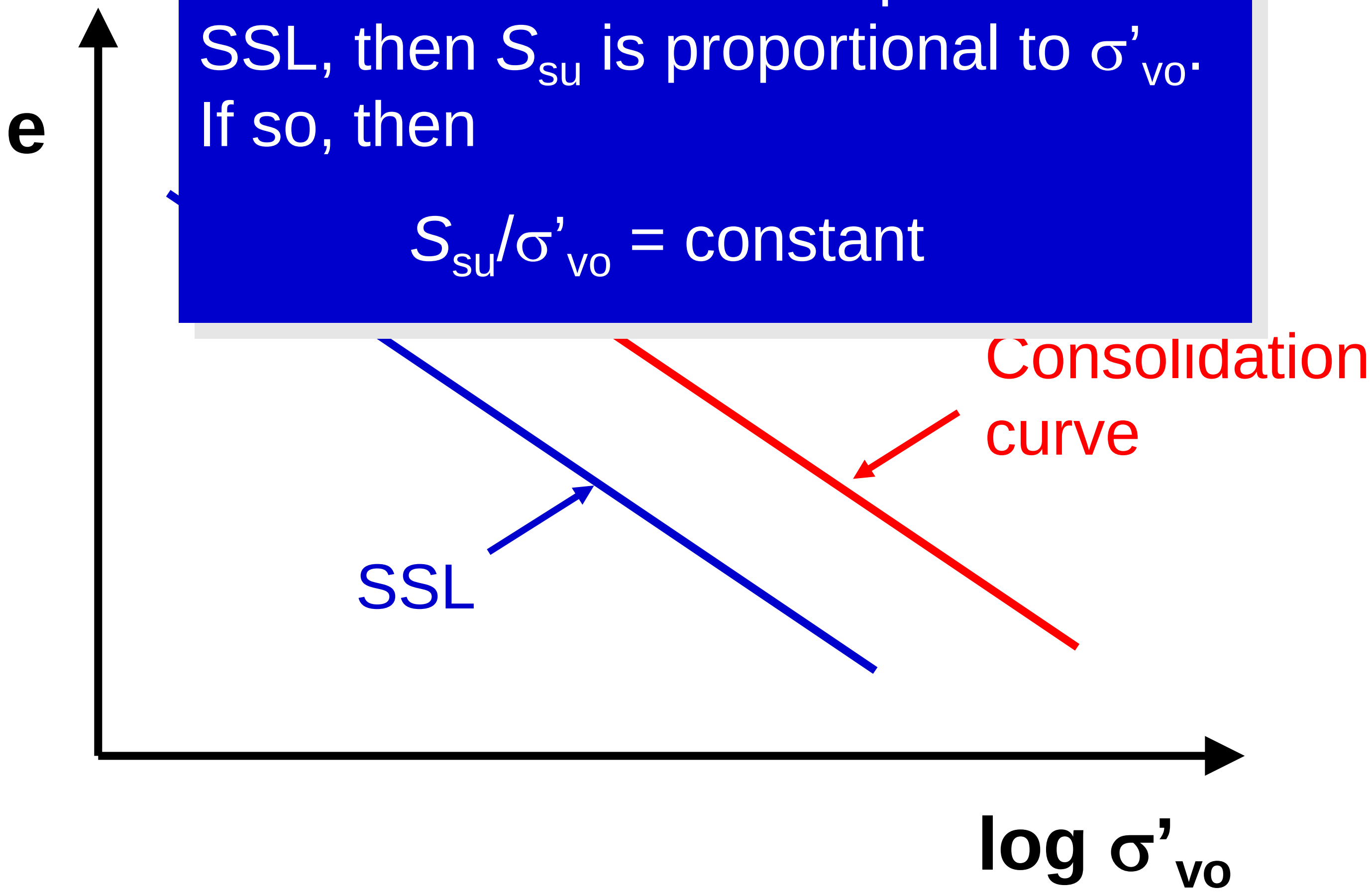
Steady state of deformation - Constant volume

Steady state strength, S_{su}, is function of density alone

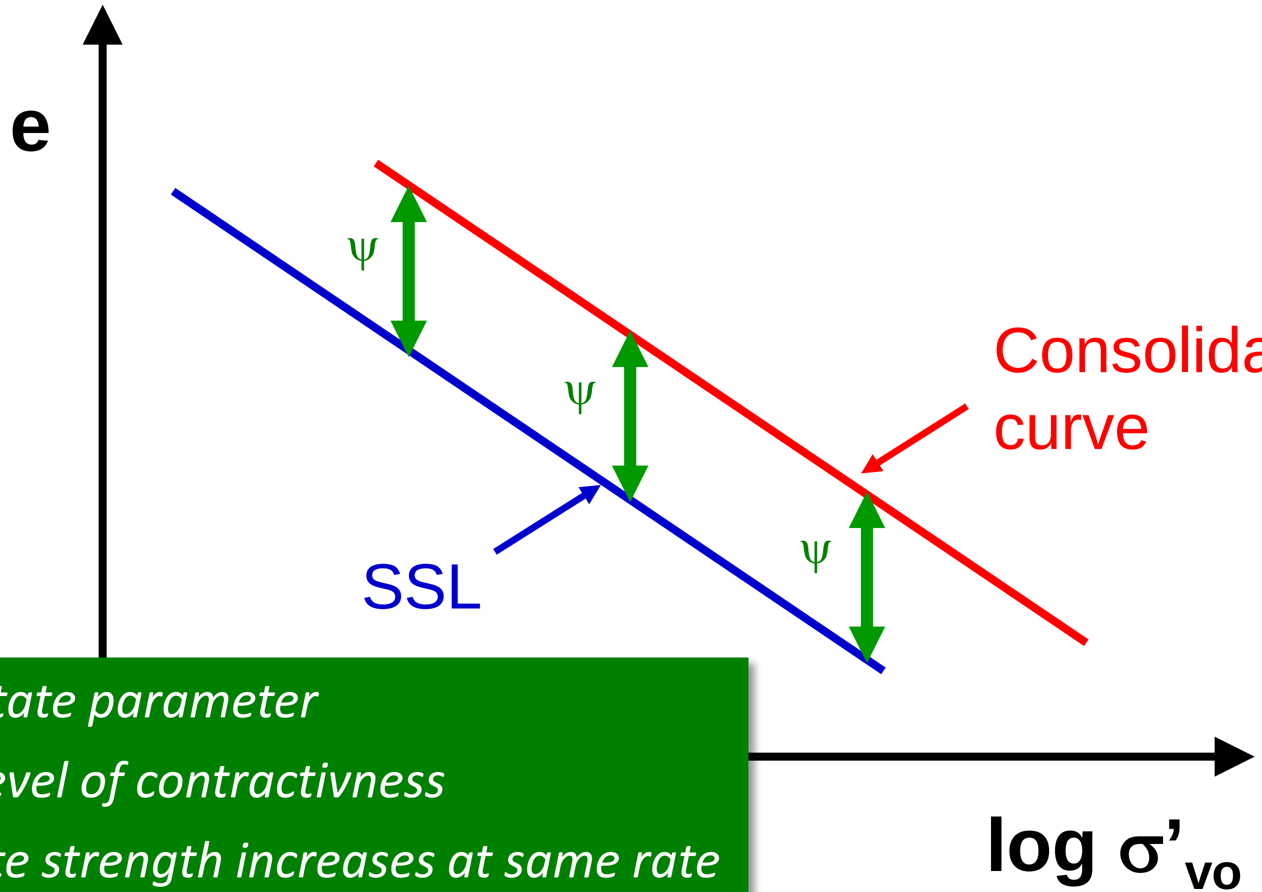
Normalized strength concept

If consolidation curve is parallel to SSL, then S_{su} is proportional to σ'_{vo}. If so, then

