Understanding Shaft Resistance in Rock Socketed Piles

Dr Chris Haberfield

Lecture 2 Outline

- *Origin of the Scatter (Load test results)*
- *Back to Basics*
- *Some Research Findings*
- *Laboratory Testing of Interfaces*
- *Roughness*
- *From Laboratory to Field*
- *Explaining the Scatter*
- *Summary*

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Acknowledgements

- Dr Julian Seidel
- Foundation QA for use of Rocket
- Researchers at Monash University

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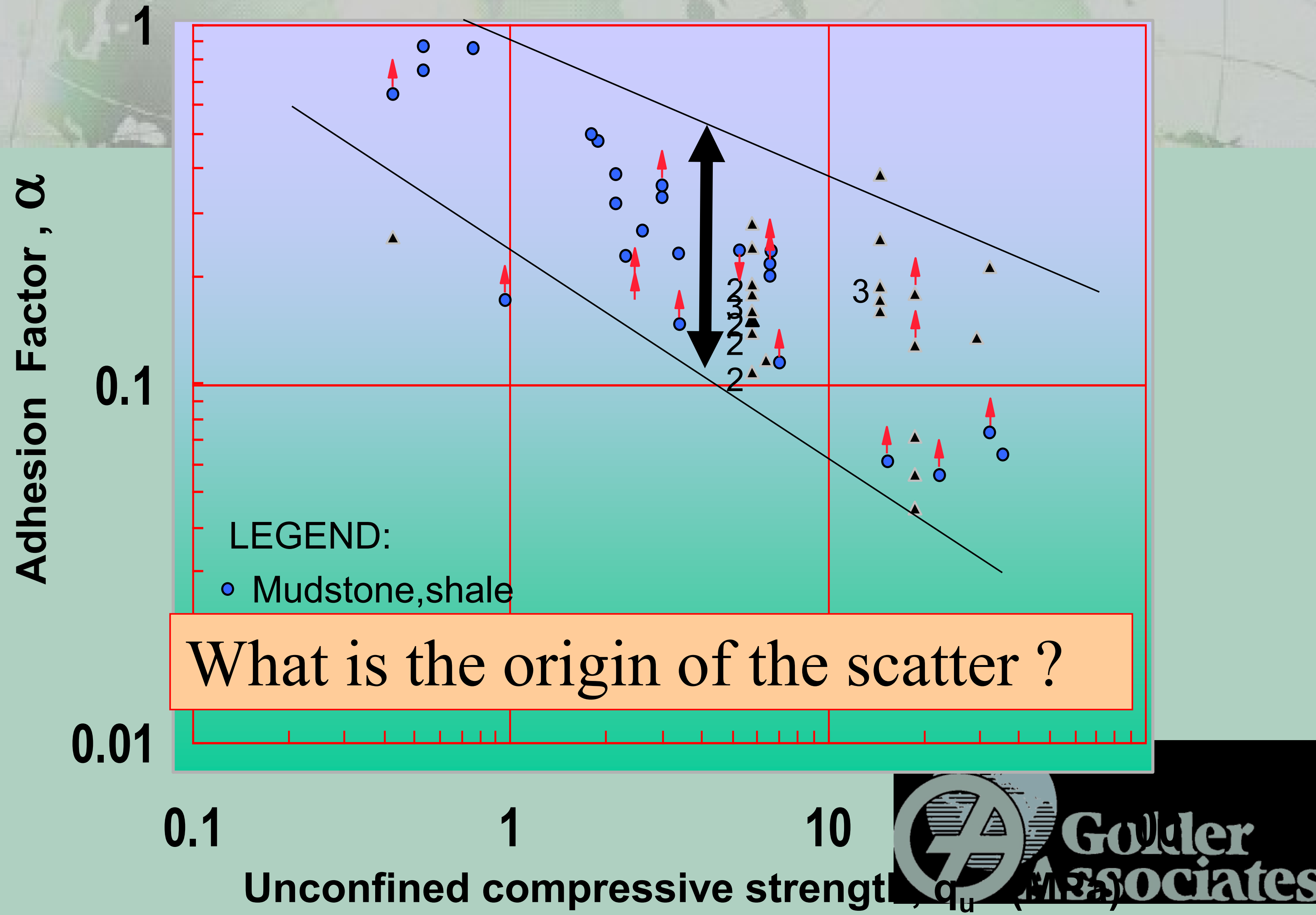
Shaft Resistance



Parameters affecting Shaft Resistance

Rock

- type, structure, weathering
- strength
- stiffness

Construction

- socket diameter
- socket roughness
- socket cleanliness
- concrete pour
- contractor experience and expertise

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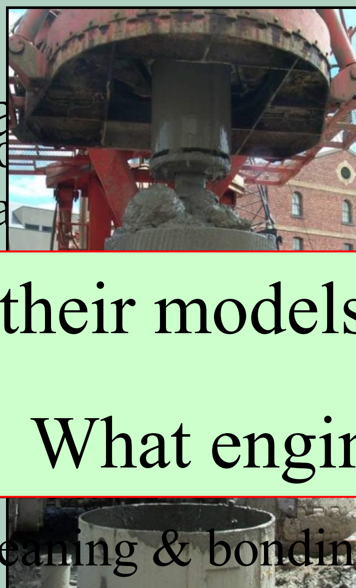
Origin of the Scatter

• socket

• pile dia

(drilling to ... ughening)

(structura ...)



• in

(co

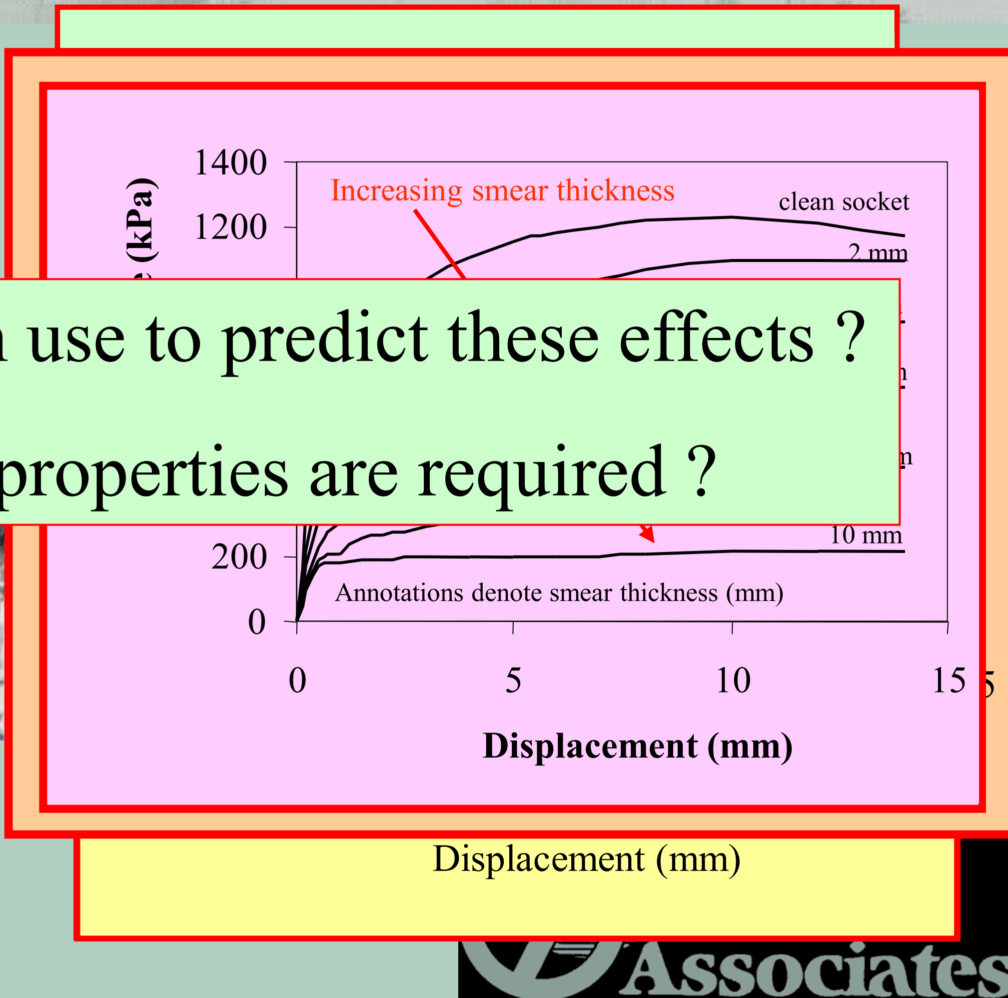
• ro

(socket cleaning & bonding)

• residual drilling fluids

(socket cleaning & bonding)

Increasing roughness



Are their models we can use to predict these effects ?

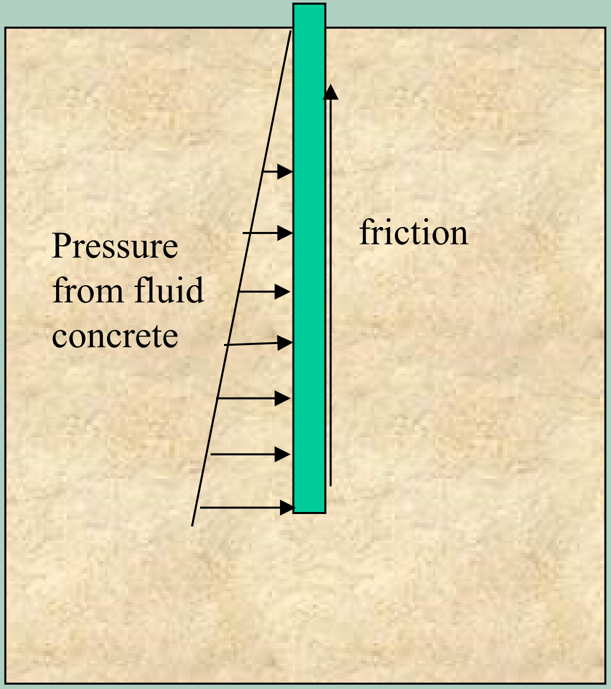
What engineering properties are required ?

Shaft Resistance - Back to basics

- Shaft resistance is developed through friction (τ) from intimate contact between the concrete of the pile and the rock
- The wet concrete applies a pressure (σ_n) to the socket wall which is locked in when the concrete hardens
- frictional resistance (+ adhesion)

$$\tau = c + \sigma_n \tan\phi$$

must be overcome before slip at the pile/rock interface can occur



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Shaft Resistance - Back to basics

- The rock socket is not smooth, but has undulations referred to as roughness
- For slip to occur at the interface, the socket must dilate
- Thus increasing the normal stress on the interface and the frictional resistance

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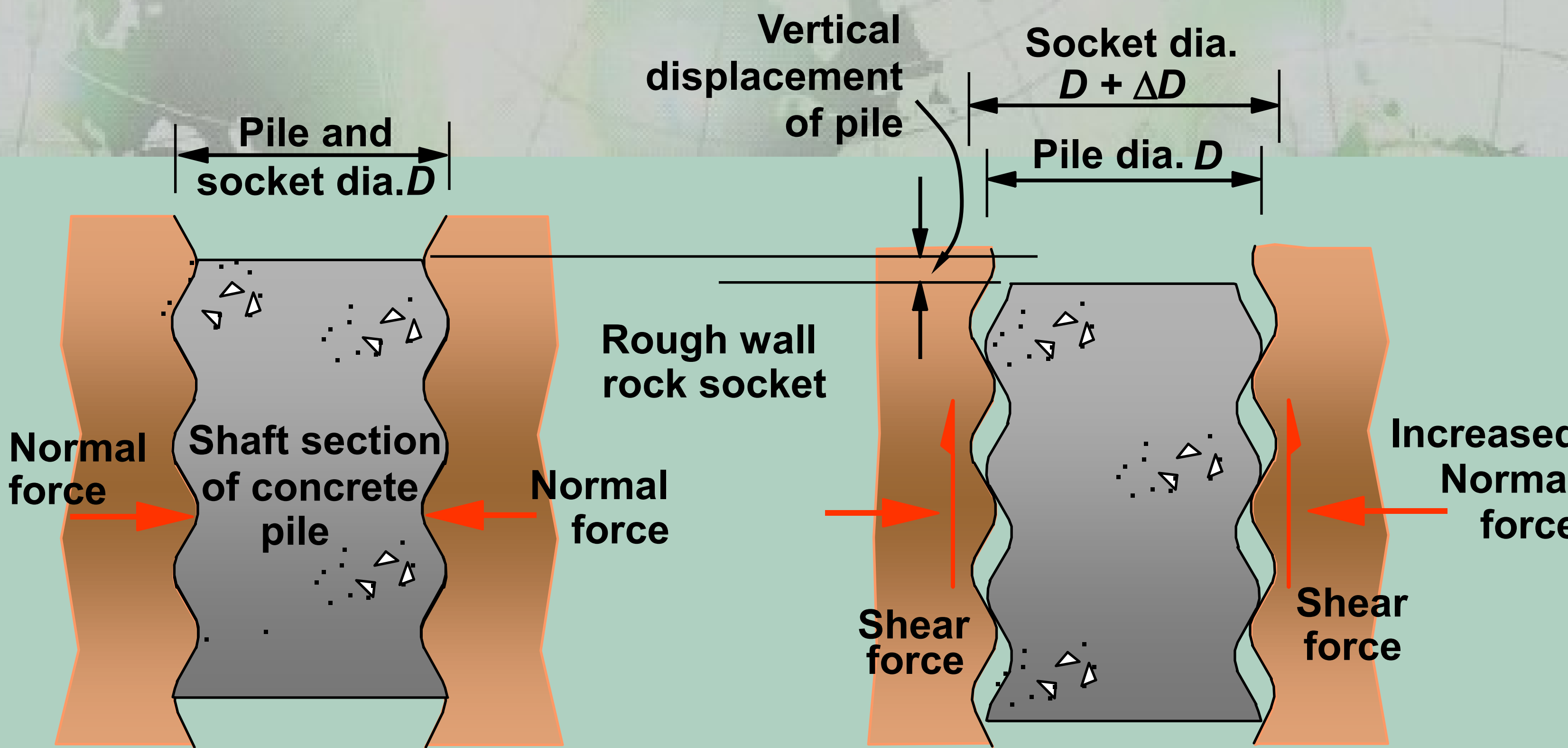
Socket Dilation



(a) Pile before displacement

(b) Pile after displacement

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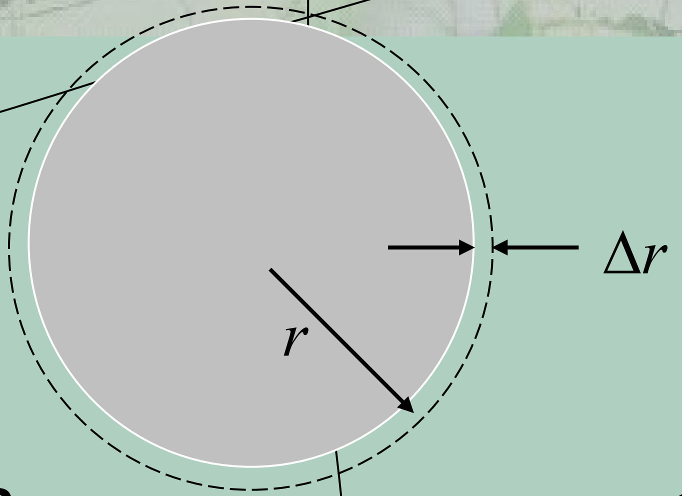
Constant Normal Stiffness (CNS)