$$S_{su}/\sigma'_{vo} = \text{constant}$$



State Parameter



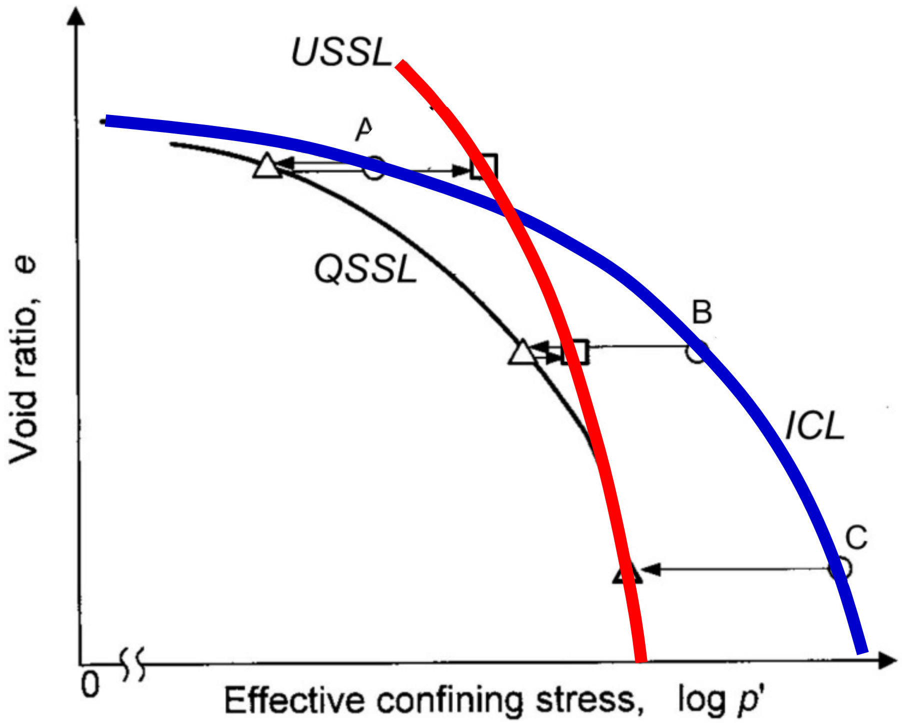
Constant state parameter

Constant level of contractivness

Steady state strength increases at same rate as effective stress

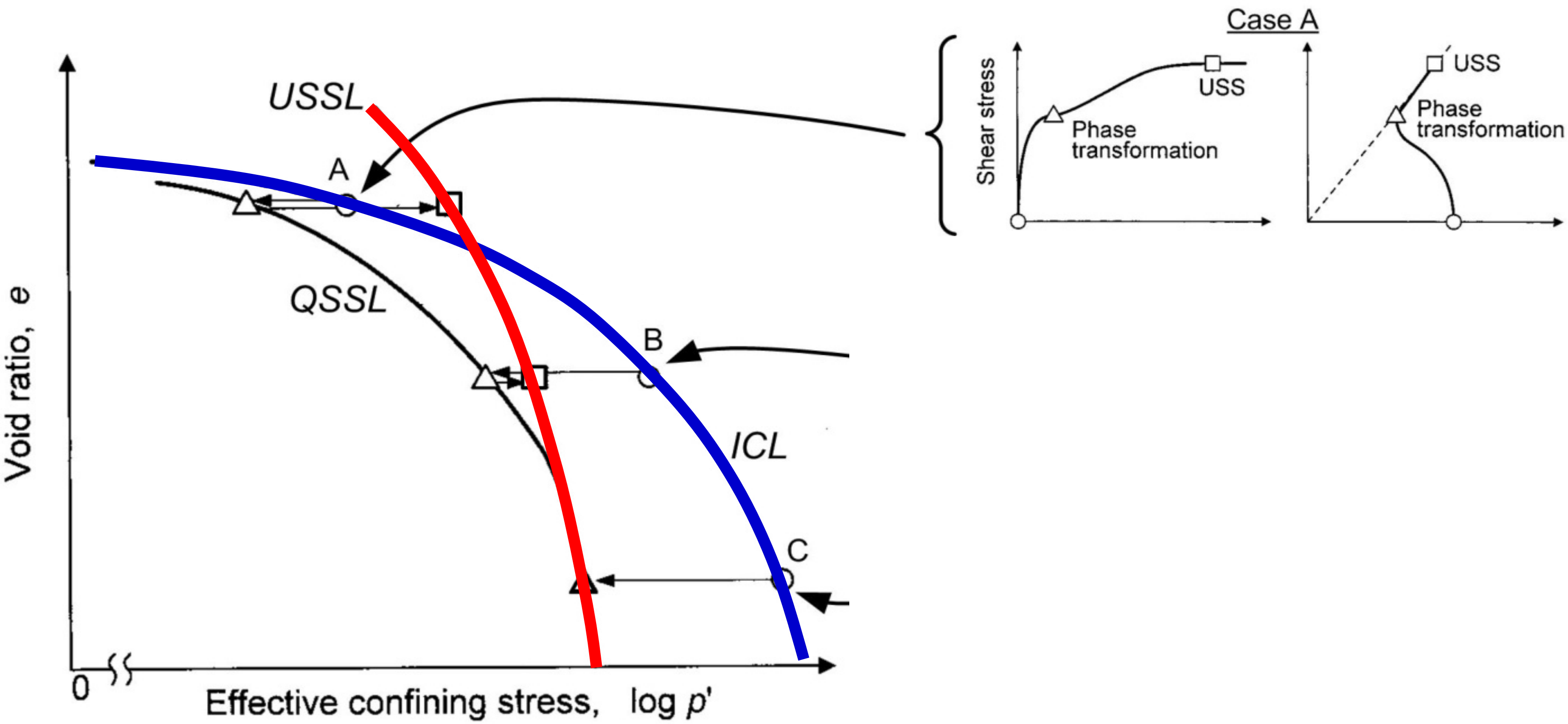
Normalized strength concept

Typical behavior



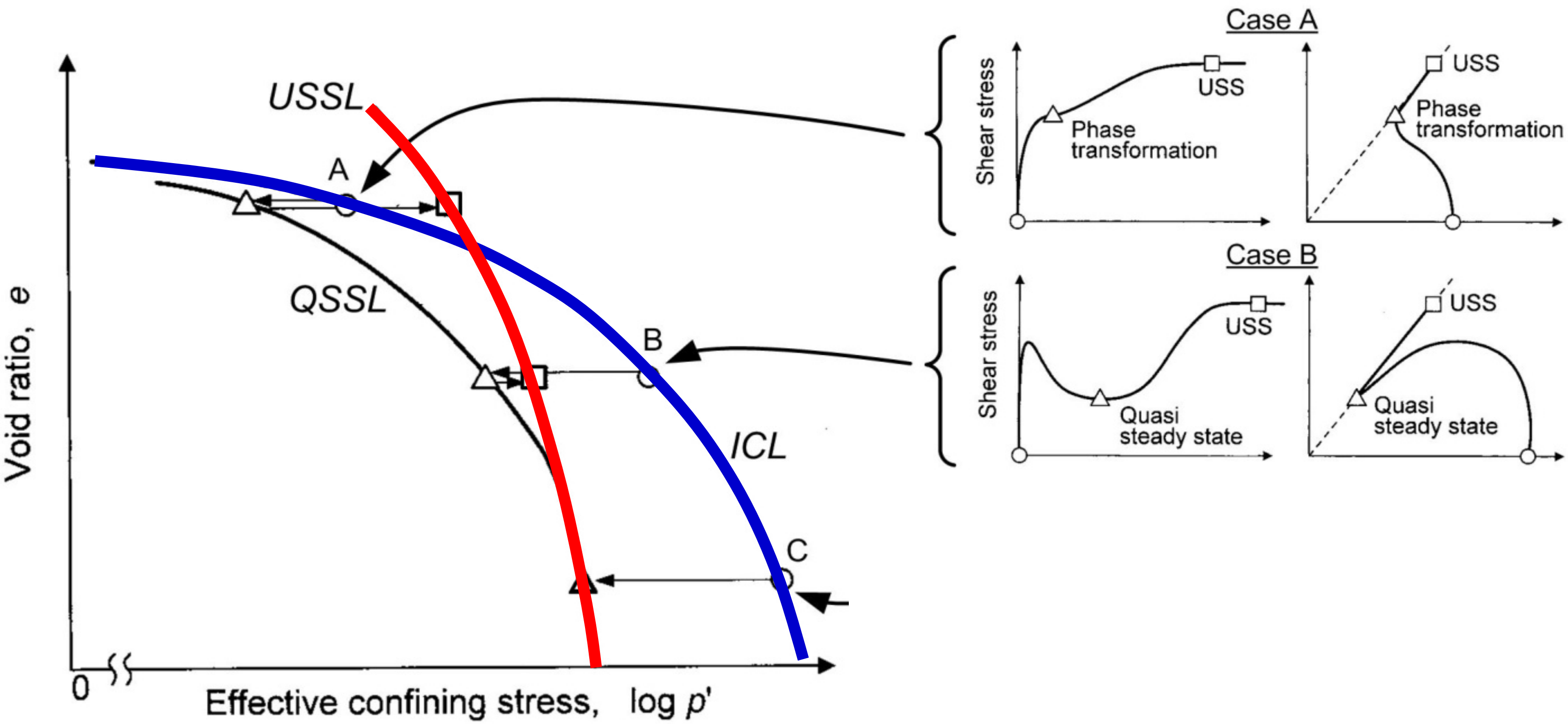
Normalized strength concept

Typical behavior



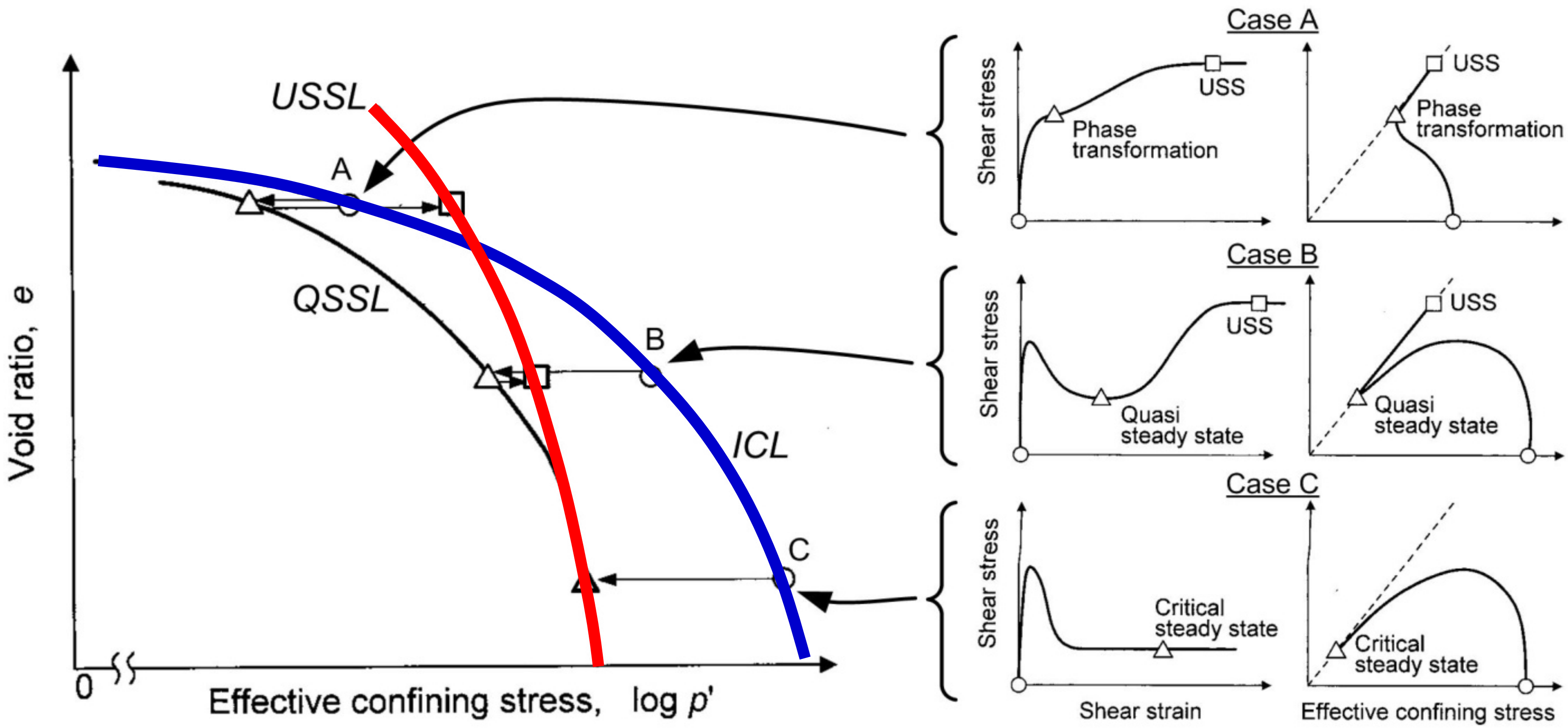
Normalized strength concept

Typical behavior



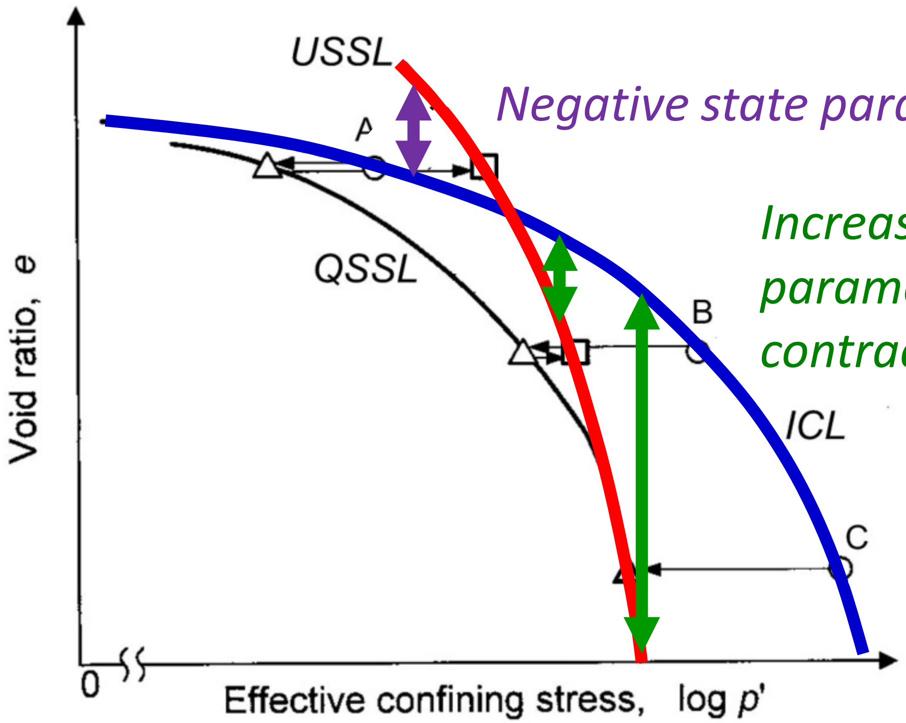
Normalized strength concept

Typical behavior



Normalized strength concept

Typical behavior



Negative state parameter → dilation

Increasingly positive state parameter → increasing contractiveness

State parameter increases with increasing effective stress

Steady state strength doesn't increase as quickly as effective stress

Laboratory-Based Approach

Common laboratory tests

Triaxial test

Simple Shear test

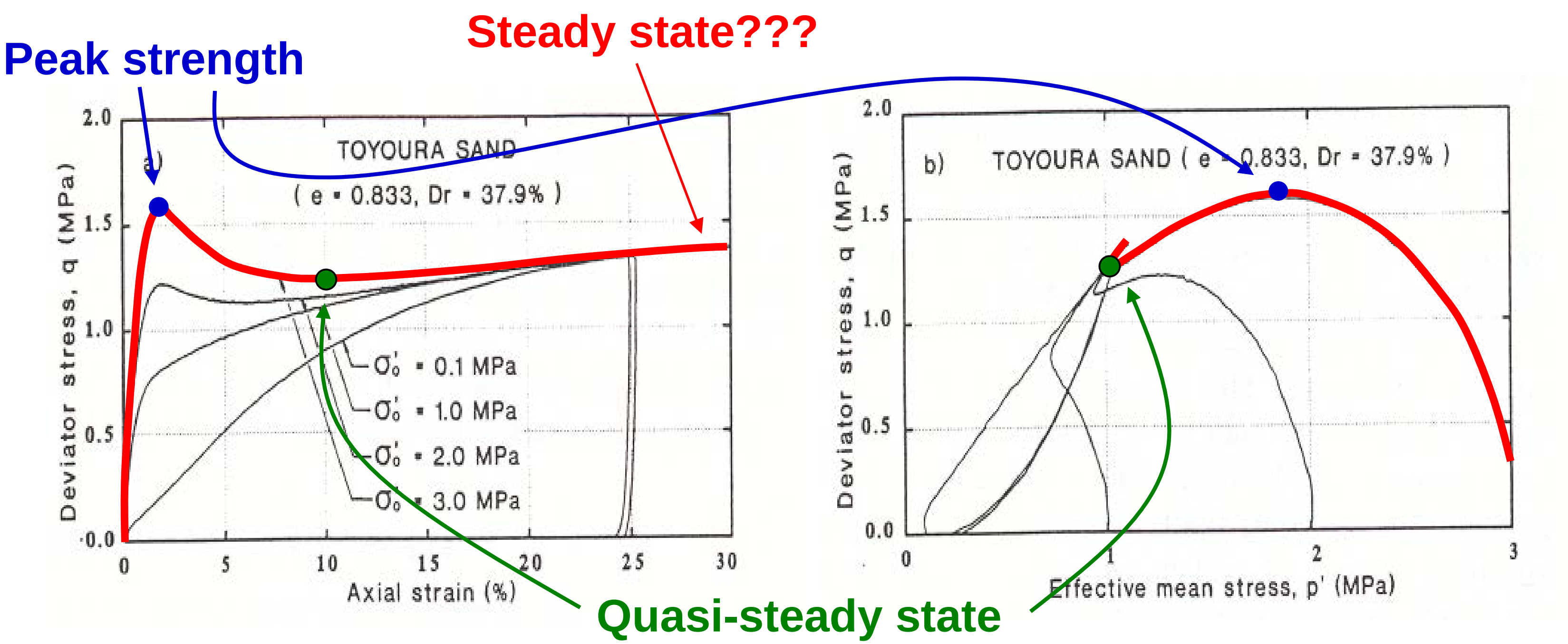
Ring Shear test

All have limited ability to achieve strains large enough to reach steady state of deformation:

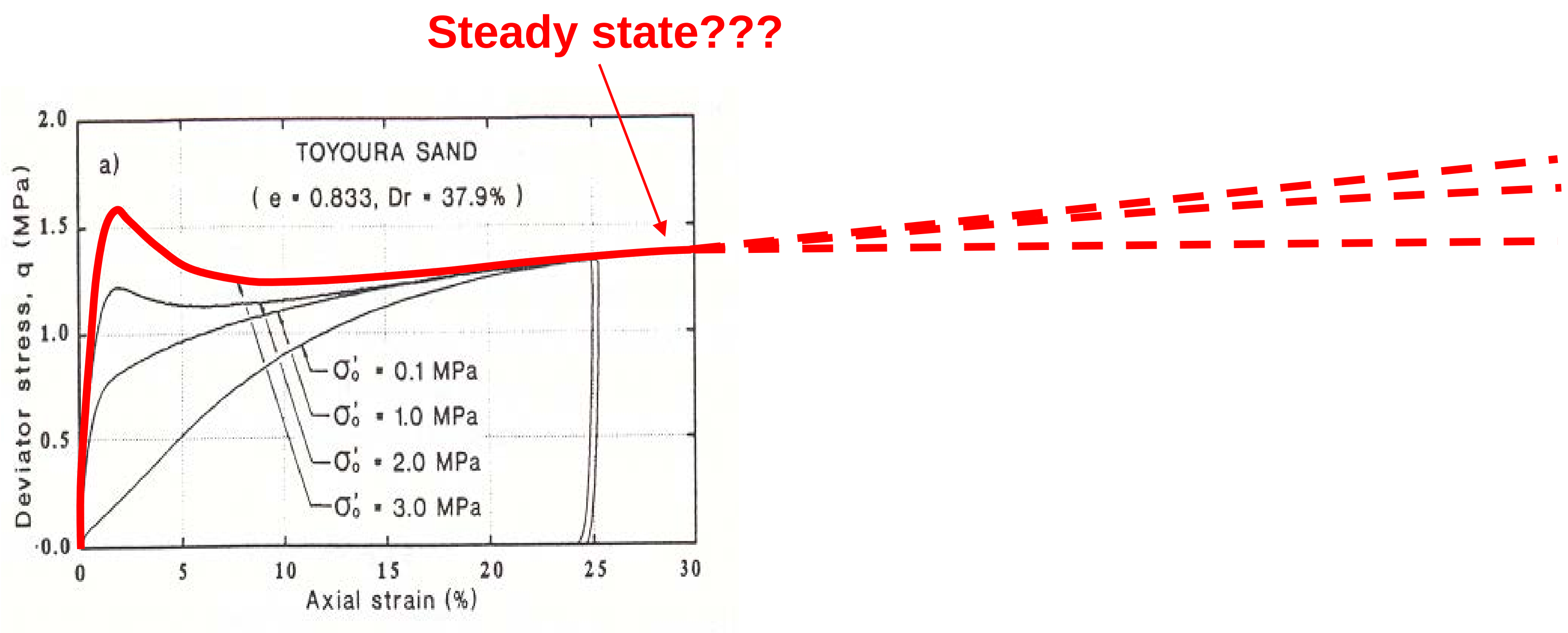
- Stresses are nonuniform, unknown
- Strains are nonuniform, unknown