Increase in normal stress

$$\Delta\sigma_n = \frac{E_m \Delta r}{(1+\nu_m) r}$$



E_m = rock mass Young's modulus

ν_m = rock mass Poisson's ratio

$r = D/2$ = radius of socket

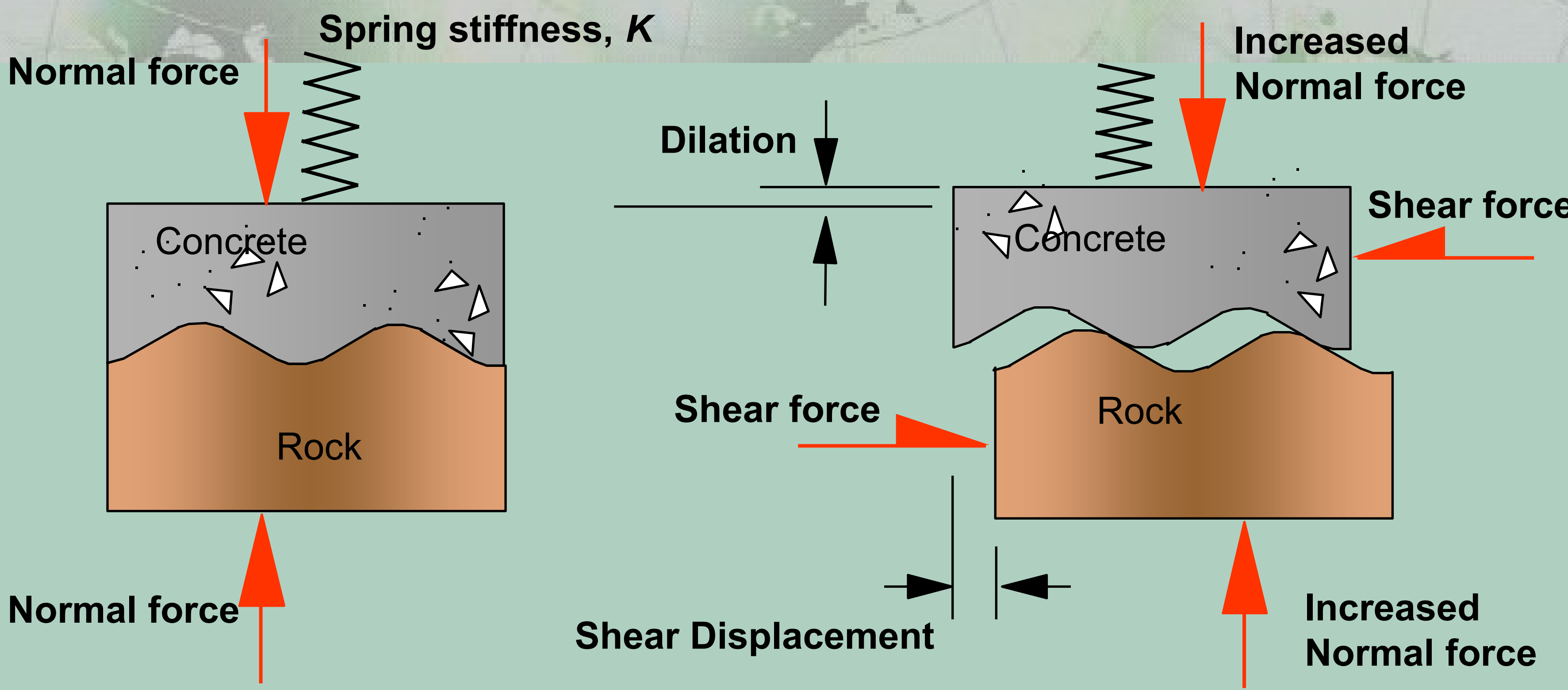
Δr = dilation of socket

$\Delta\sigma_n$ = change in normal stress

K = normal stiffness

$$K = \frac{\Delta\sigma_n}{\Delta r} = \frac{E_m}{(1+\nu_m).r}$$

Modelling socket shear in the laboratory
CNS Direct Shear Tests



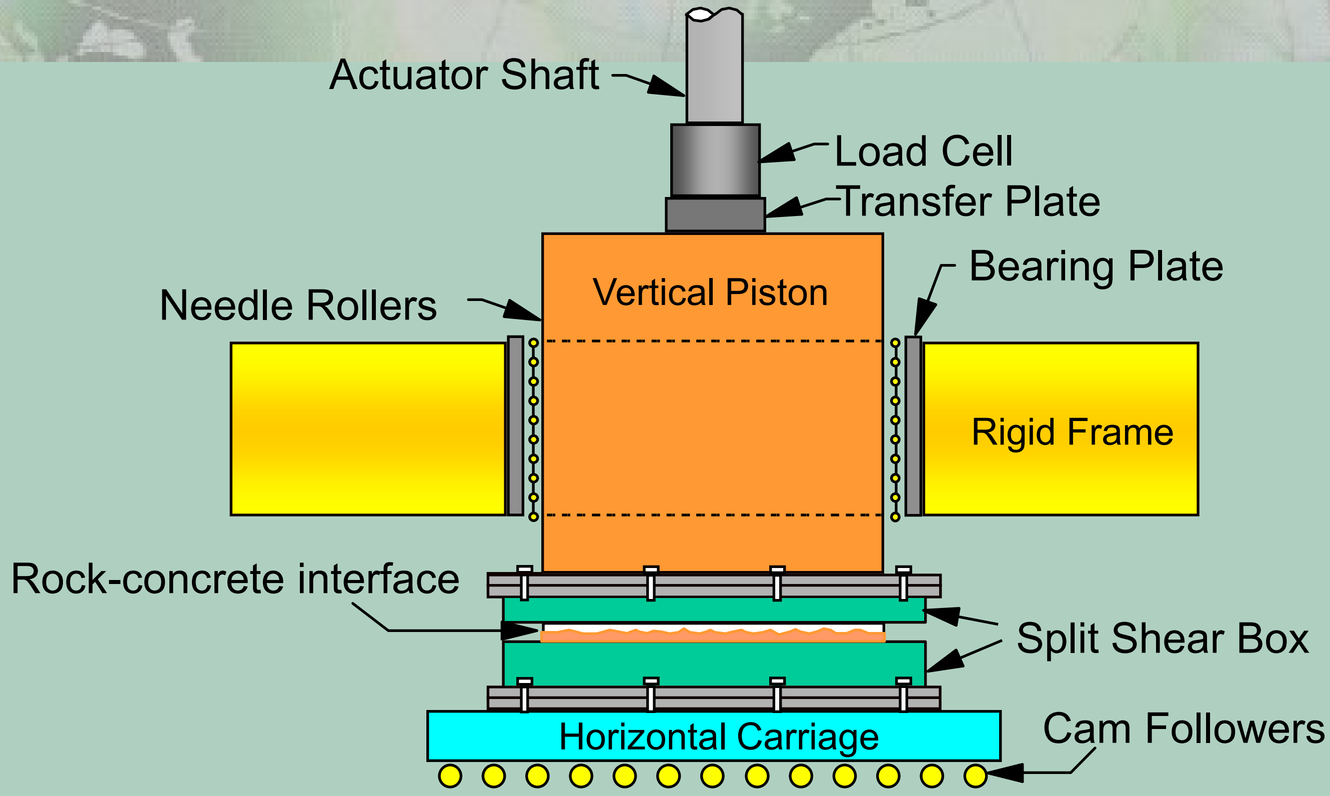
(c) Equivalent 2-D model for before displacement

(d) Equivalent 2- for after displacement

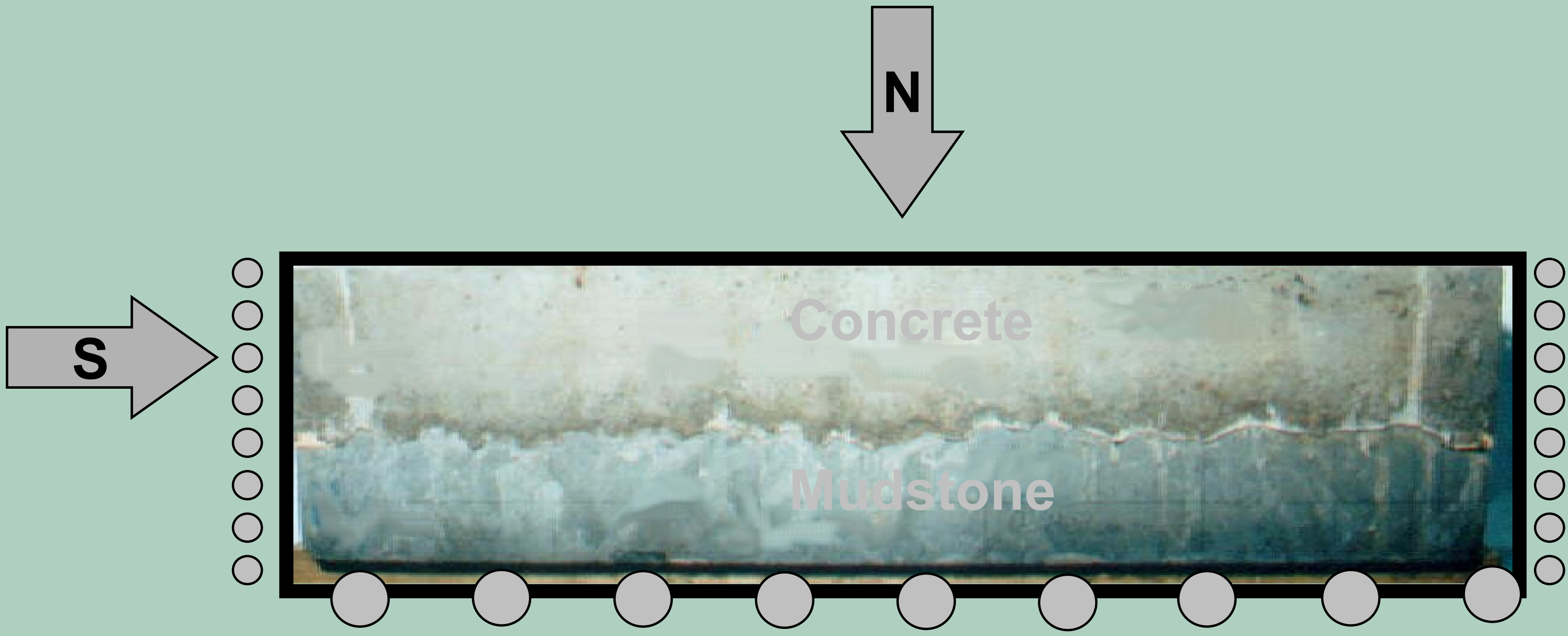
Laboratory Testing : CNS Rig

- Computer feedback control
- 250 kN hydraulic actuators for shear and normal stress
- Monotonic and cyclic loading
- Stress or strain control
- Automatic data logging

CNS Direct Shear Testing Rig



Rough interface sample prior testing



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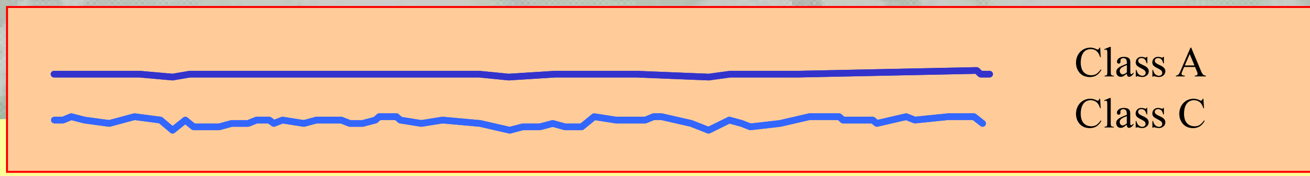
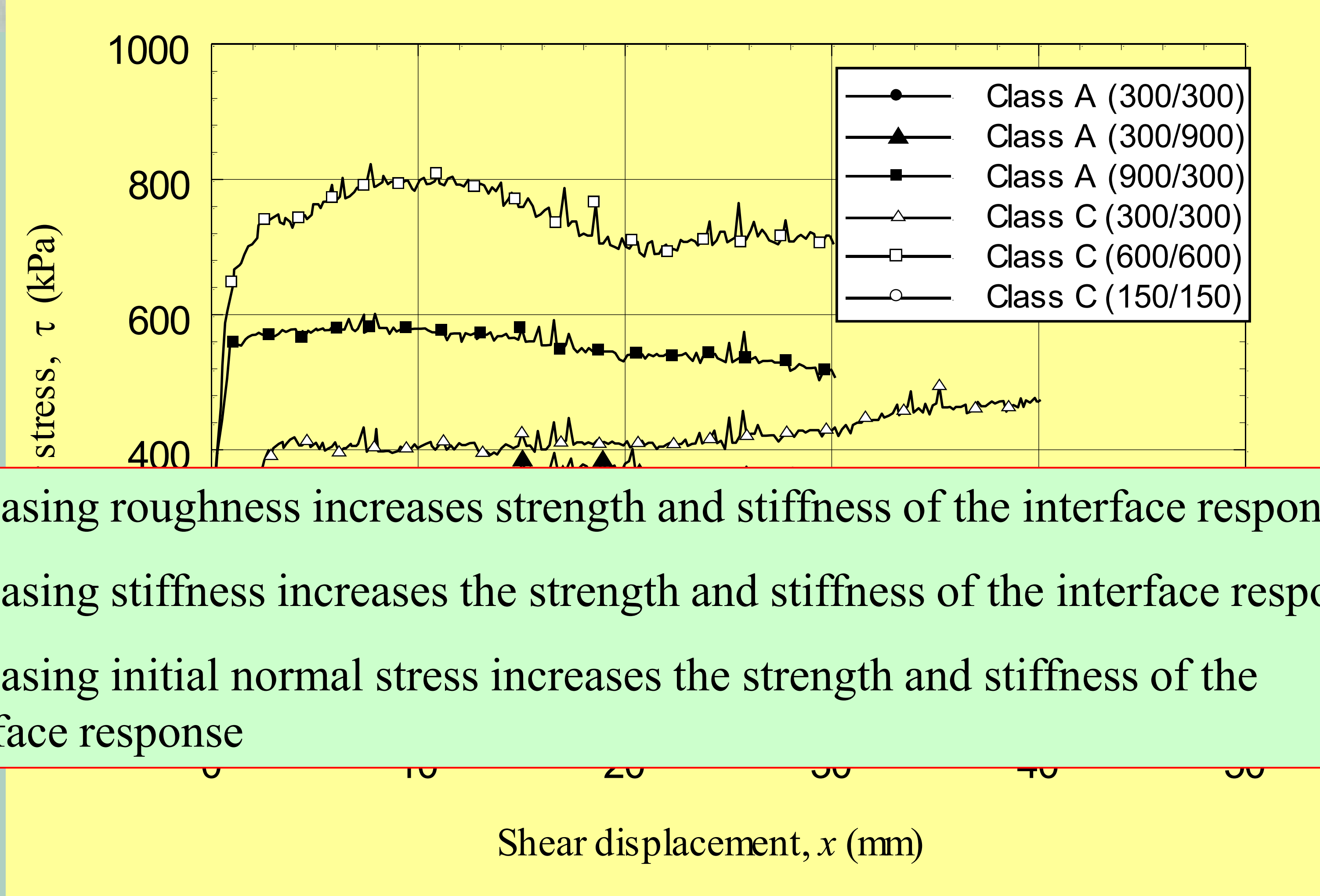
CNS test results : Impact of roughness, normal stress and stiffness



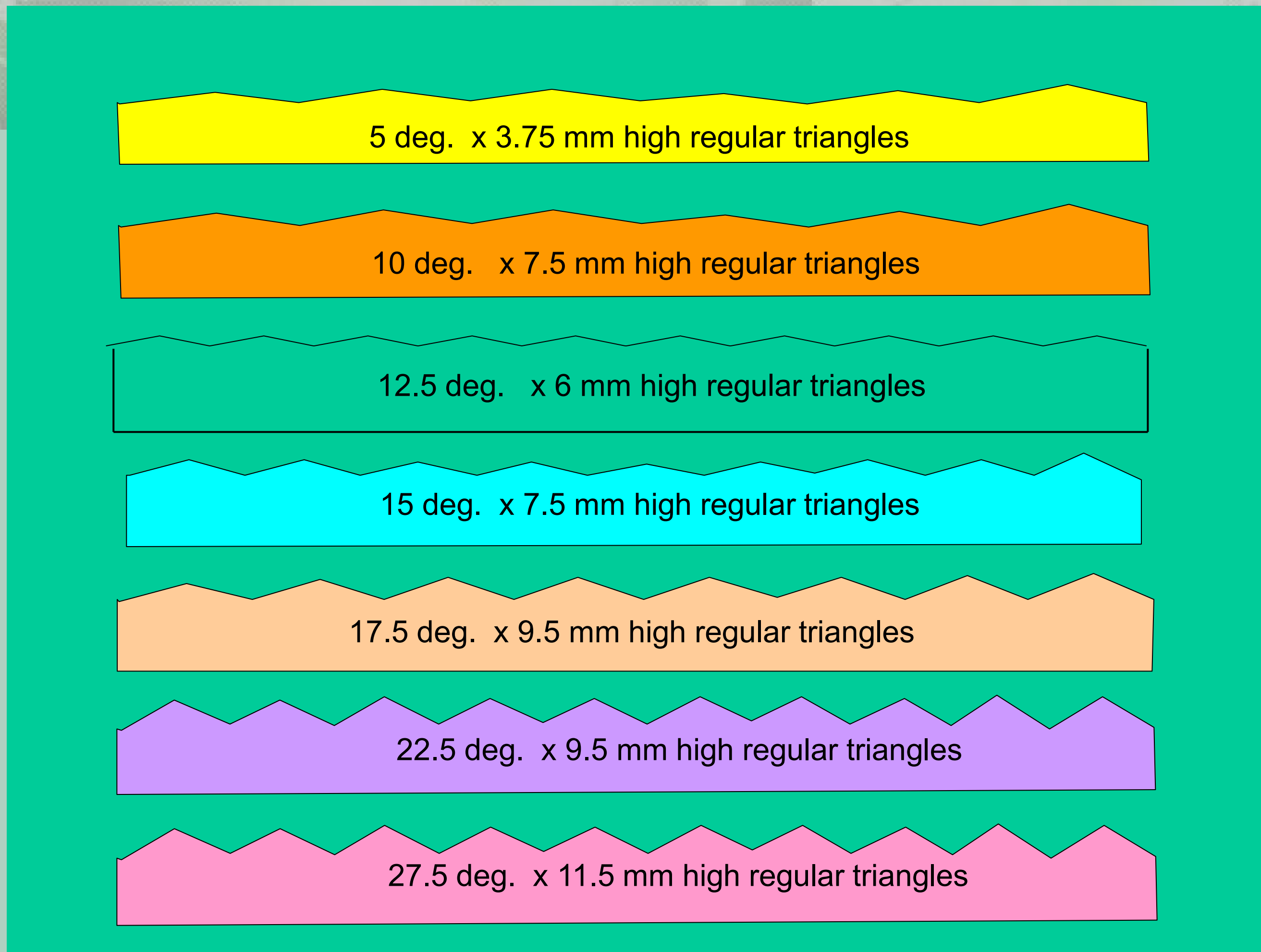


Increasing roughness increases strength and stiffness of the interface response

Increasing stiffness increases the strength and stiffness of the interface response

Increasing initial normal stress increases the strength and stiffness of the interface response