Resulting strengths are questionable

Laboratory-Based Approach

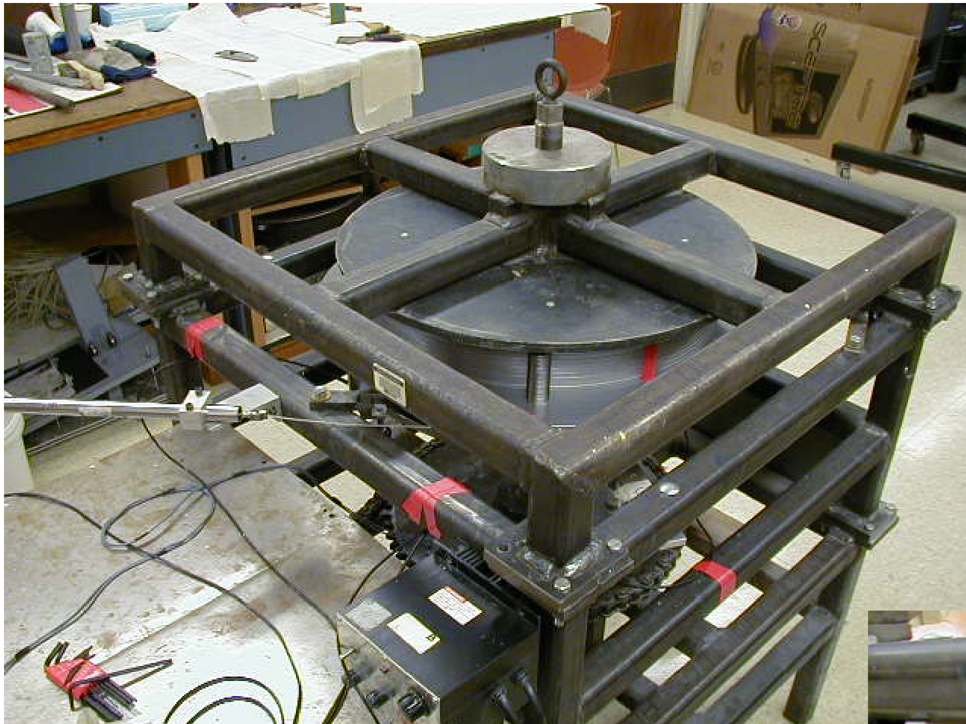


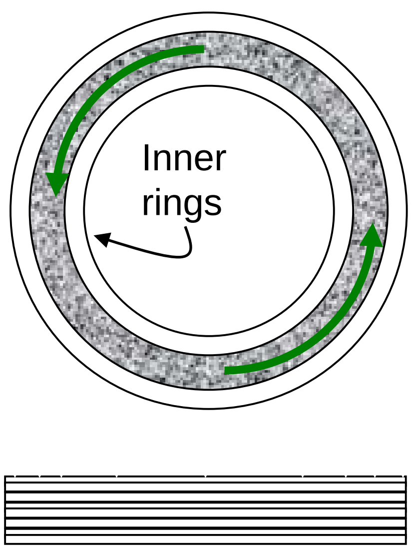
Laboratory-Based Approach

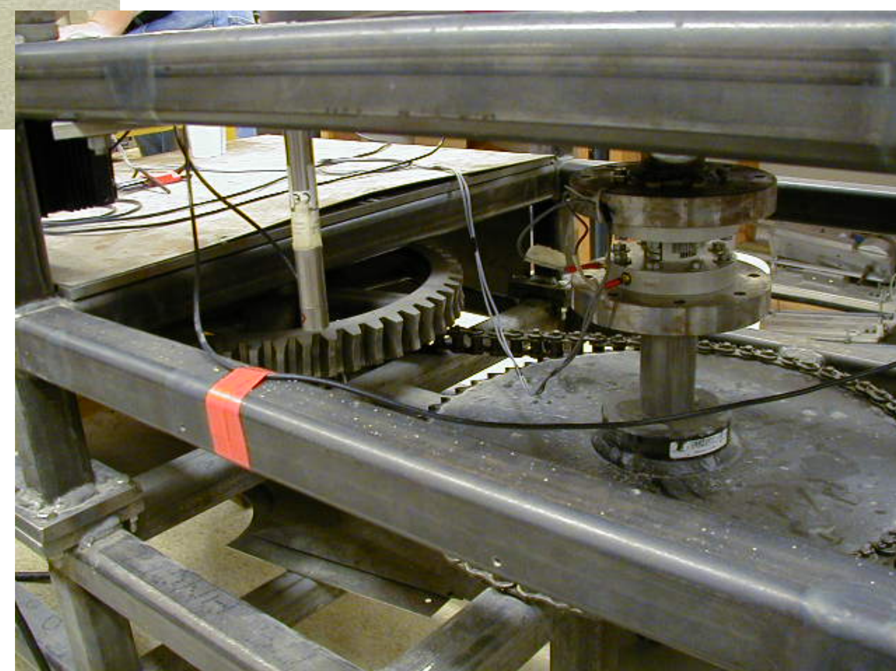


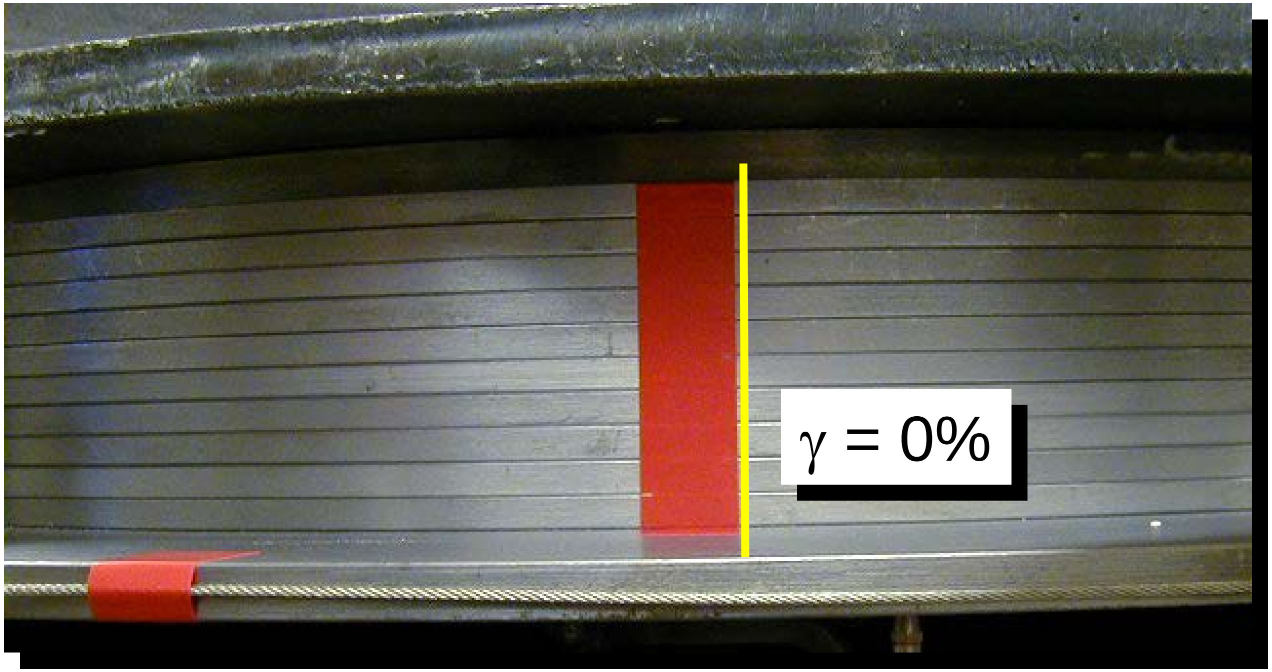
Ring Simple Shear Device (RSSD)