CNS Test Samples - Triangular Asperities



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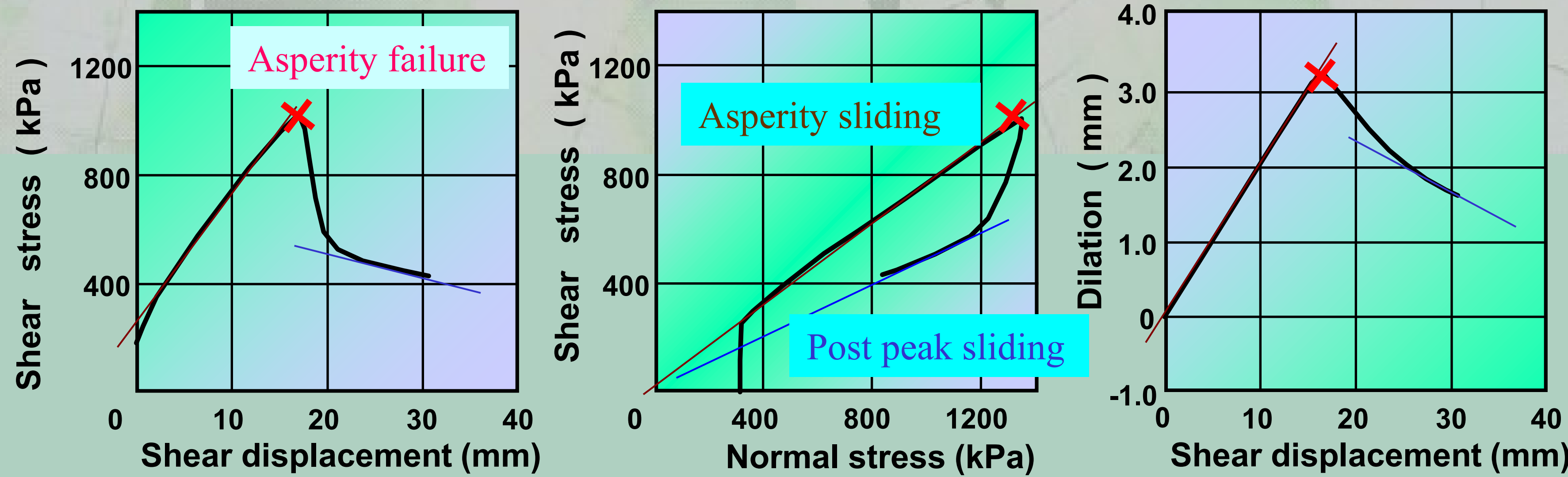
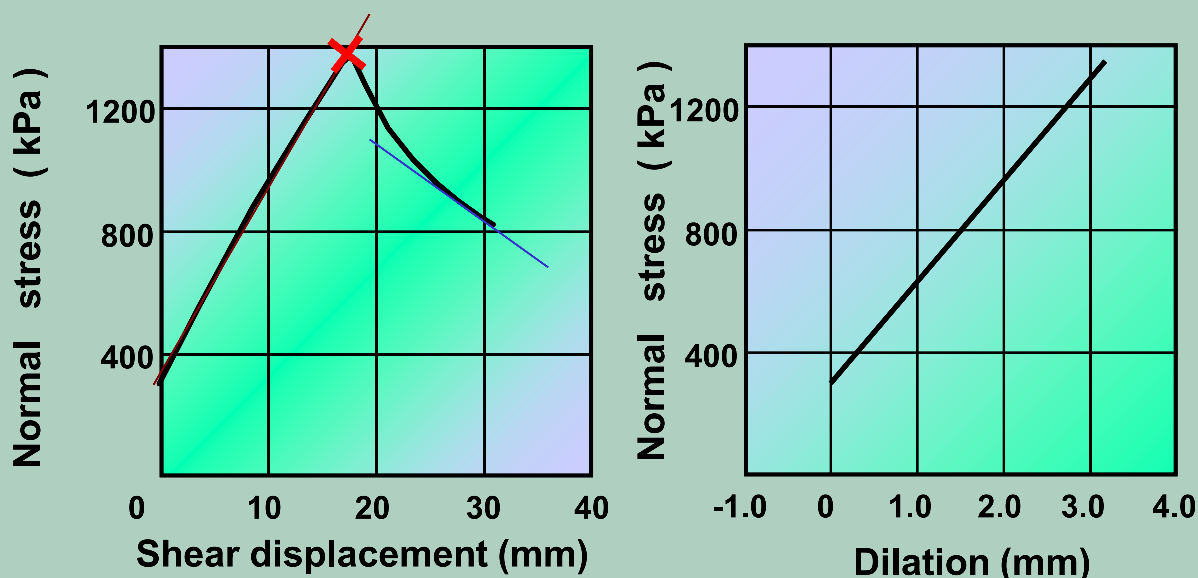
Typical Test Results - Triangular Asperities





TEST No. M1b 16/4/1992

Johnstone sample 6C

12.5° ± 0°

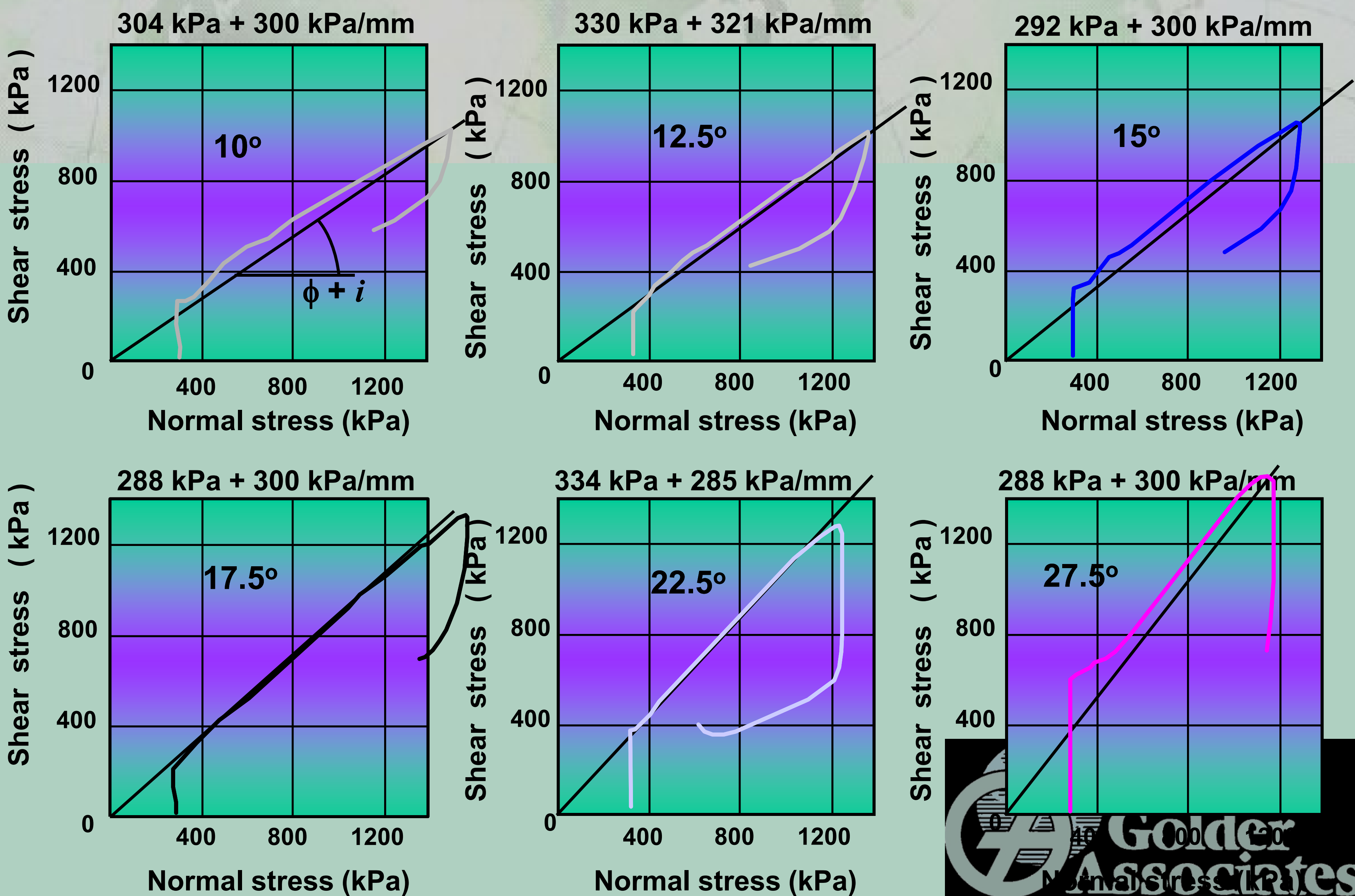
Bandsaw cut / gladwrap o'nite

Initial nor. stress = 330 kPa

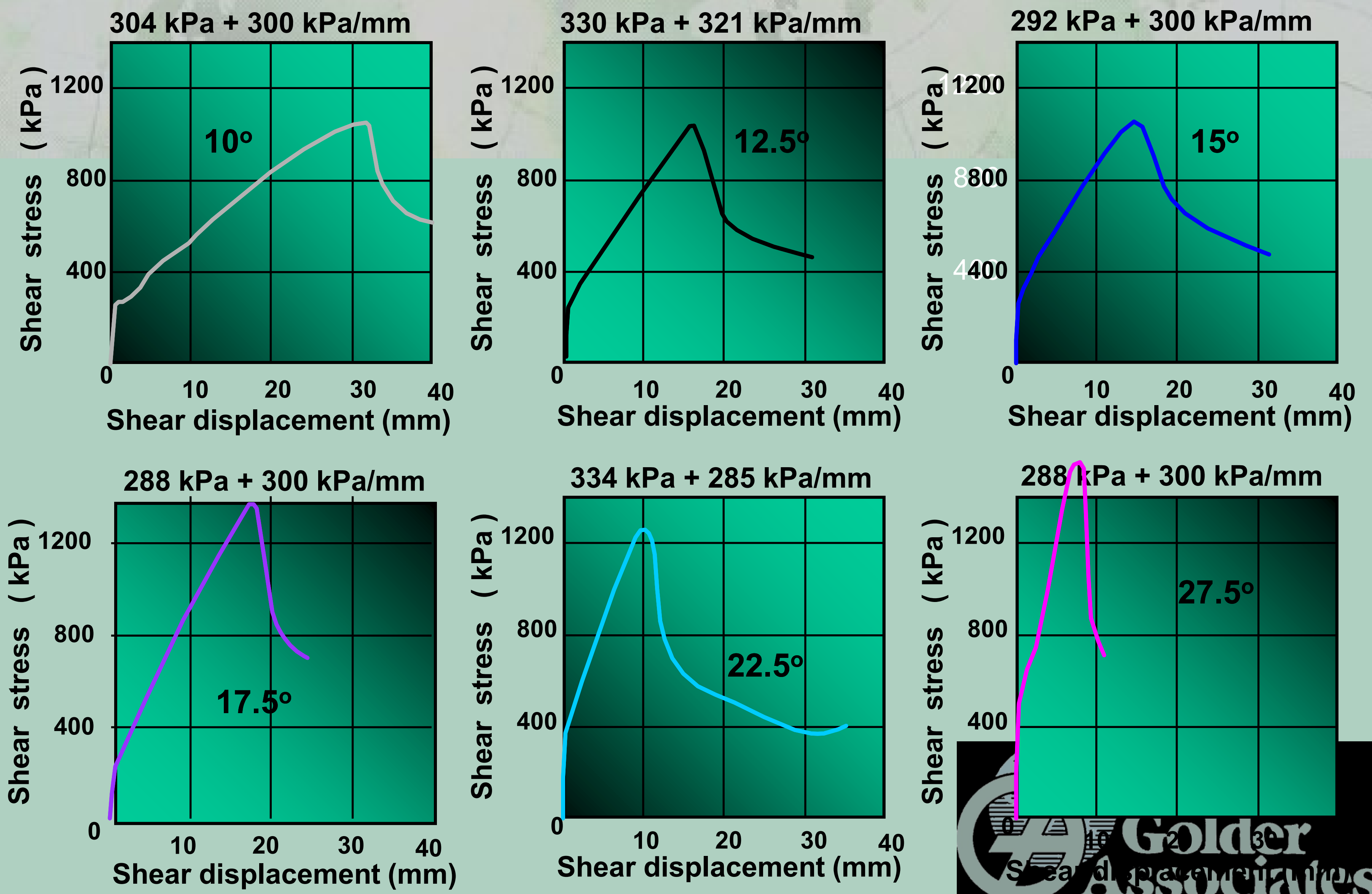
Normal stiffness = 321kPa/mm

Shear rate = 0.5 mm/min

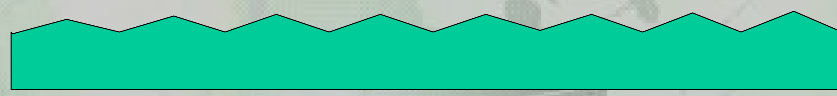
Summary 'A' for Triangular Asperities



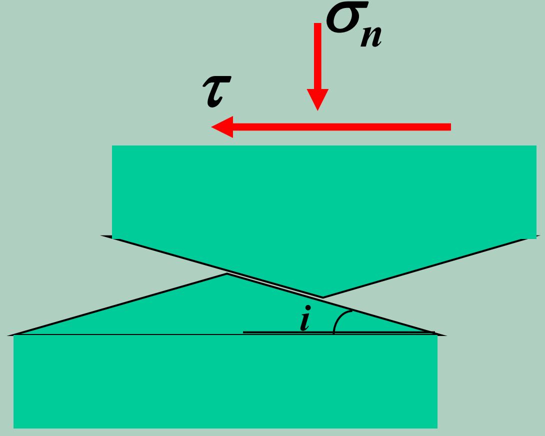
Summary ‘B’ for Triangular Asperities

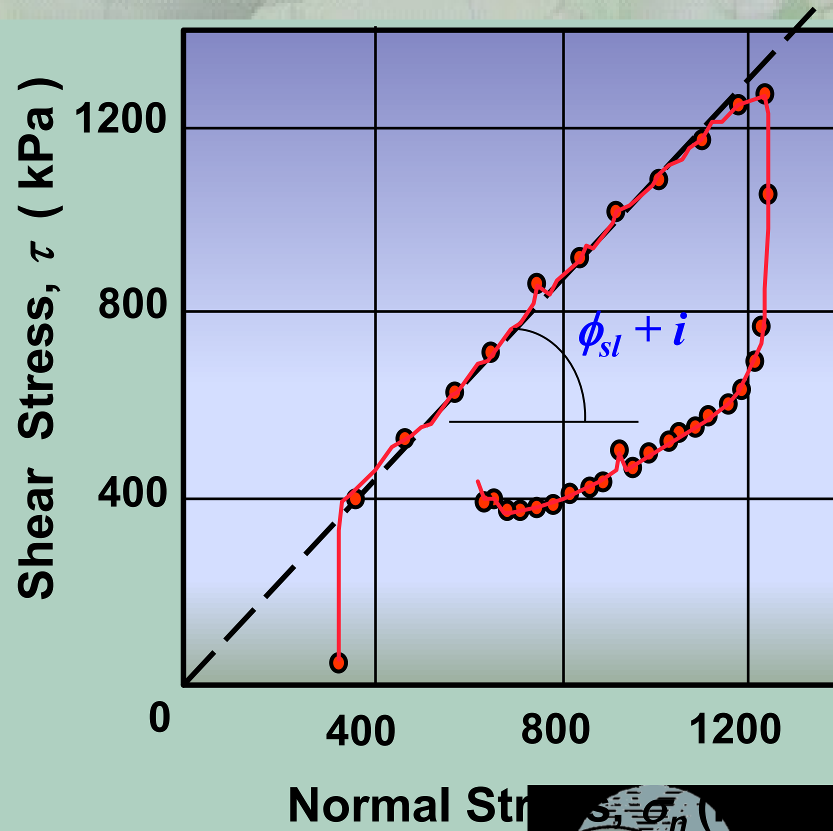


Simple Sliding Model

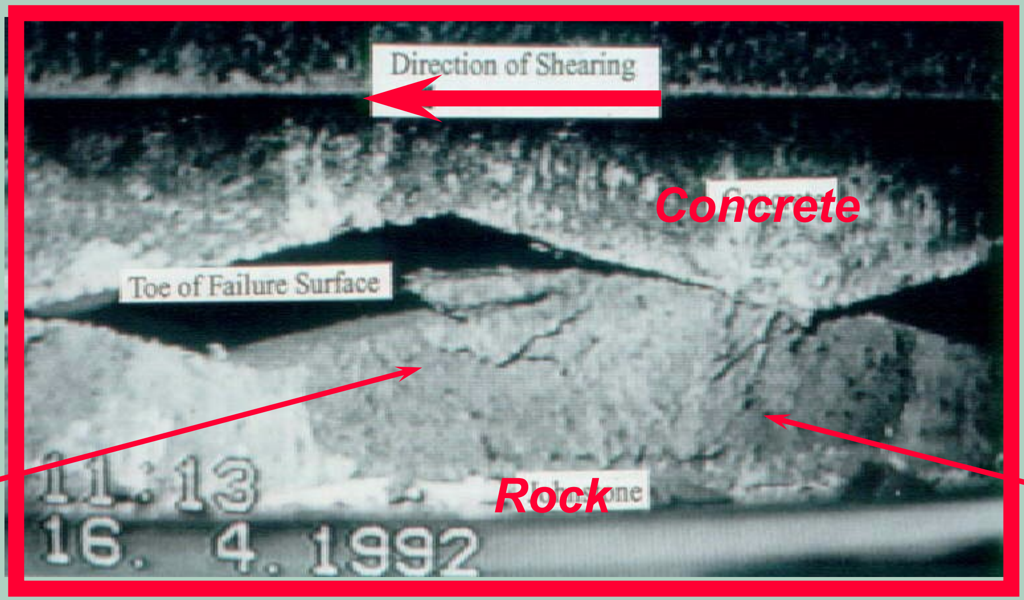


$$\tau = \sigma_n \tan(\phi_{sl} + i)$$





Video image of regular 12.5^o siltstone asperity at failure



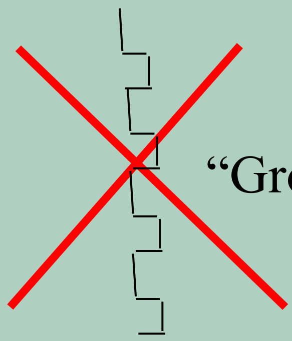
toe of failure surface

rotational failure

At a critical shear displacement, the asperity can no longer support the applied load and fails.

Effective Roughness

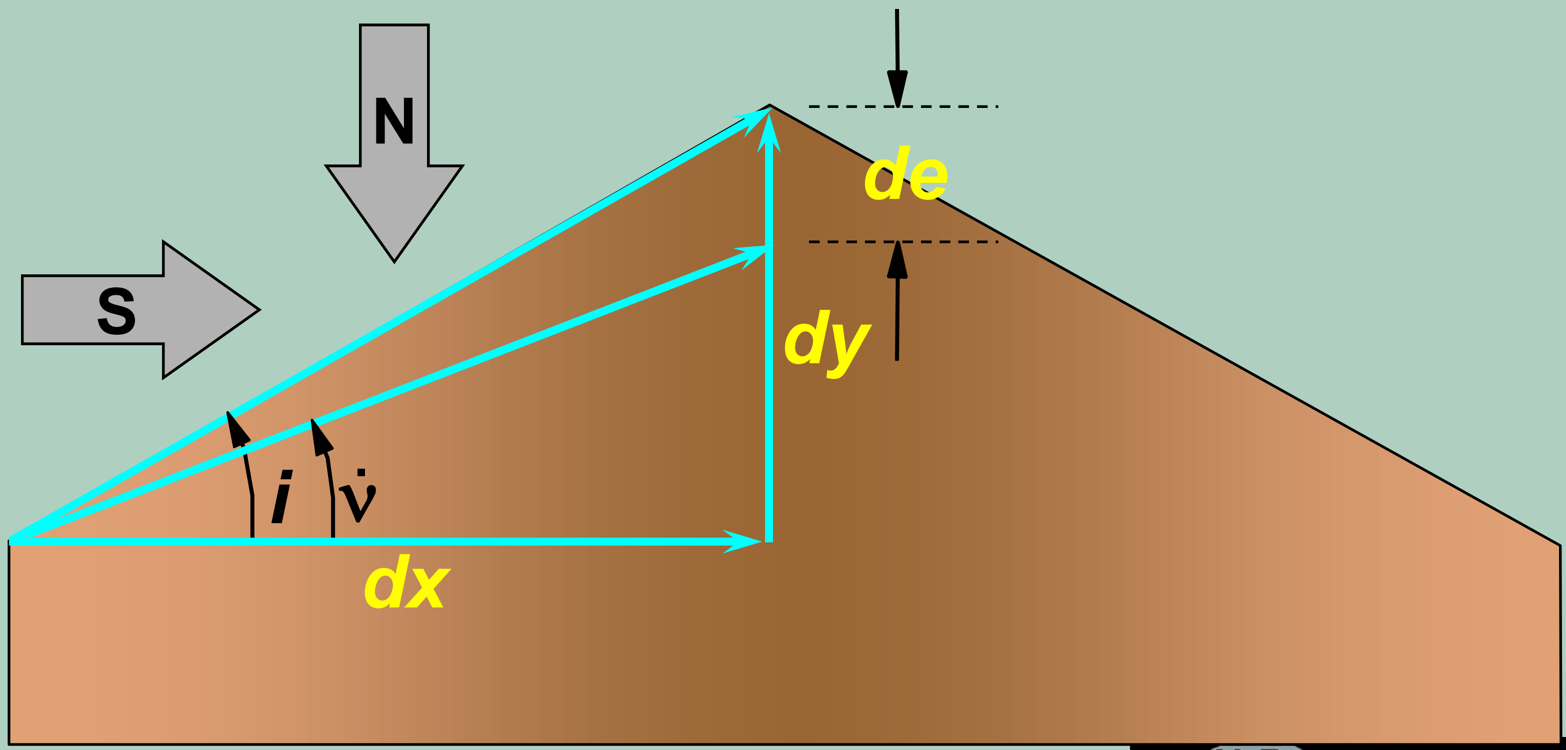
If asperities are too steep, there will be no sliding and no dilation. As a result, the interface may have lower shear strength and will behave in a more brittle manner. There is an optimal level of roughness, beyond which no improvement to shear performance will occur.