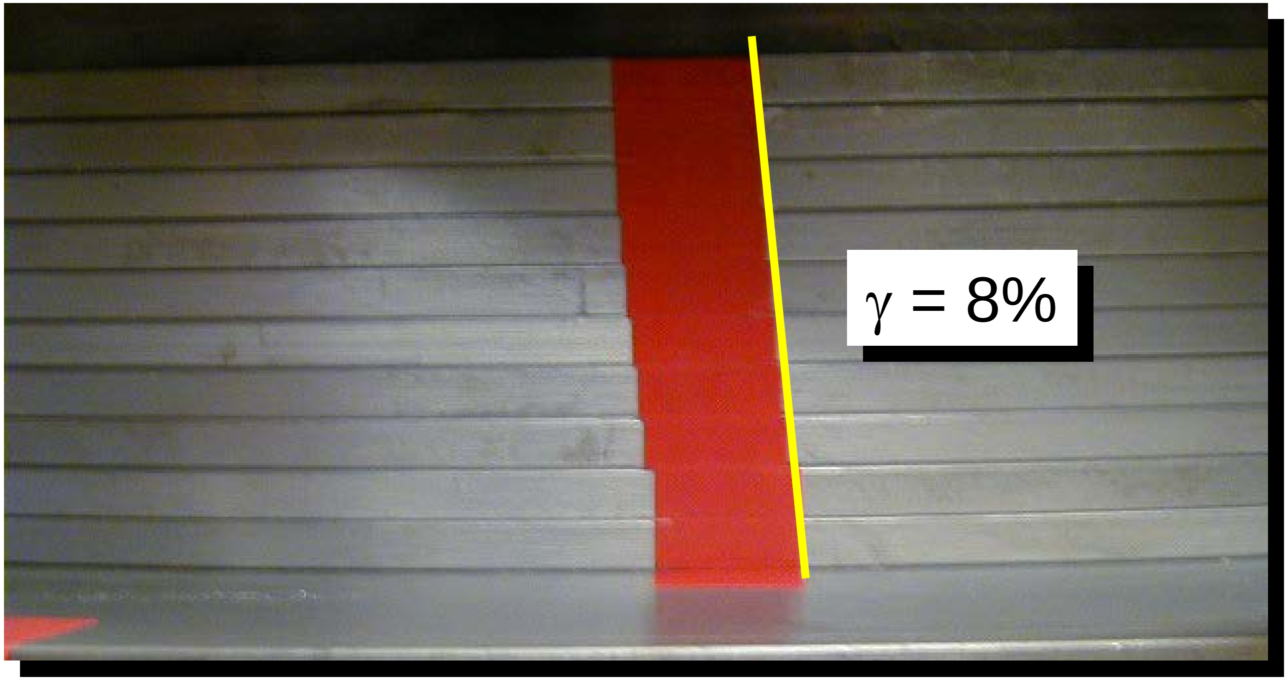
University of Washington



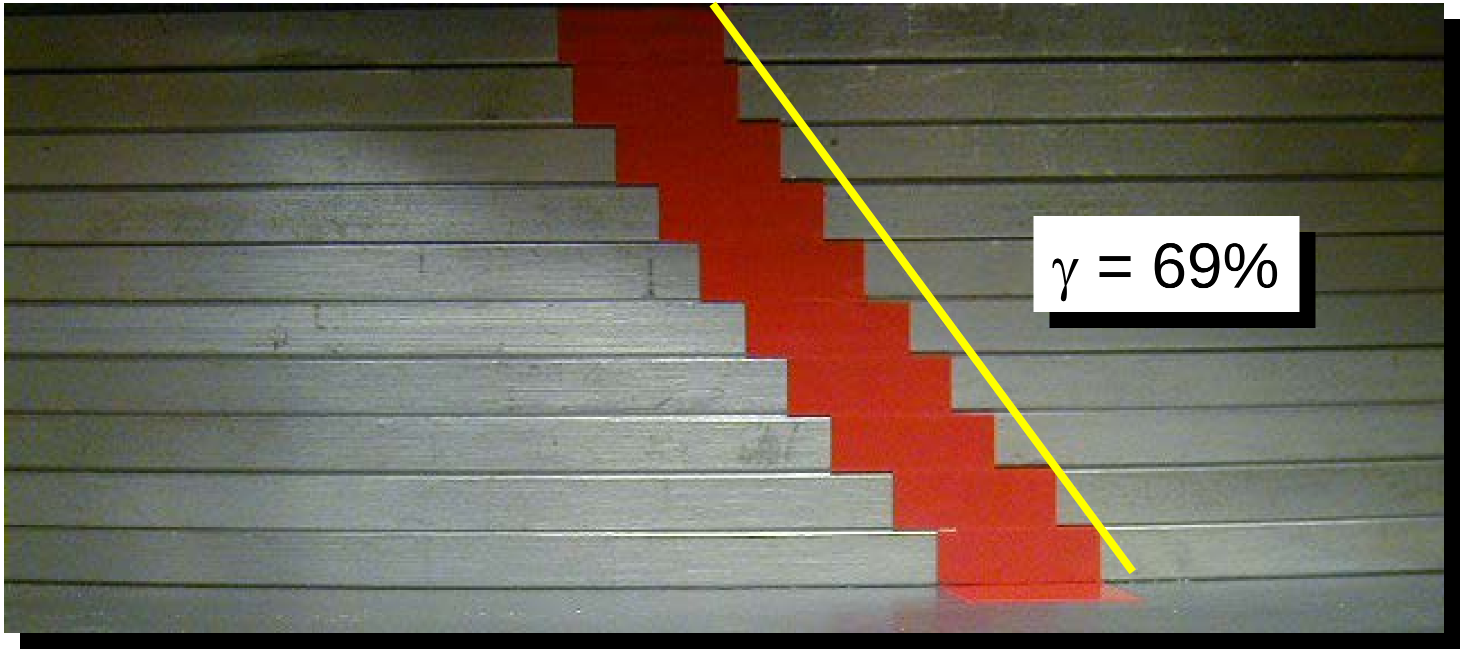


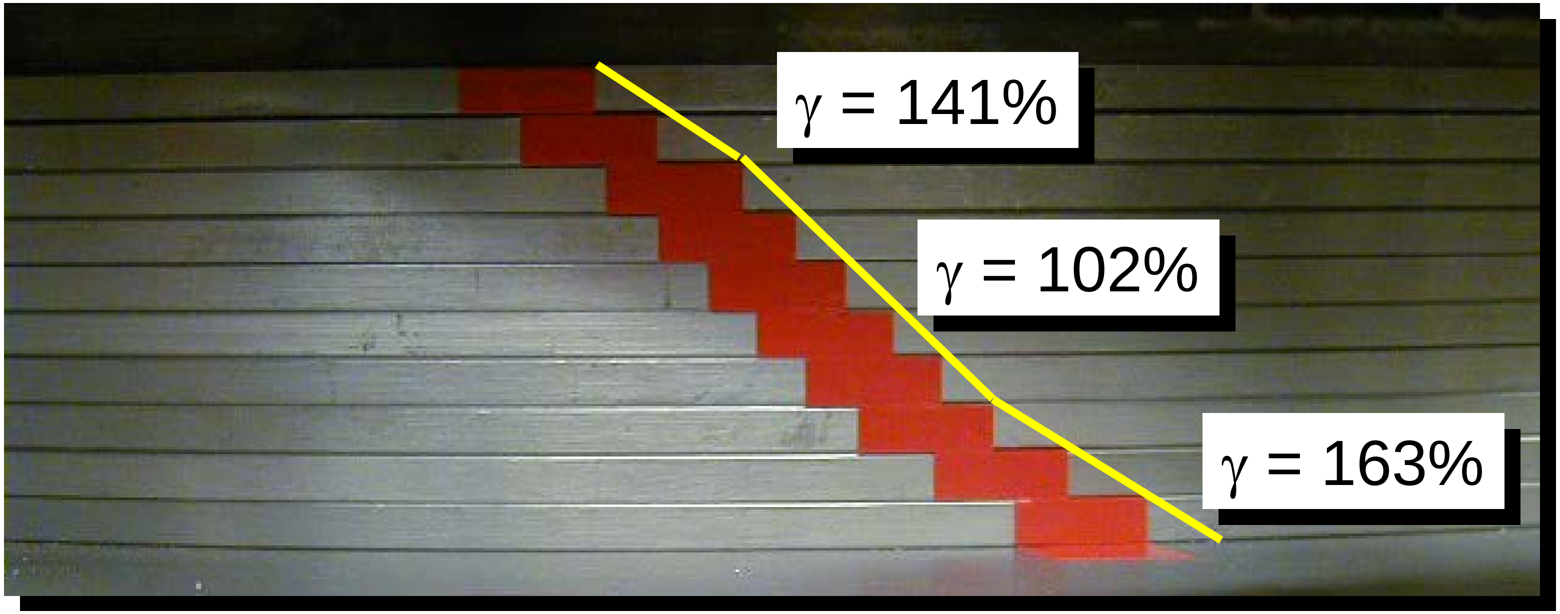


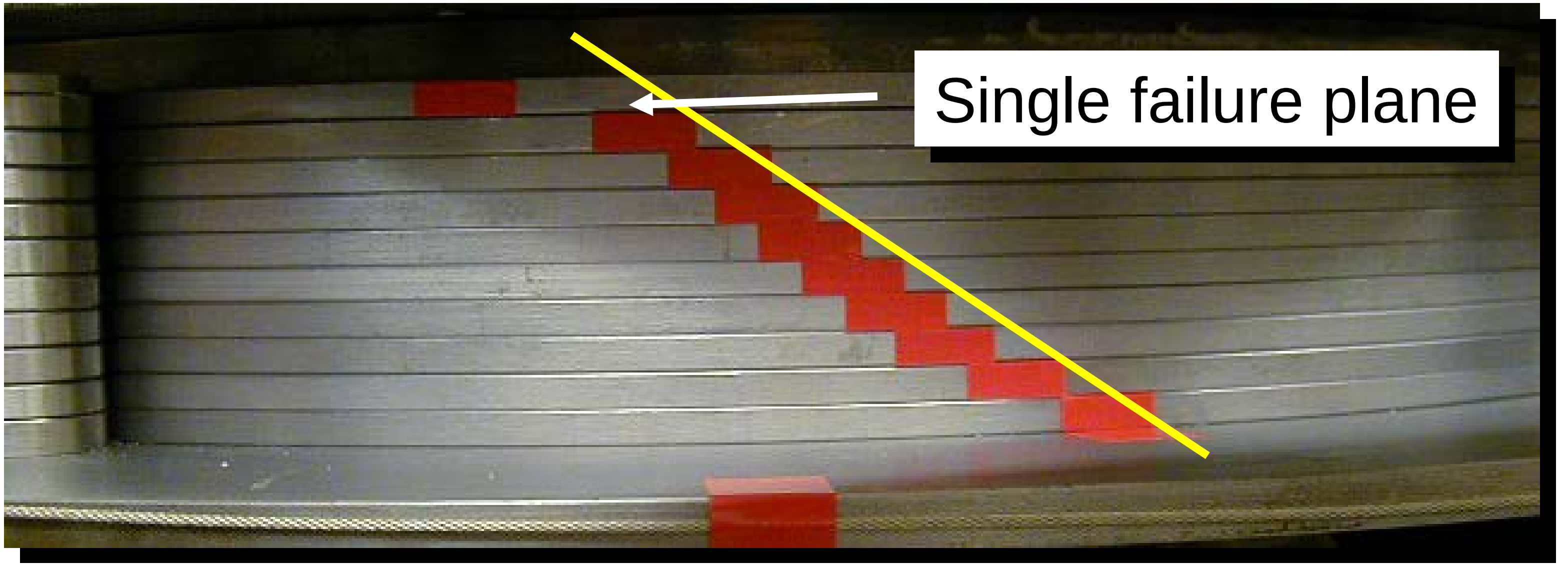

γ = 0%


γ = 8%

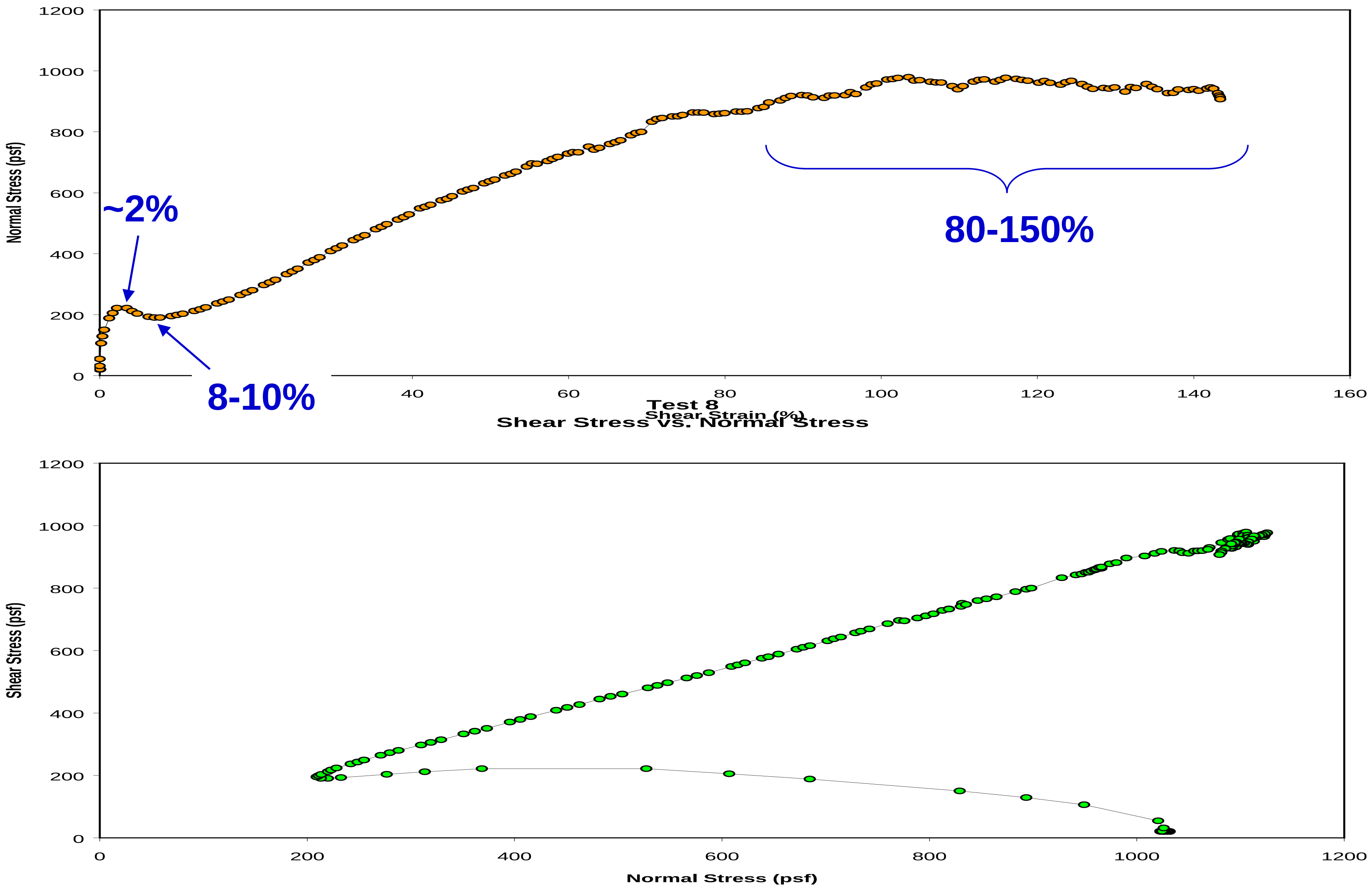

γ = 41%


γ = 69%

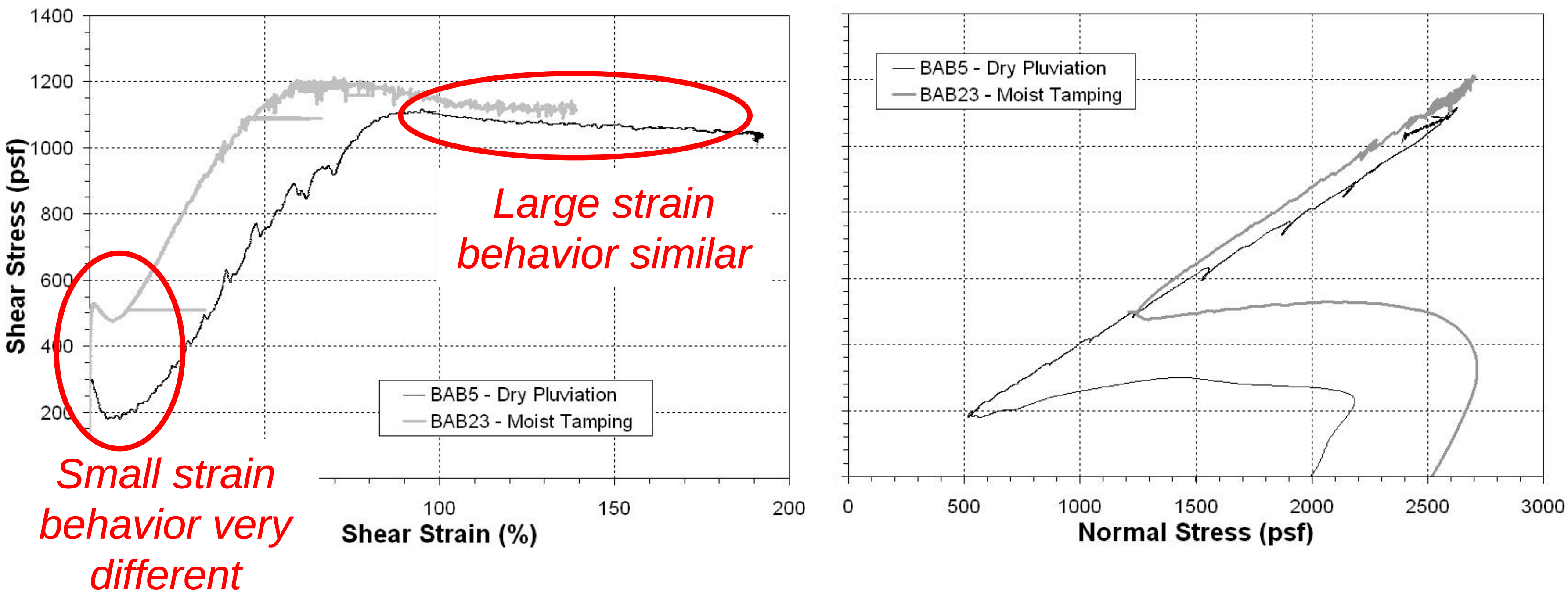

γ = 141%
γ = 102%
γ = 163%


Single failure plane

Stress-Strain and Stress Path



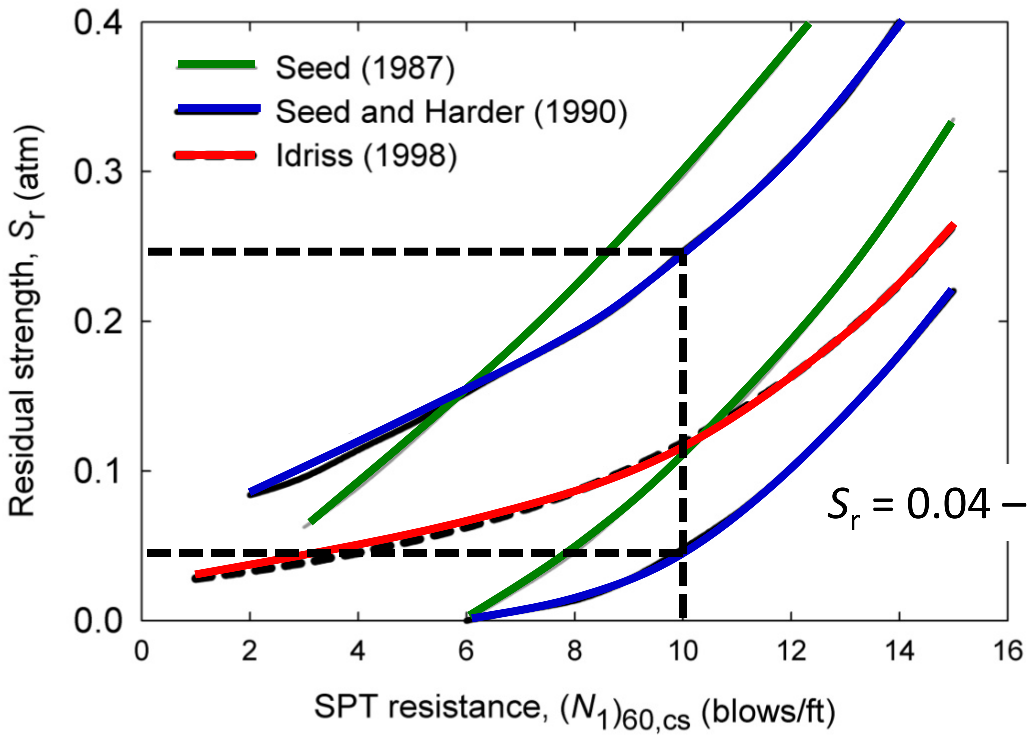