"Grooving"

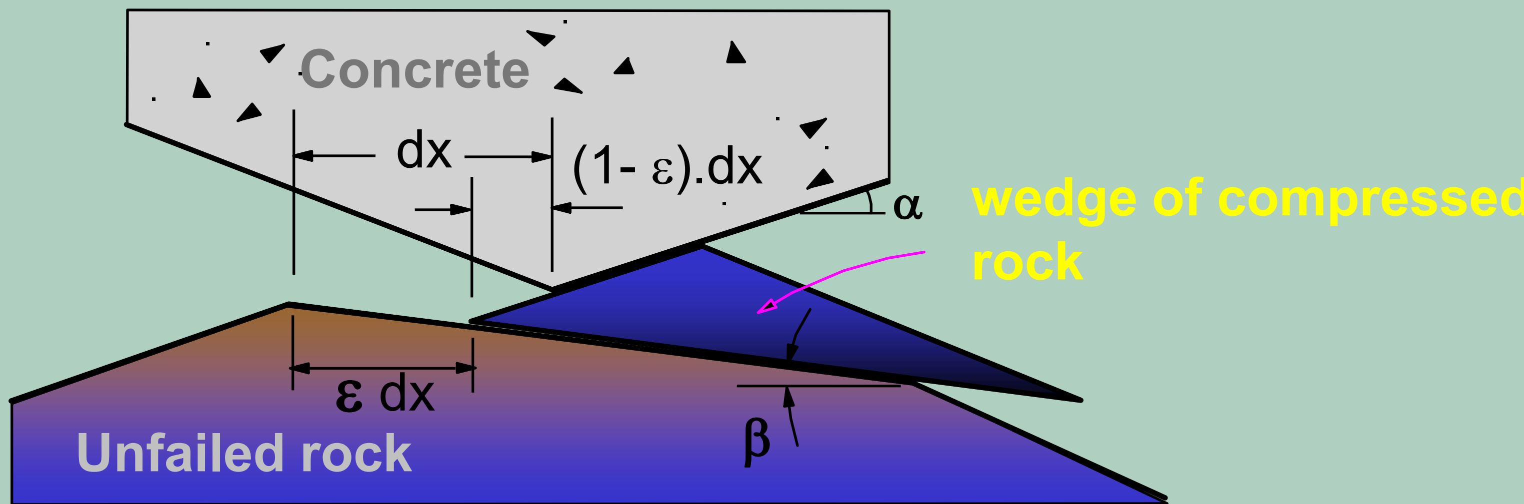
Deformation and dilation

Asperities deform under load and reduces dilation (to less than the asperity angle)



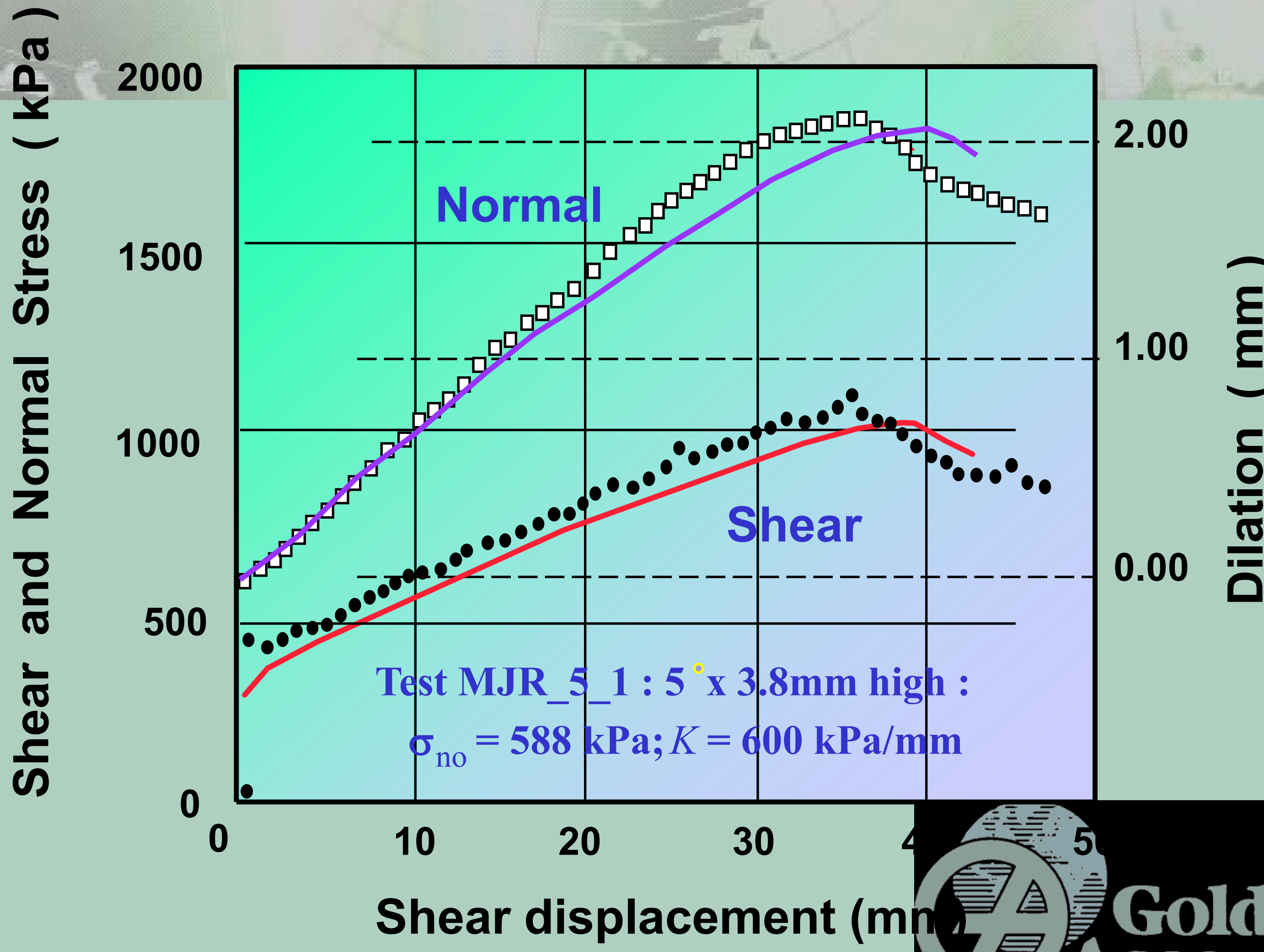
Behaviour after Failure

- After failure of the asperity, there is a wedge of compressed rubble which effectively acts as a door-stopper

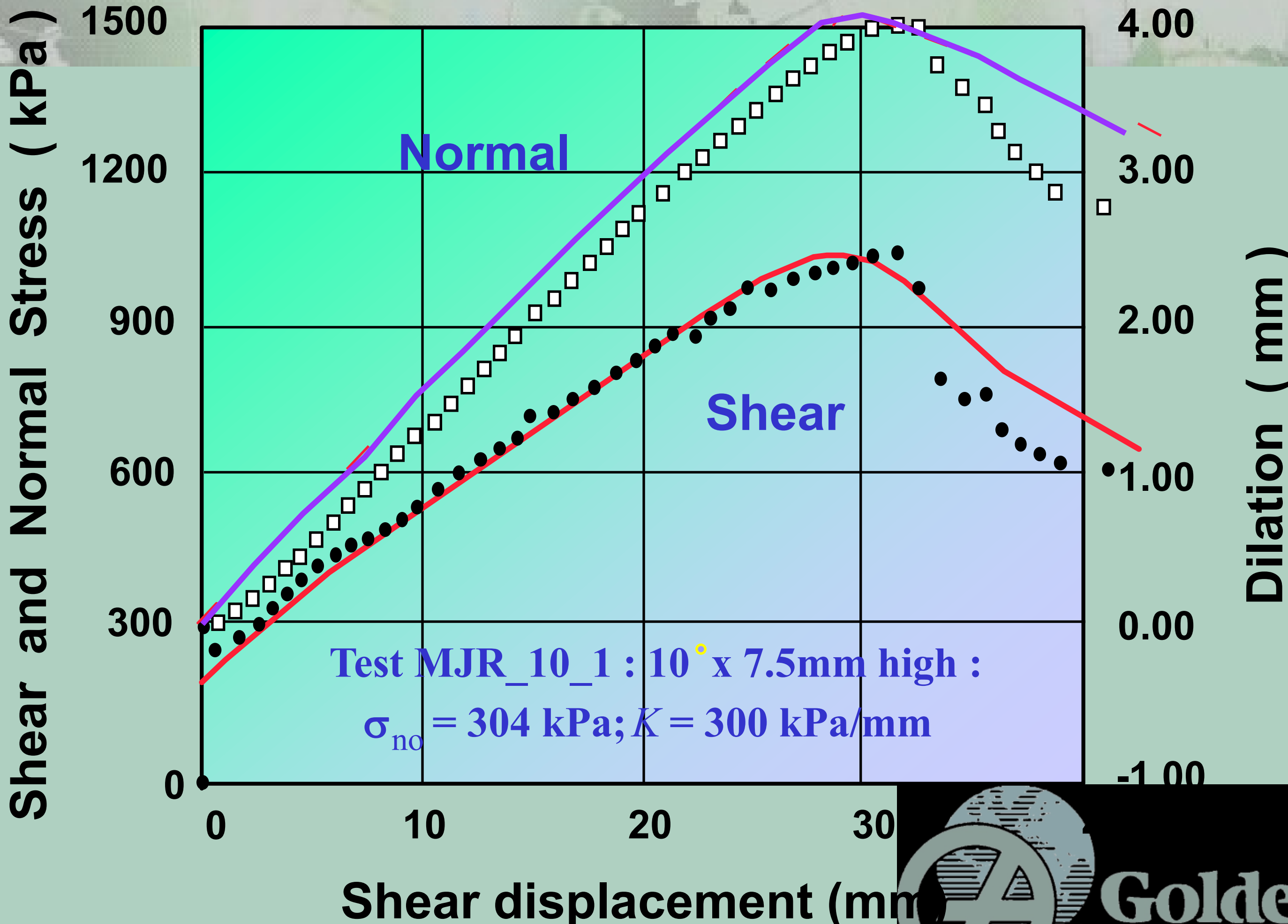


Relative movement occurs between <u>both</u> the concrete and the wedge <u>and</u> the wedge and unfailed material. This results in a residual strength greater than the residual strength of the rock.

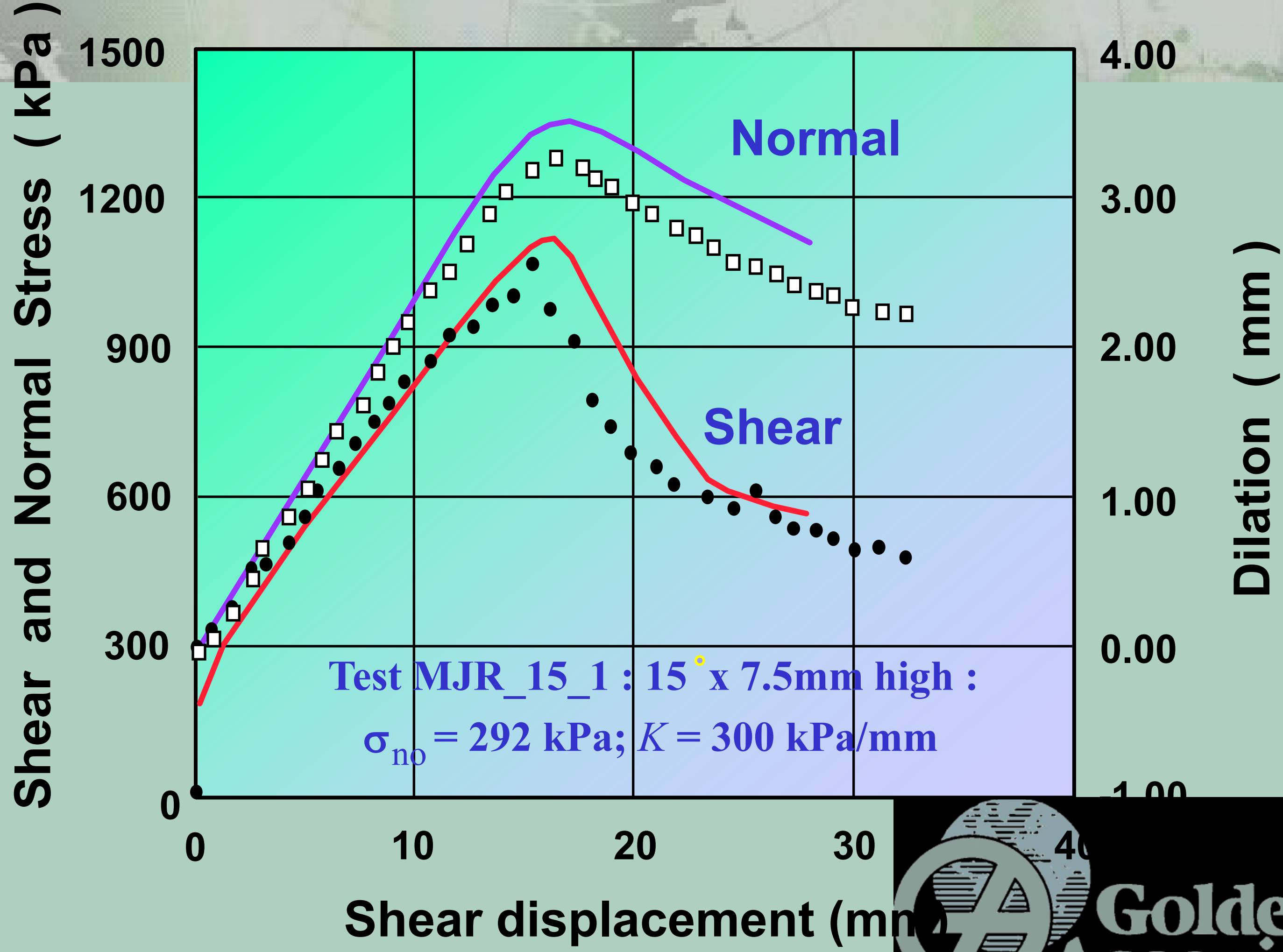
5º asperity profile - measured vs predicted



10º asperity profile - measured vs predicted



15° asperity - measured vs predicted



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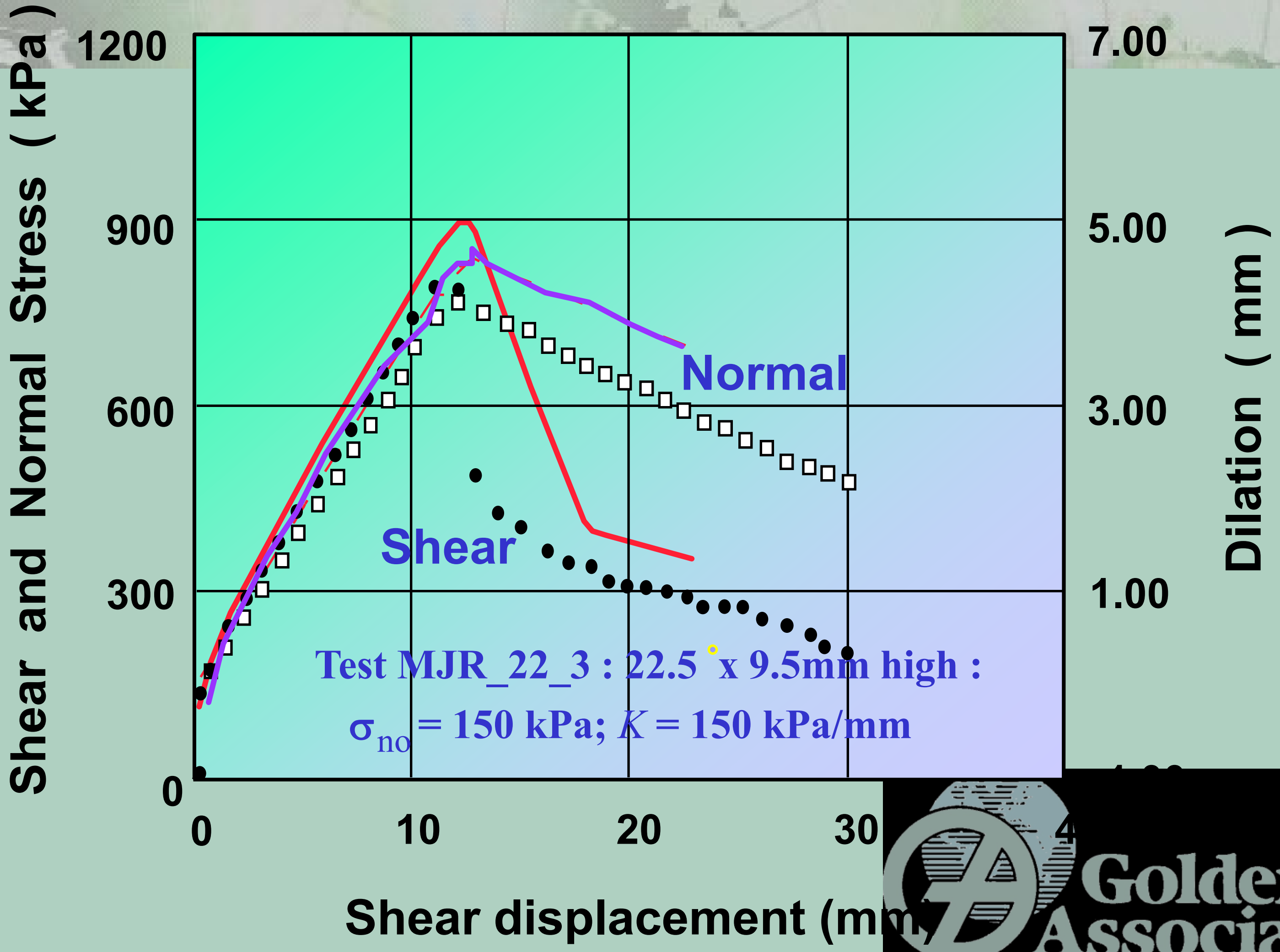
22.5º asperity - measured vs predicted



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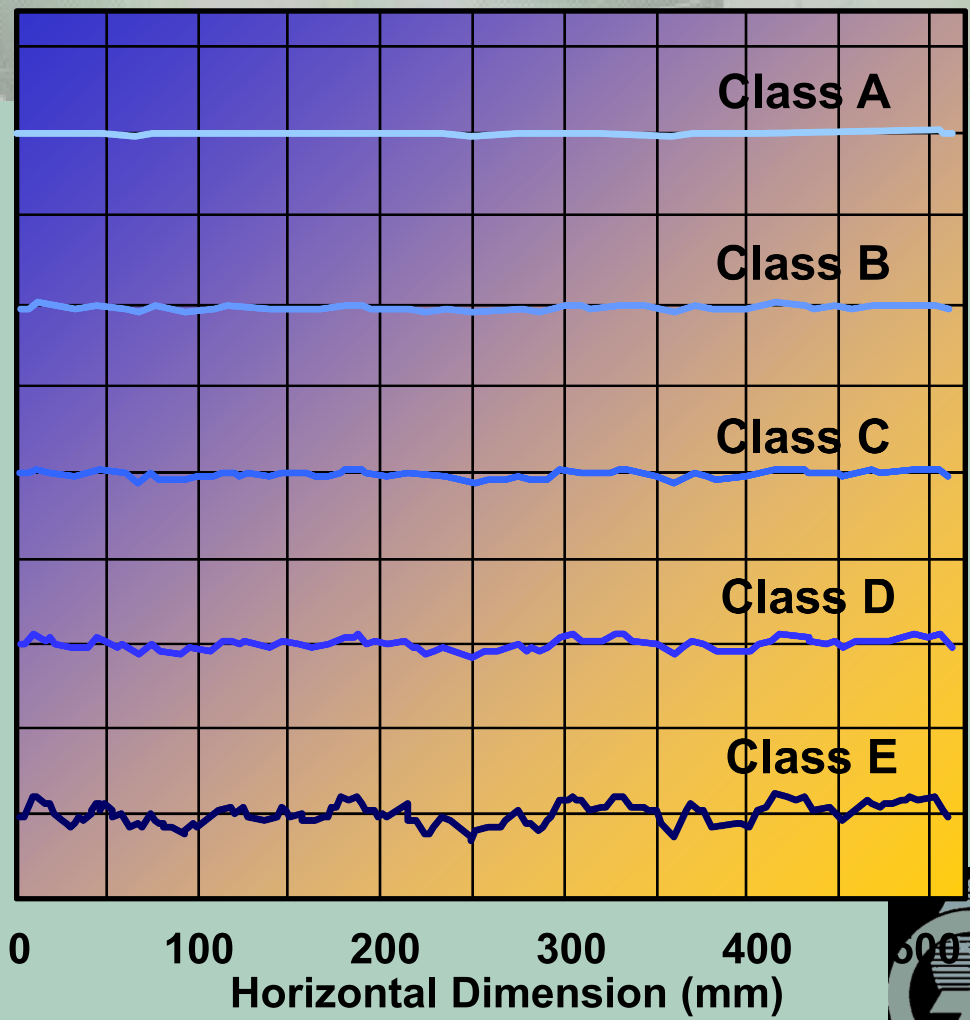
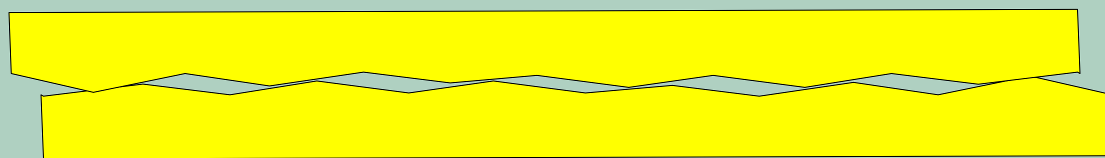
Extension to rough profiles



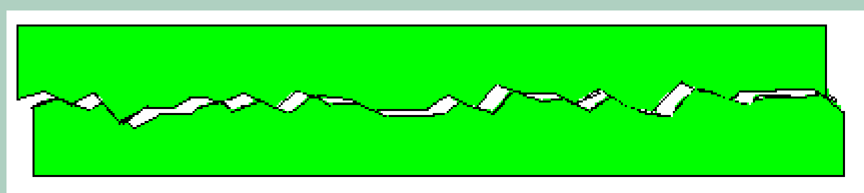
Same basic behaviour but more complex !

Regular triangular asperity profiles



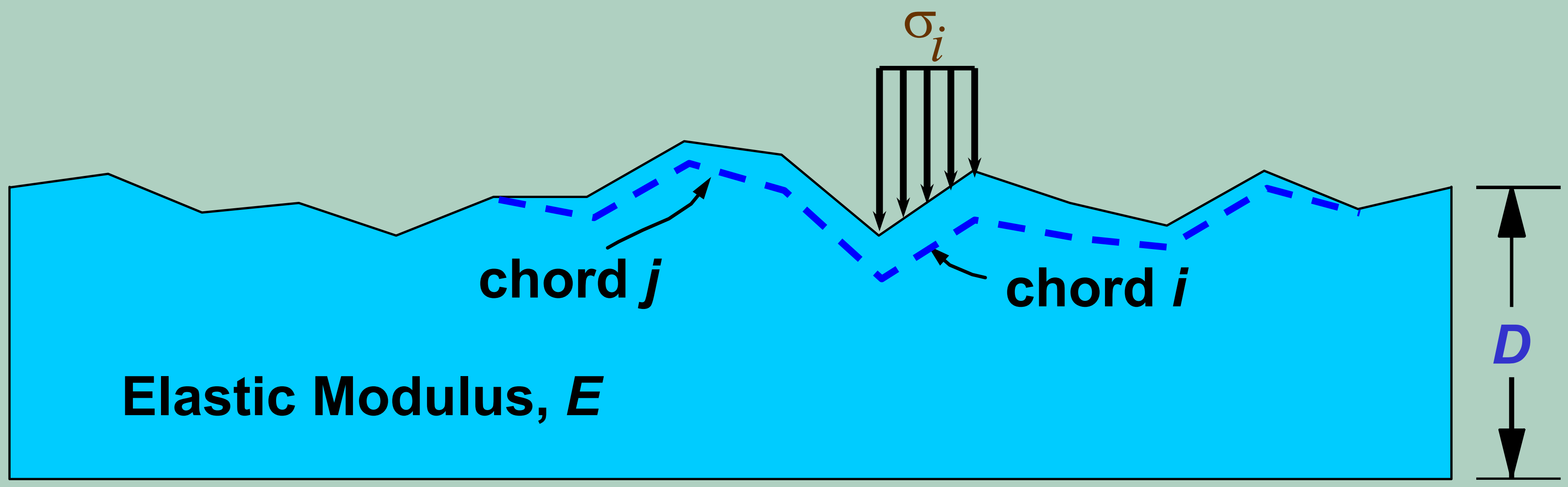
The conditions at every asperity are the same

Rough asperity profiles



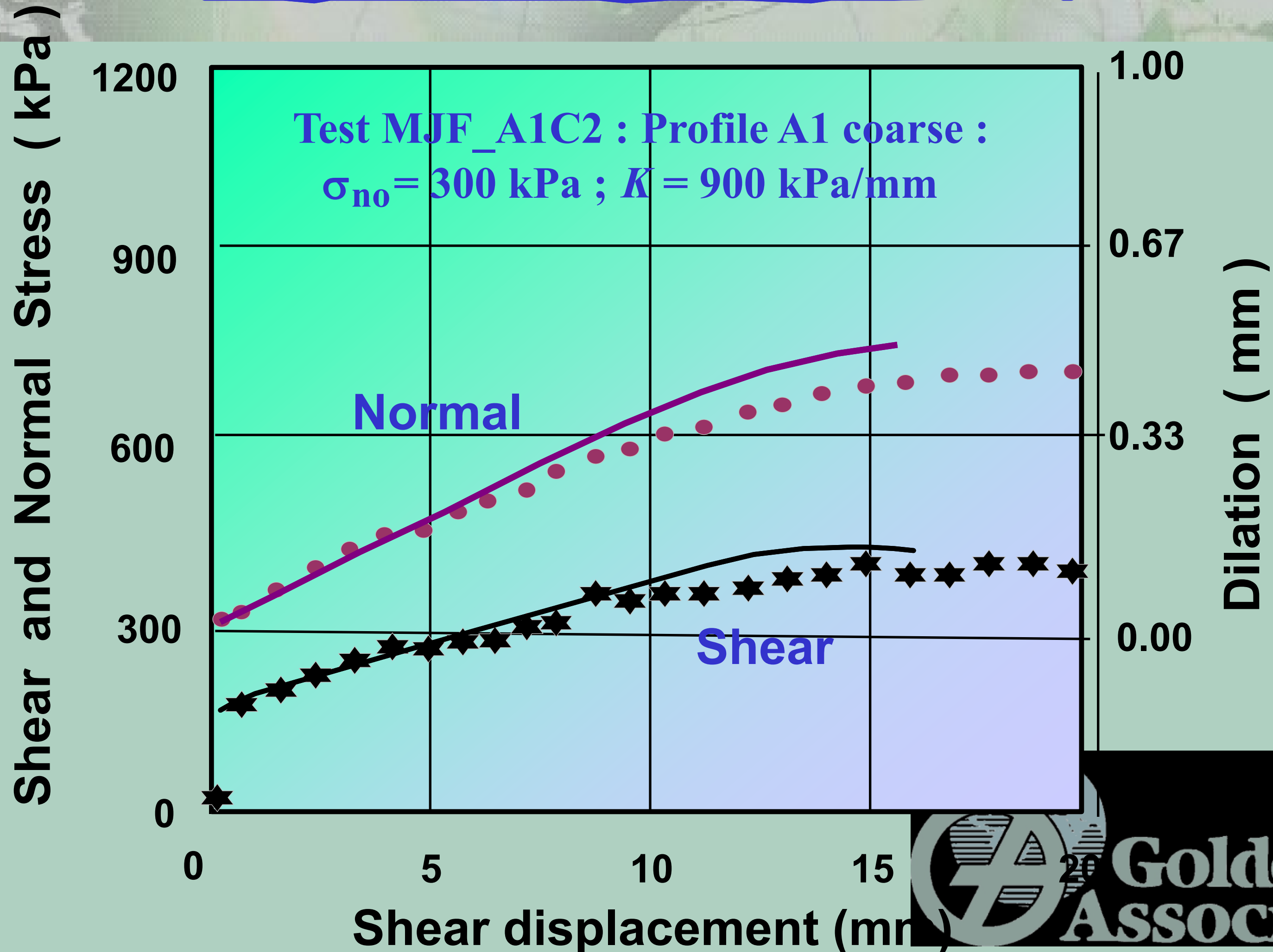
The conditions at every asperity are different