Effects of Specimen Preparation



Back-calculated residual strength

Original approach

- Based on soil mechanics
- Accounts for dilation at low confining pressures
- Predicts same residual strength for same density



$S_r = 0.04 – 0.25$ atm

Back-calculated residual strength

Original approach

Based on soil mechanics

Accounts for dilation at low confining pressures

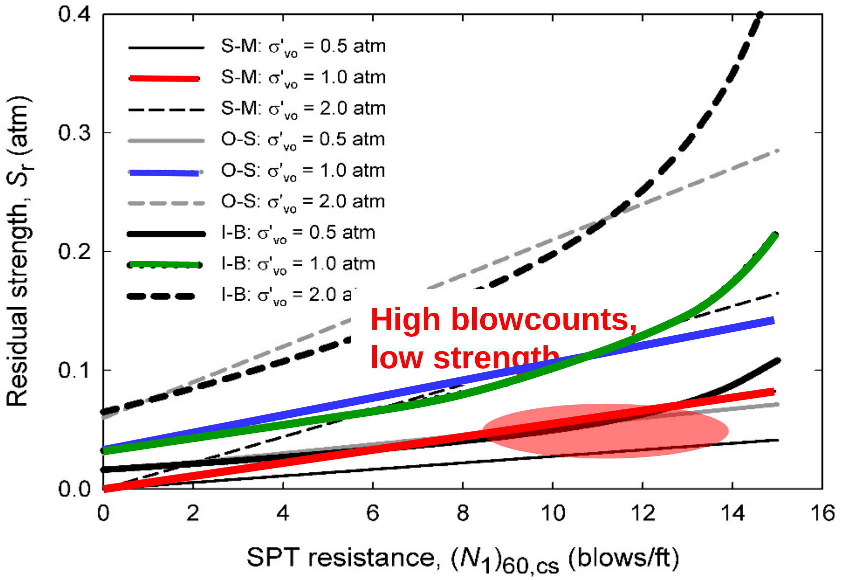
Predicts same residual strength for same density

Normalized strength approach

Recognizes increased density with depth

Predicts high residual strength at great depths

Can predict very low residual strength at shallow depths, even for relatively high blowcount material



Back-calculated residual strength

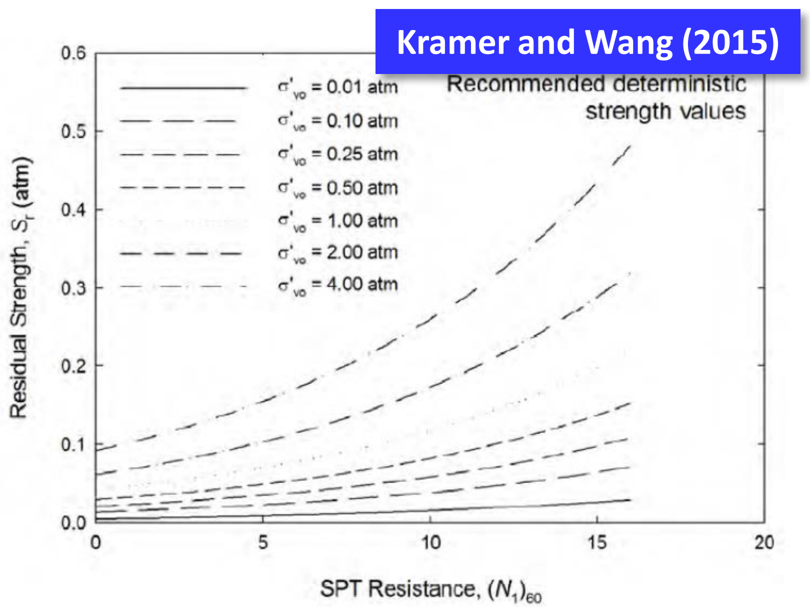
<u>Newer approaches</u>

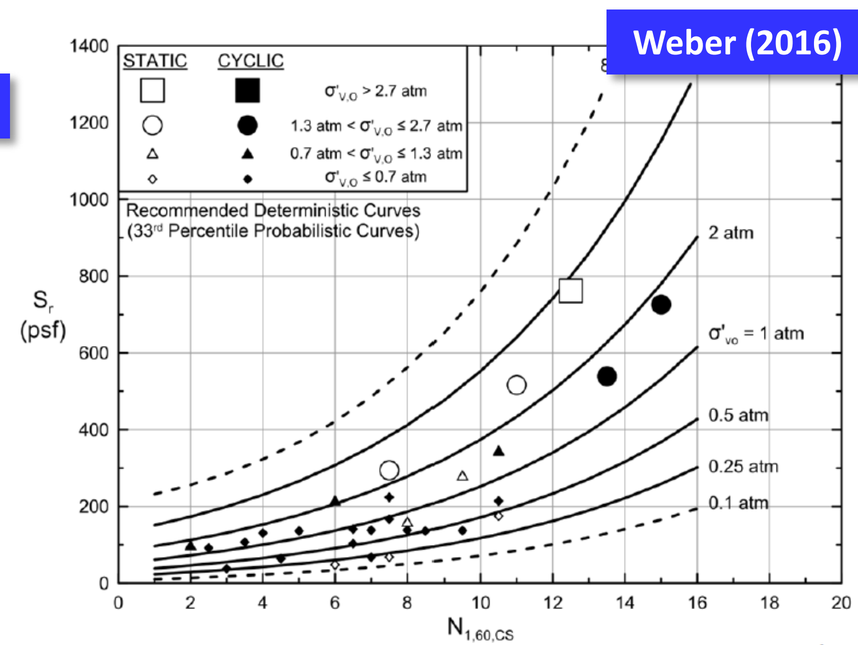
Based on soil mechanics

Recognize increased density with depth

Recognize increasing contractiveness with depth

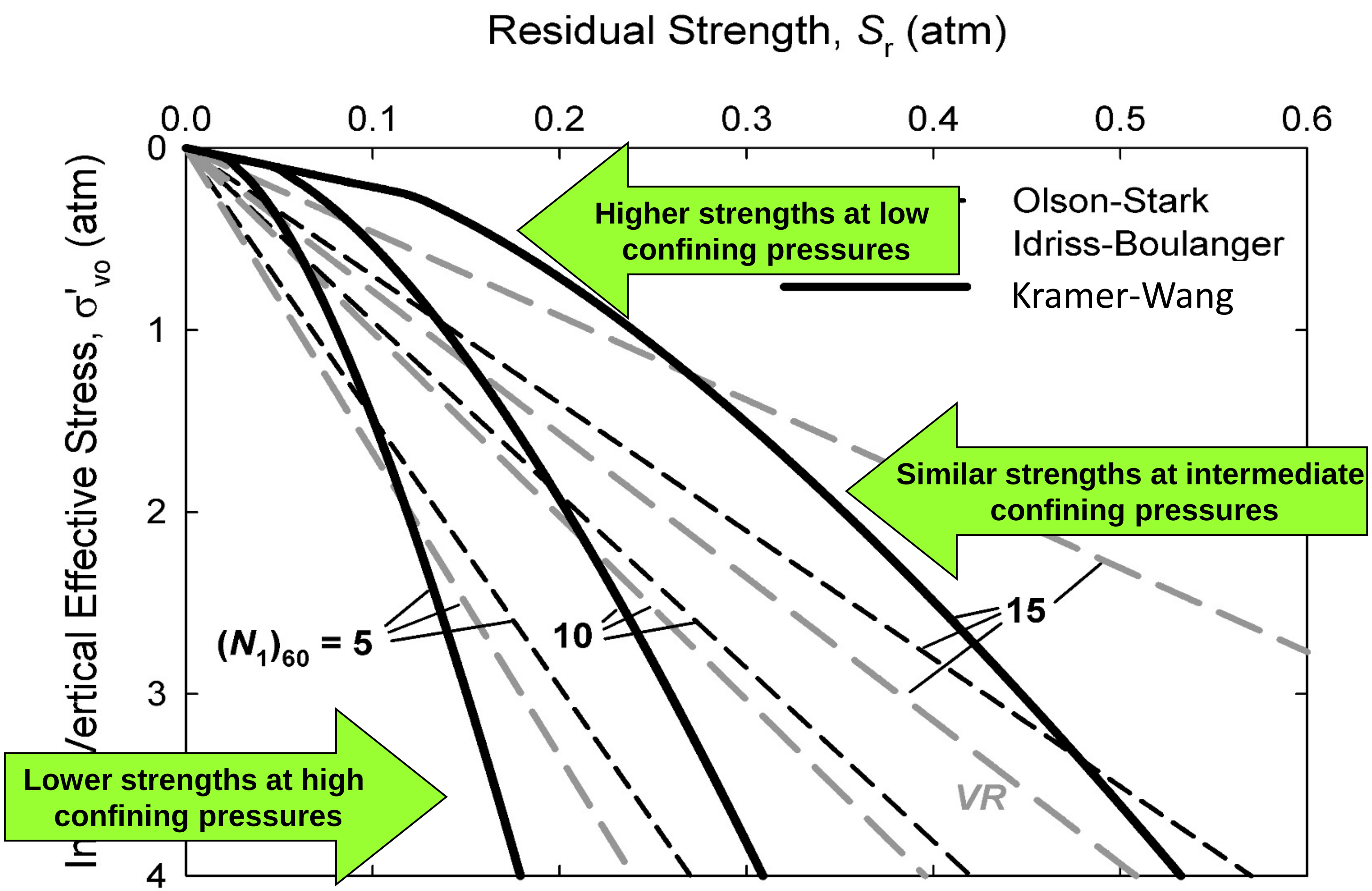
Account for lateral spreading at low confining pressures





Back-calculated residual strength - Newer approach

Comparison of predicted strengths



Issues in Residual Strength Model Development and Application

- Definition of residual strength
    - Ultimate vs. quasi-steady state
    - Stress path effects
    - Soil fabric effects

- Initial stress effects
    - None
    - Linear dependence (proportionality)
    - Nonlinear dependence (non-proportionality)

- Dynamic effects
    - Inertial effects influence final displacements
    - Viscosity of liquefied soil

Issues in Residual Strength Model Development and Application

- Flow slide case history investigation/documentation
  - Variable quantity of available information
  - Variable quality of available information
  - Characterization of uncertainty
    - In input parameters
    - In predicted residual strengths
- Selection of penetration resistance
- Effects of fines content
- Void redistribution effects
- Effects of mixing and hydroplaning
- Extrapolation beyond bounds of data
  - Denser soils
  - Greater depths