Asperity Deformation and Load Sharing

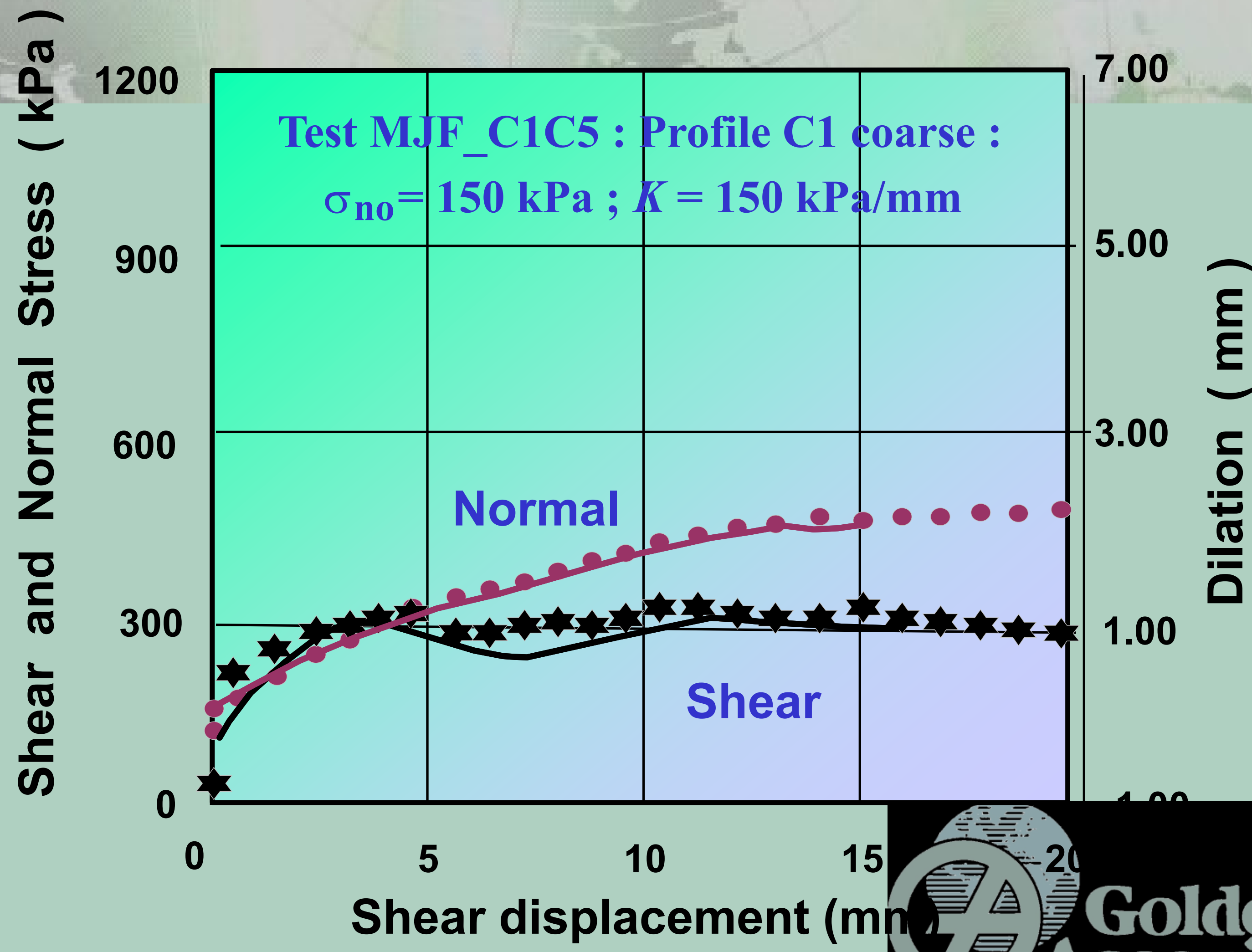


Laboratory Validation : fractal profiles

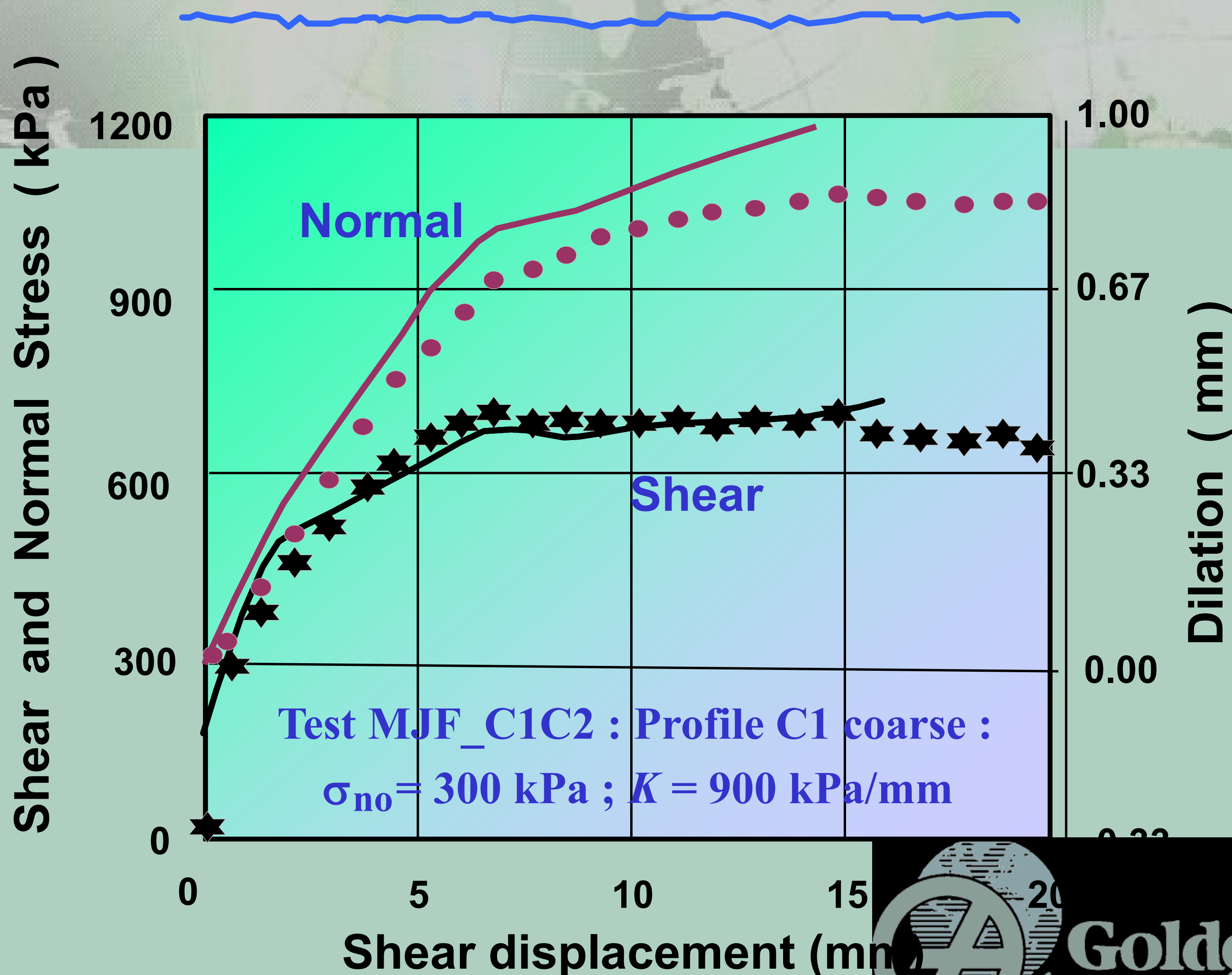
Class A Profile - measured vs predicted



Class C Profile - measured vs predicted

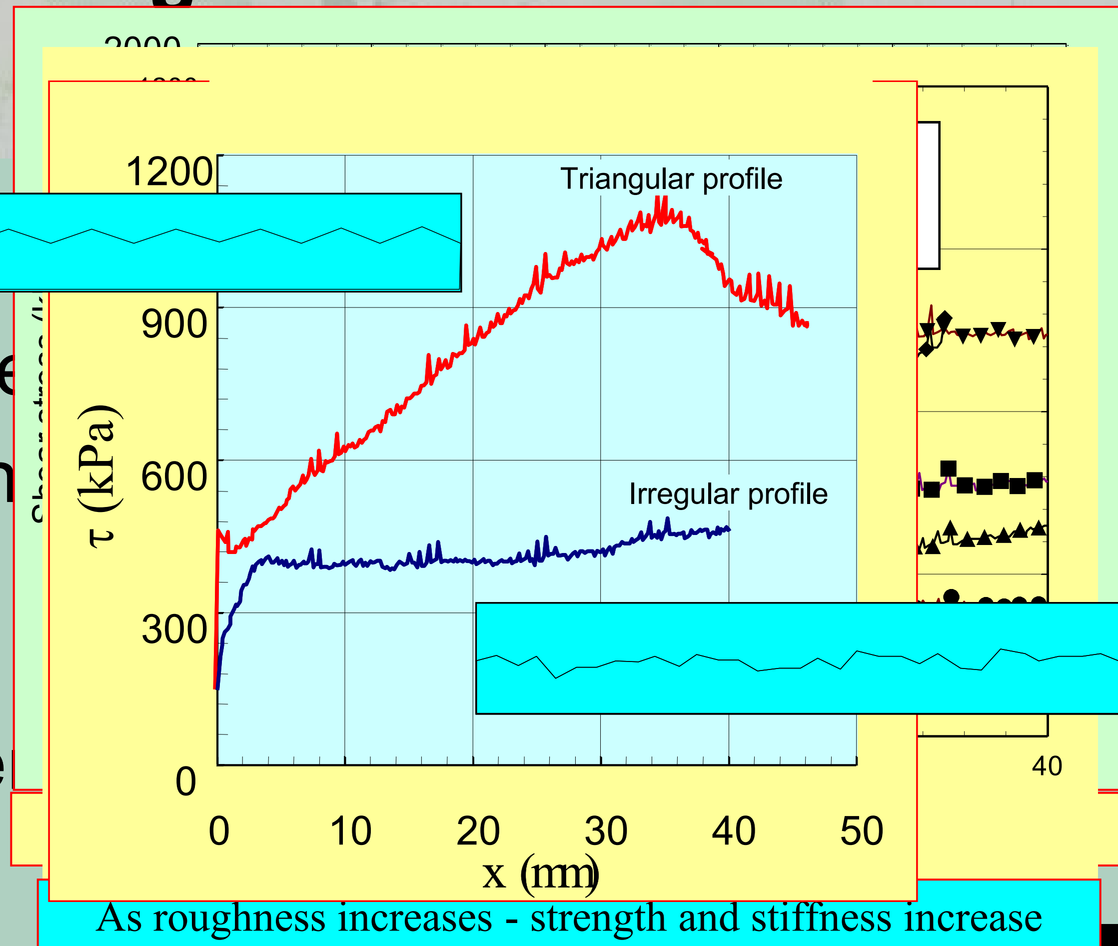


Class C Profile - measured vs predicted

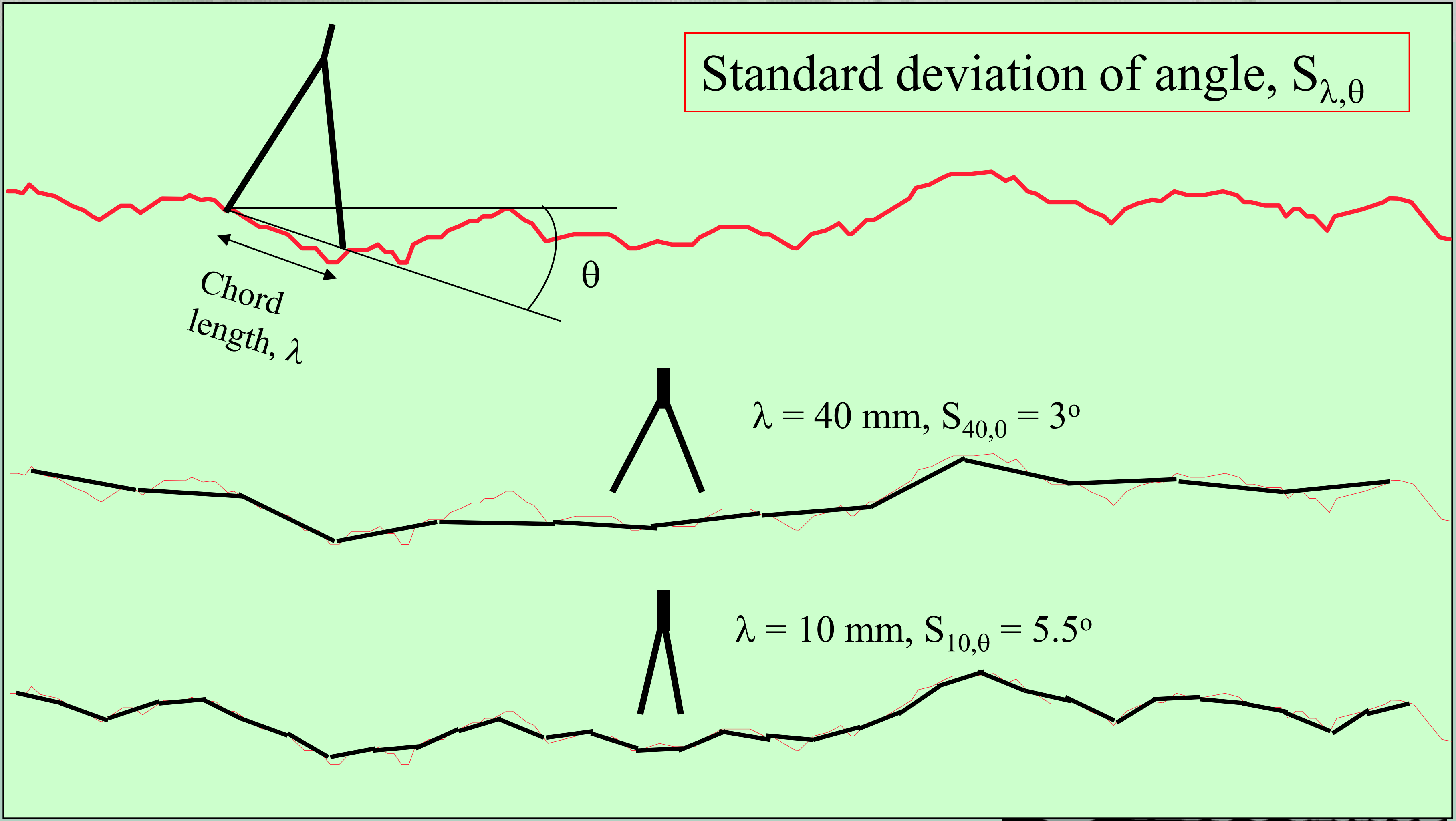


Understanding Roughness

- Impact is
- Shape depende
- Optimal roughn interlock but to dilation
- Scale depende

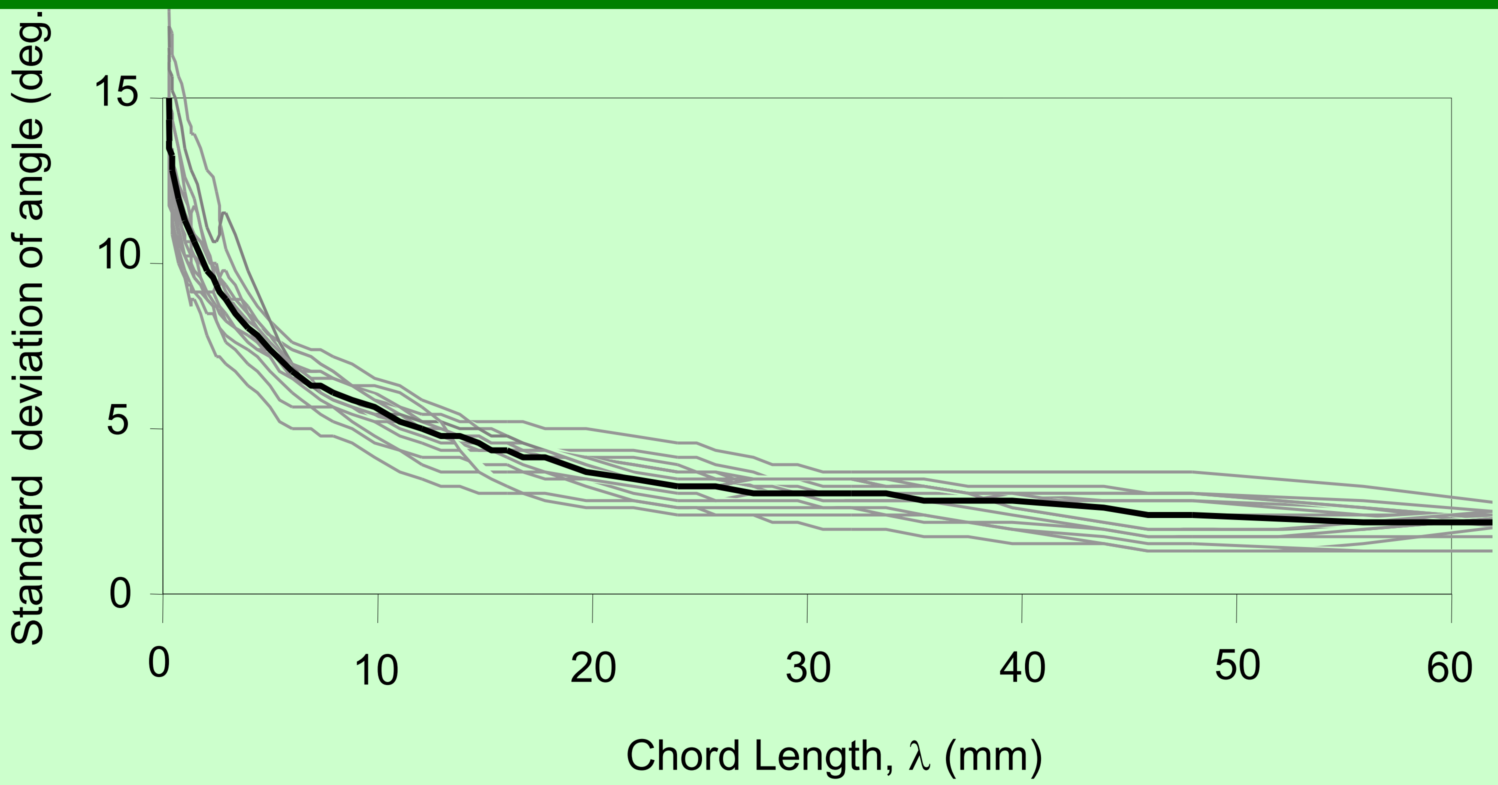


Scale effects



Roughness Parameter vs Scale

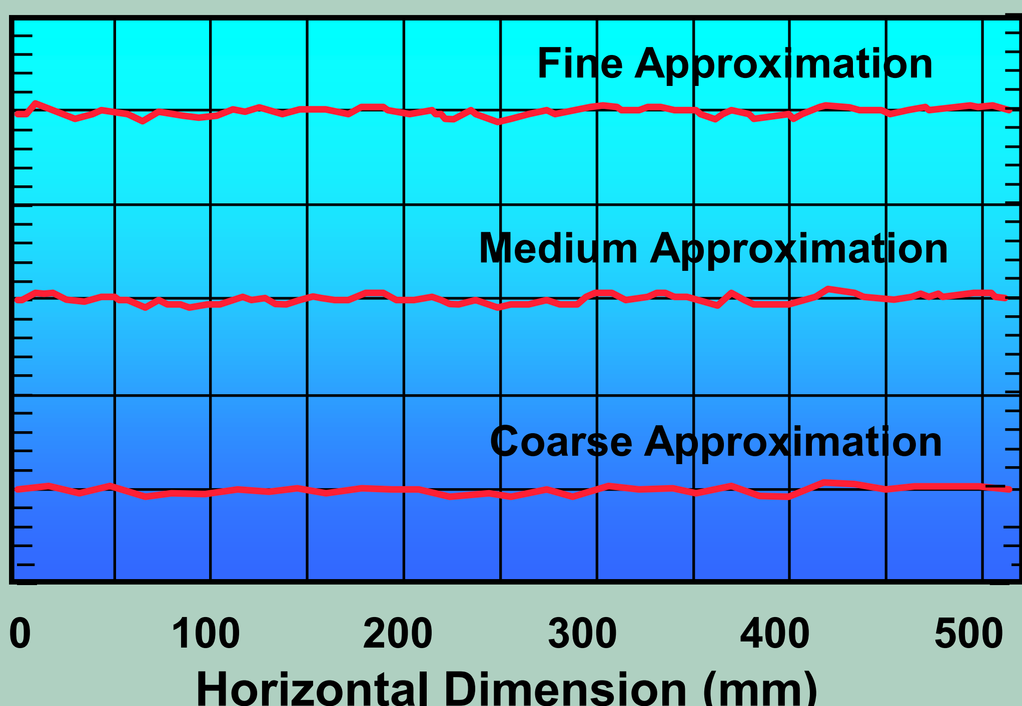
If we want to represent real roughness as a set of statistics - e.g. standard deviation of asperity angle (or height), what length scale (chord length) is appropriate?

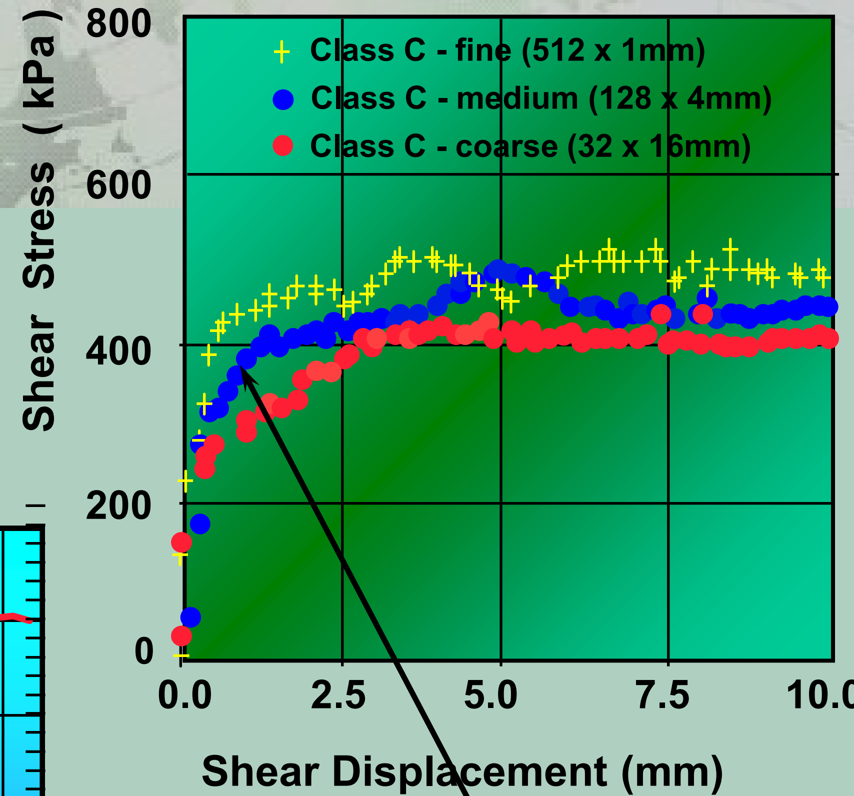


Answer : All scales, but …
in practical terms : it depends on the scale at which performance (often displacement) is being considered.

Some CNS direct shear test results

Coarse, medium and fine approximations of the same profile





- Stiffness is systematically higher for finer profiles
- Peak shear strength does vary systematically

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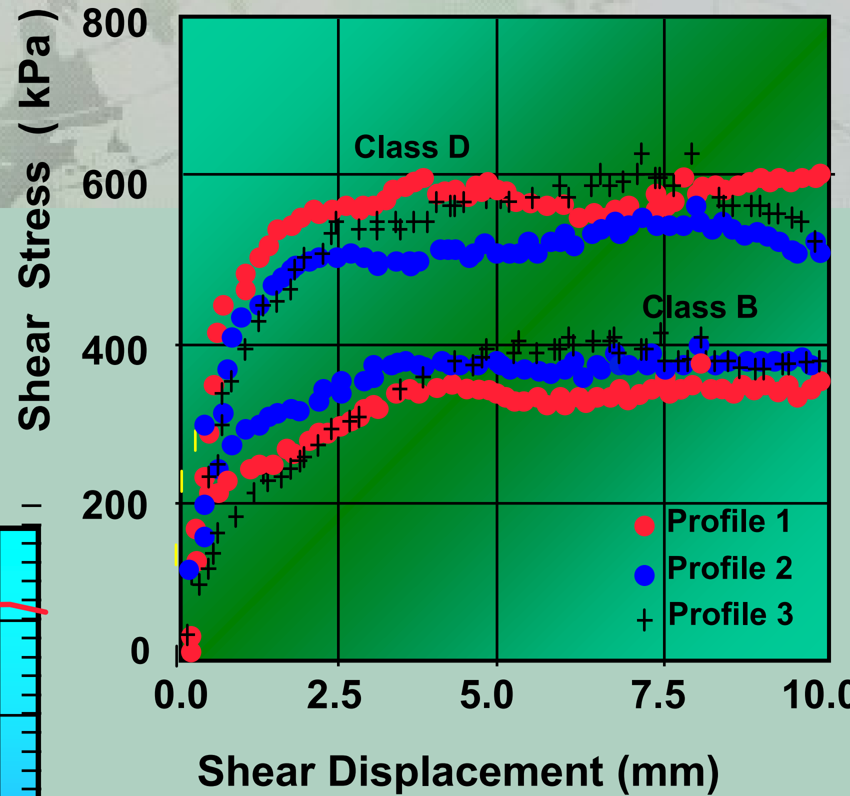
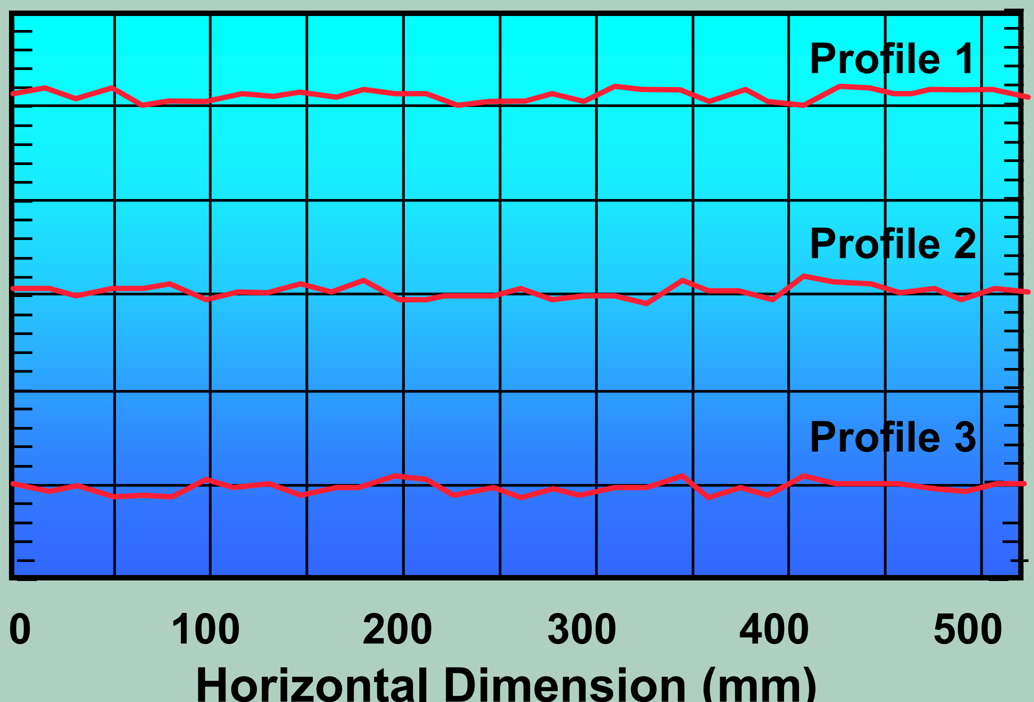
Some more CNS direct shear test results

Profiles with different geometry but similar statistics also perform in an essentially similar manner.





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Impact of Roughness - Summary

- All scales of roughness important
- Small scale roughness impacts on initial stiffness
- Large scale roughness impacts on peak shear strength
- “Grooving” may not be advantageous

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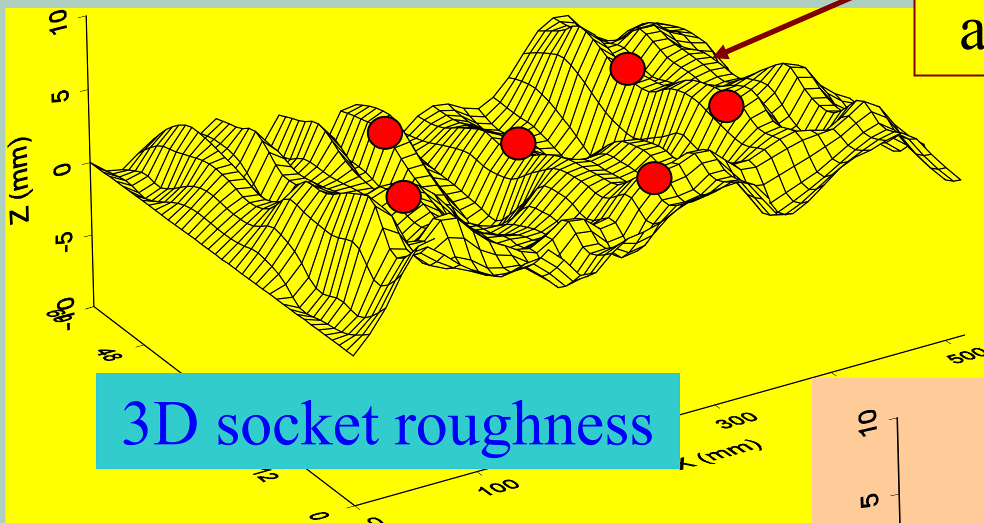
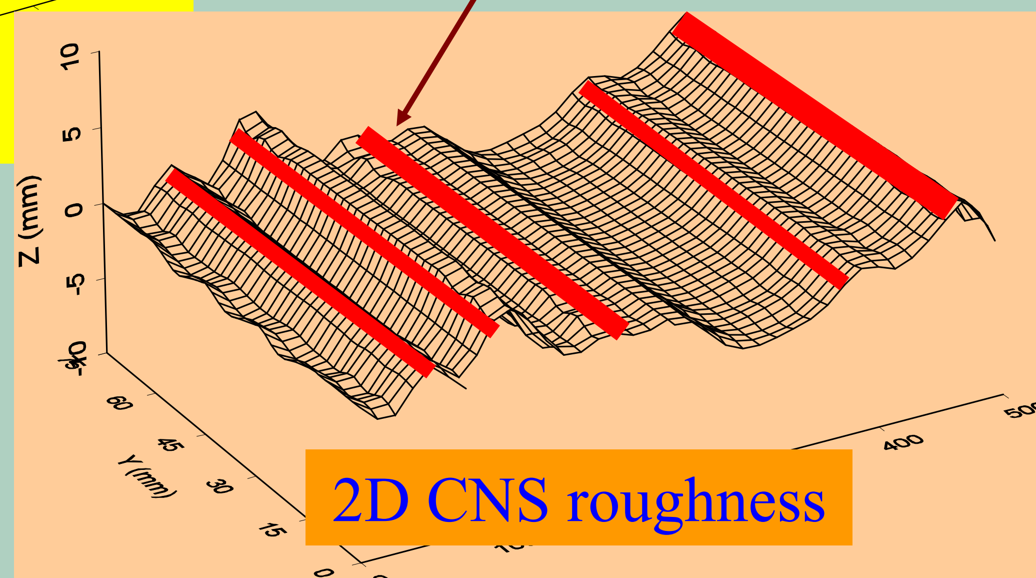
From laboratory test to rock socket

What are differences in roughness?

Patch contact and loading



Strip contact and loading

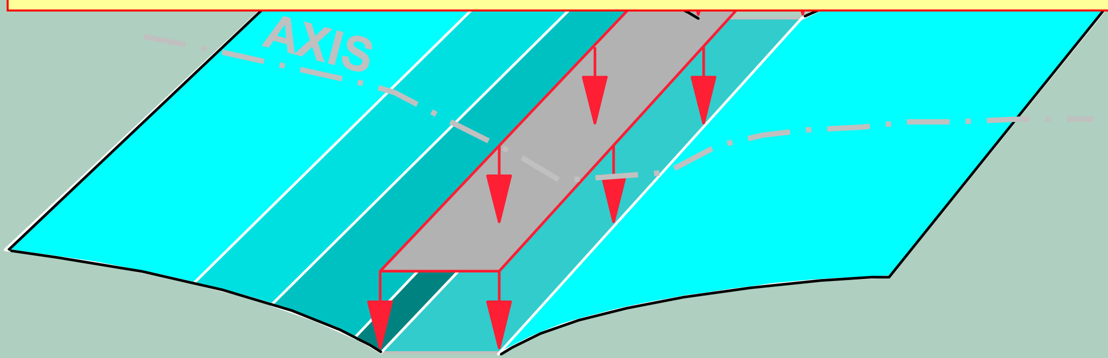


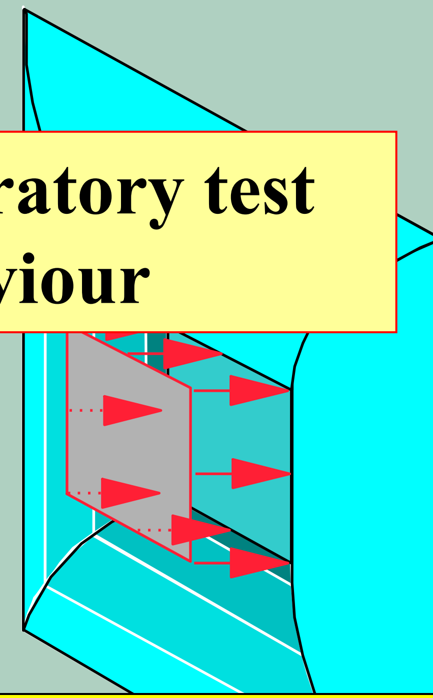
Rock socket roughness is 3D not the 2D approximation used in CNS laboratory testing

From laboratory test to rock socket

Displacements and load sharing between asperities in laboratory sample and field

Take care when extrapolating CNS laboratory test results directly to field socket behaviour





Plane-strain : extensive but moderate deformation effect about loaded strip and along axis of sample. Thickness of sample is finite.

Patch-loading : intensive but localized effect about loaded patch both along pile axis and around circumference. Thickness is infinite.

ROCKET input parameters

- Shear strength parameters - c' and ϕ'
  - drained triaxial tests
  - UCS and Hoek Brown
- Sliding friction angle - direct shear tests.
- Rock mass modulus and Poisson's ratio
  - pressuremeter tests.
  - triaxial tests, correction for jointing ?
  - moisture content correlations, correction for jointing ?
- Socket diameter (structural strength requirements)
- Socket roughness
  - direct measurements
  - back calculated from load tests
- Initial normal stress - estimated

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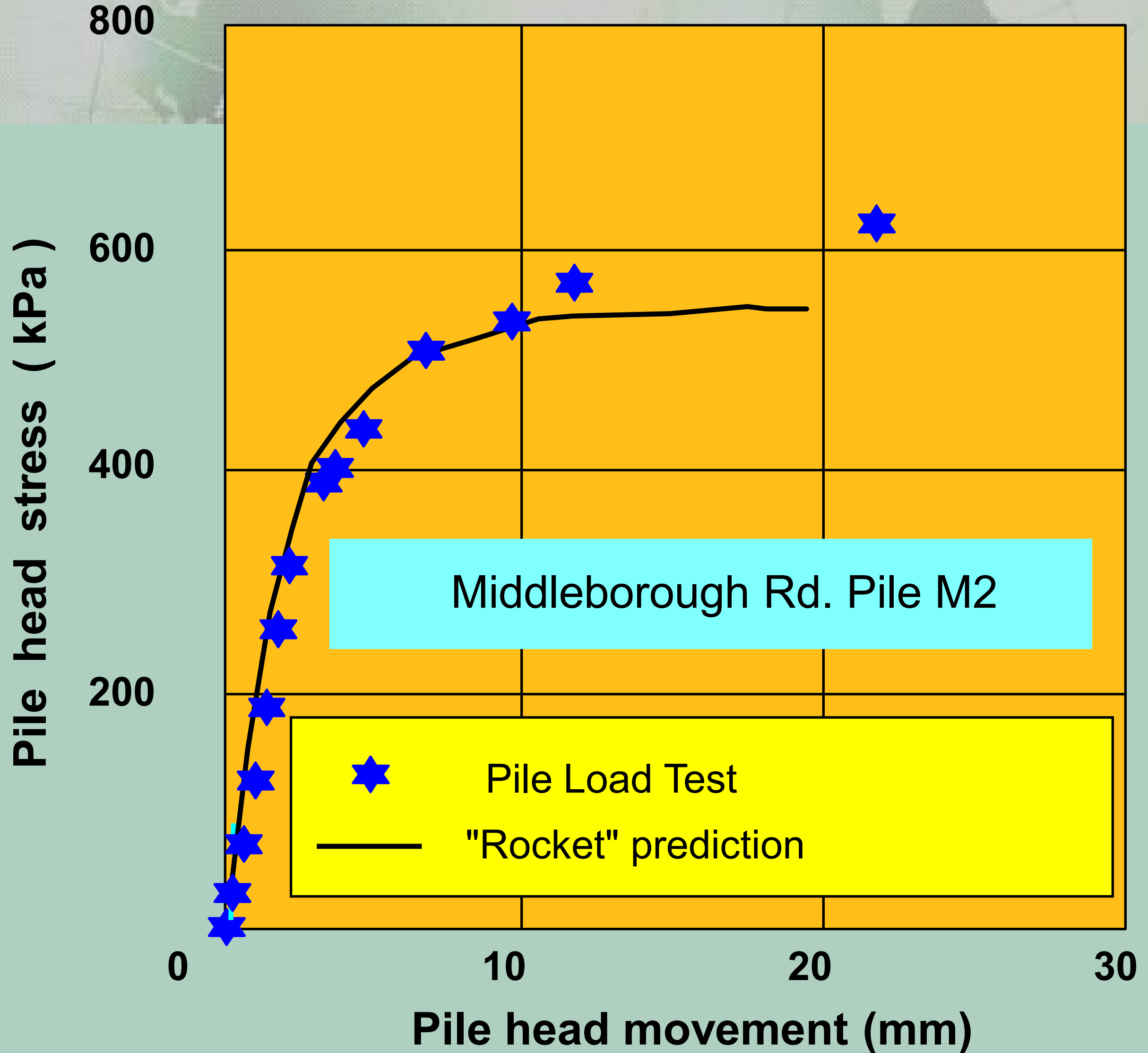
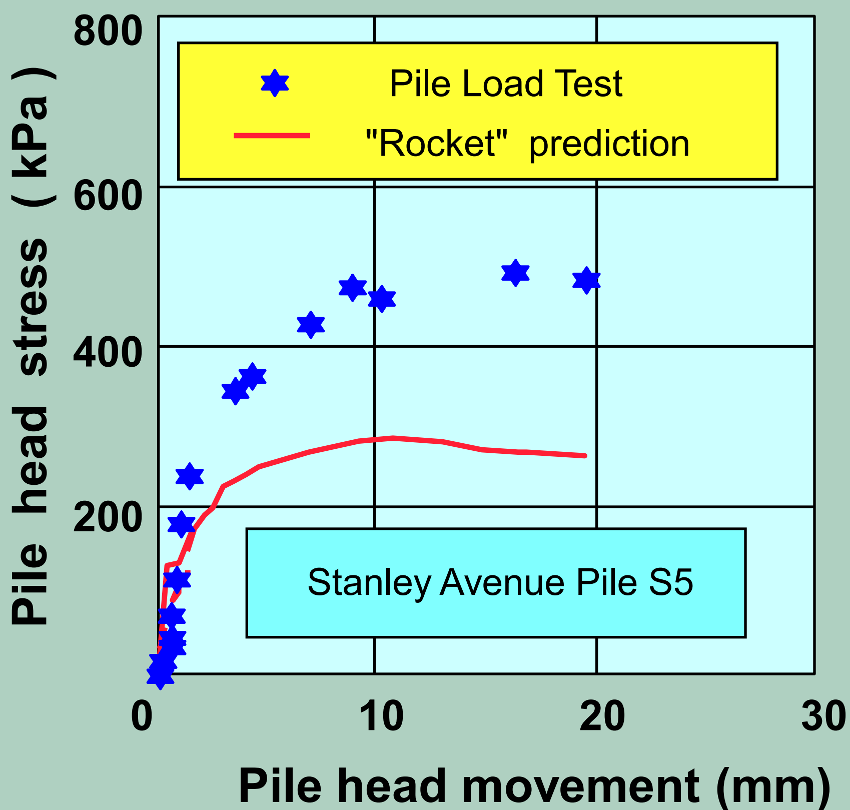
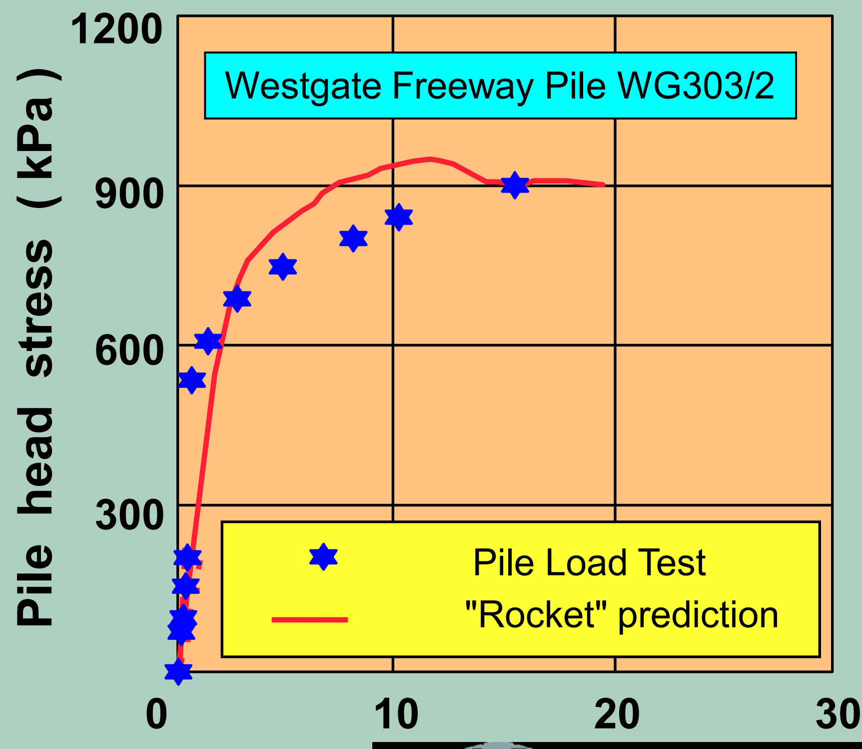
Field Validation



Field validation





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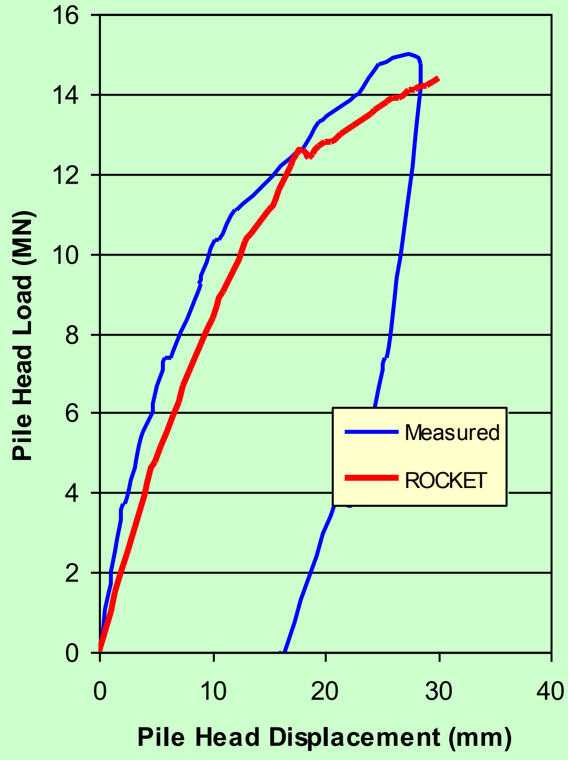
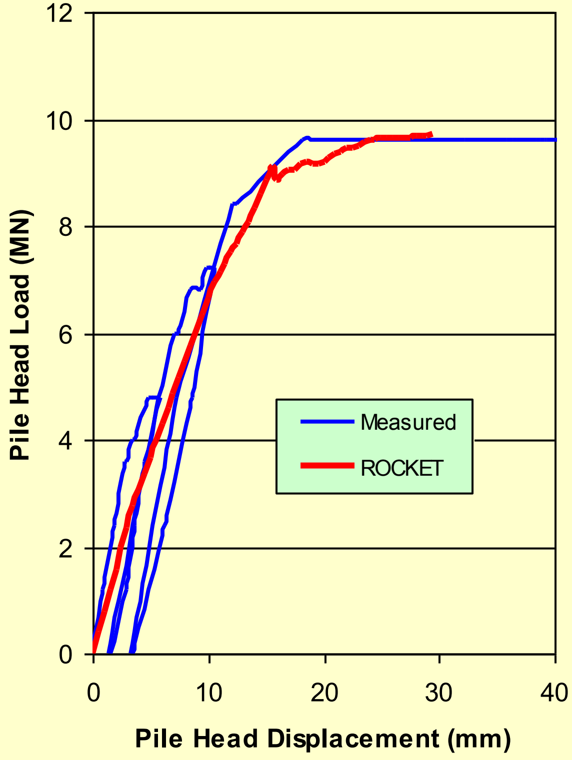
Field validation



(a) TP1



(b) TP2B

Bahrain

9 m sockets in 1 to 2 MPa calcareous siltstone

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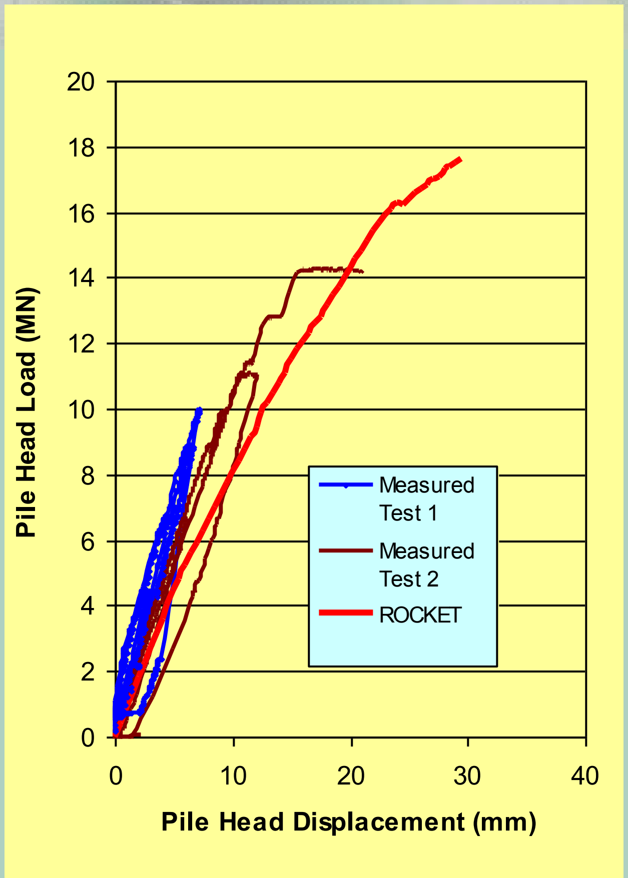
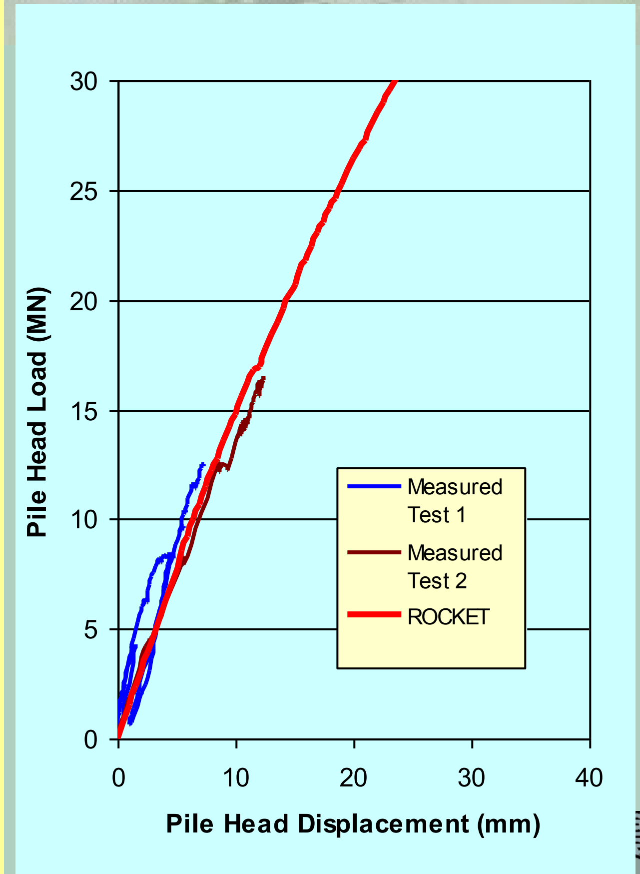
Field validation



(e) TP5



(f) TP6

Bahrain

12 m and 15 m sockets in 1 to 2 MPa calcareous siltstone, toe of 15 m socket in strong limestone

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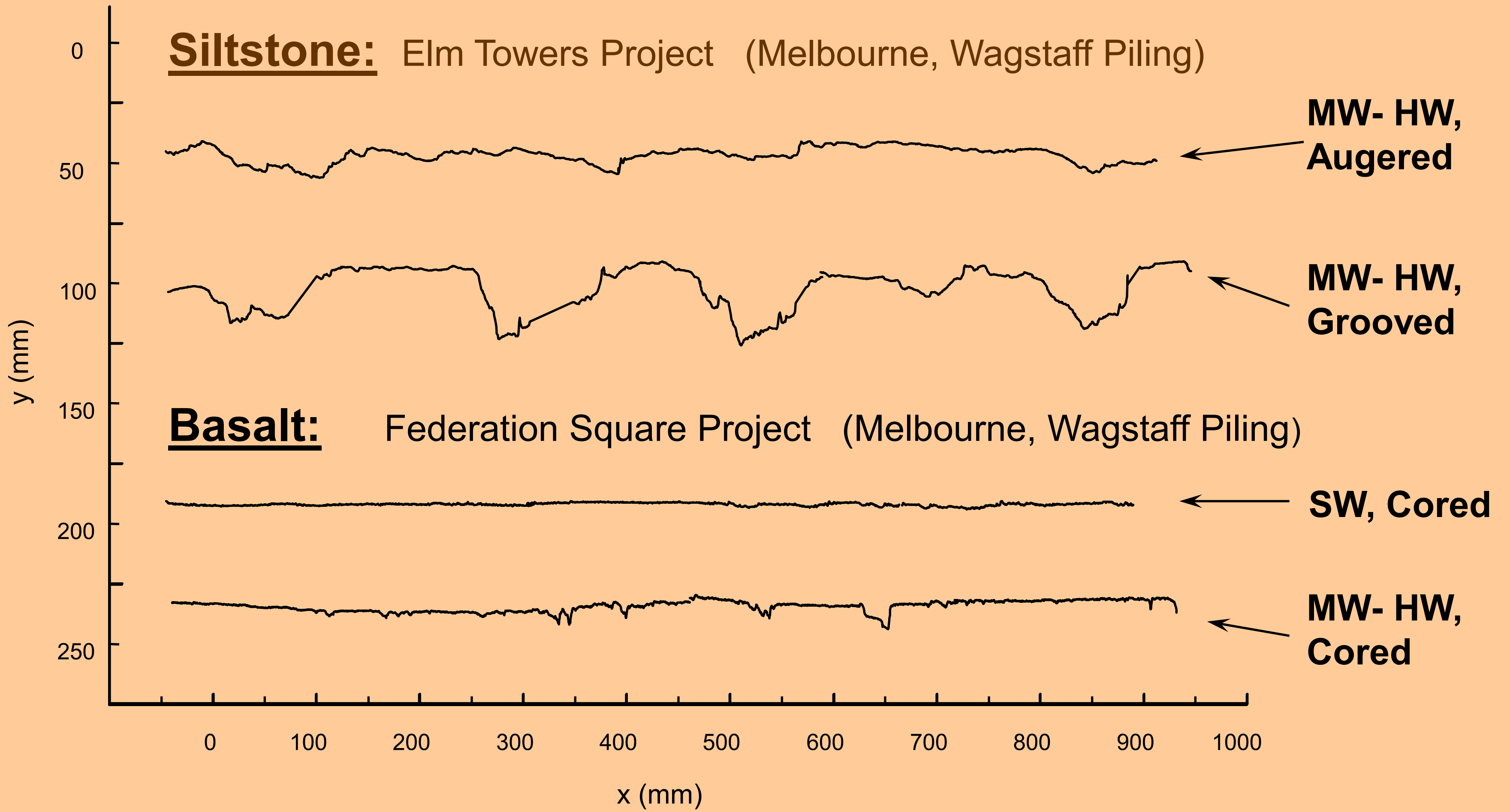
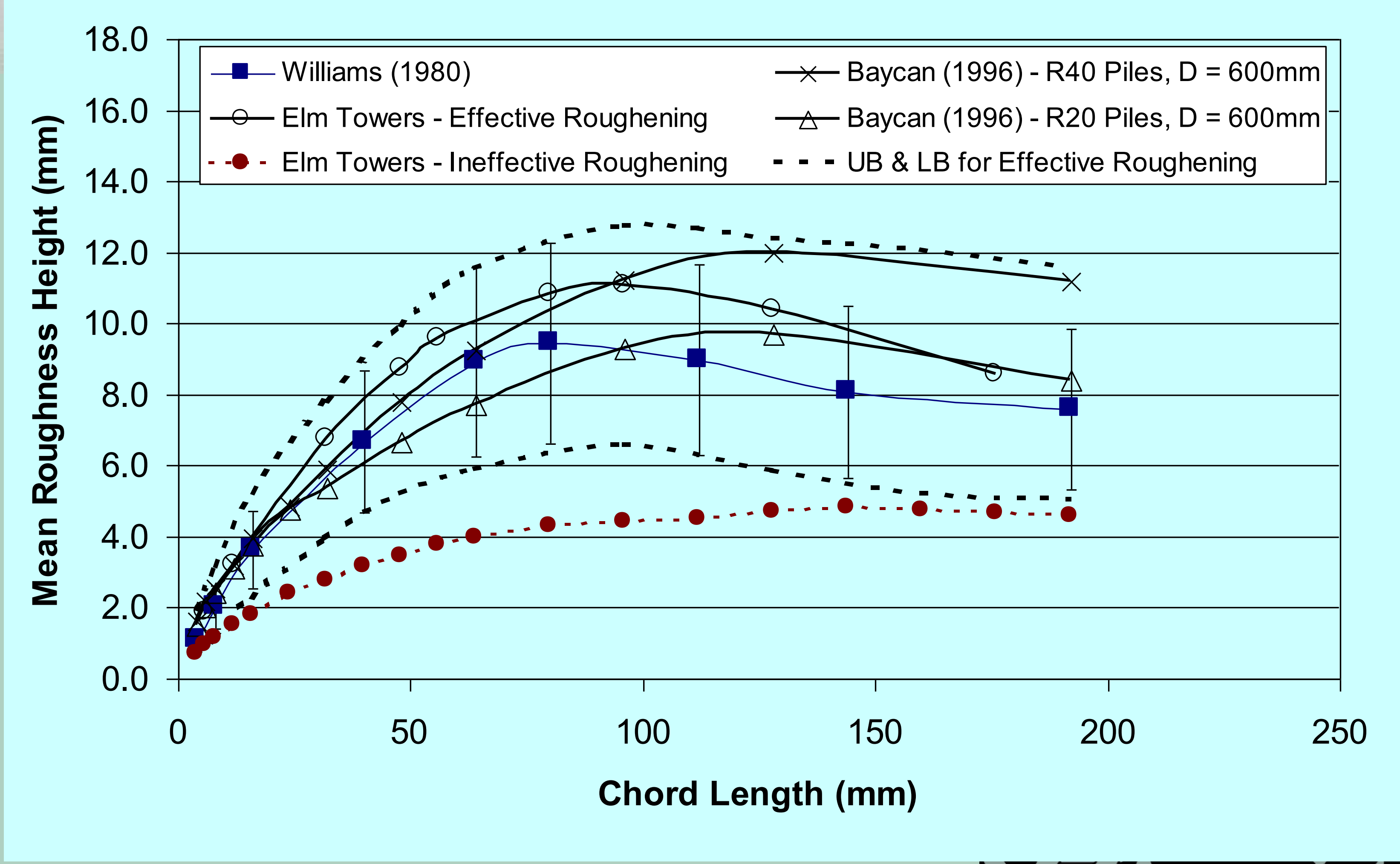
Field measurement of roughness

Example Profiles

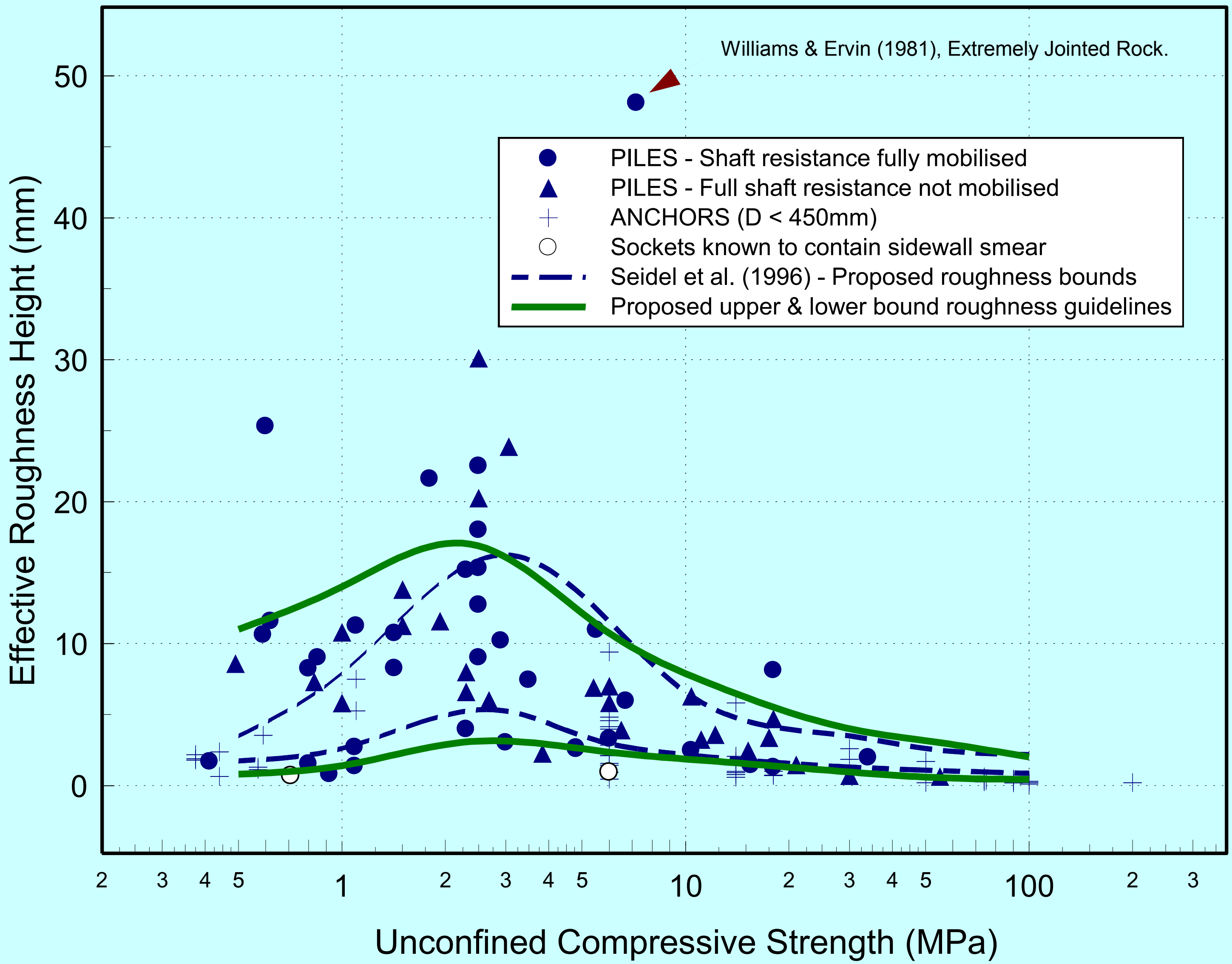


Some results in Siltstone

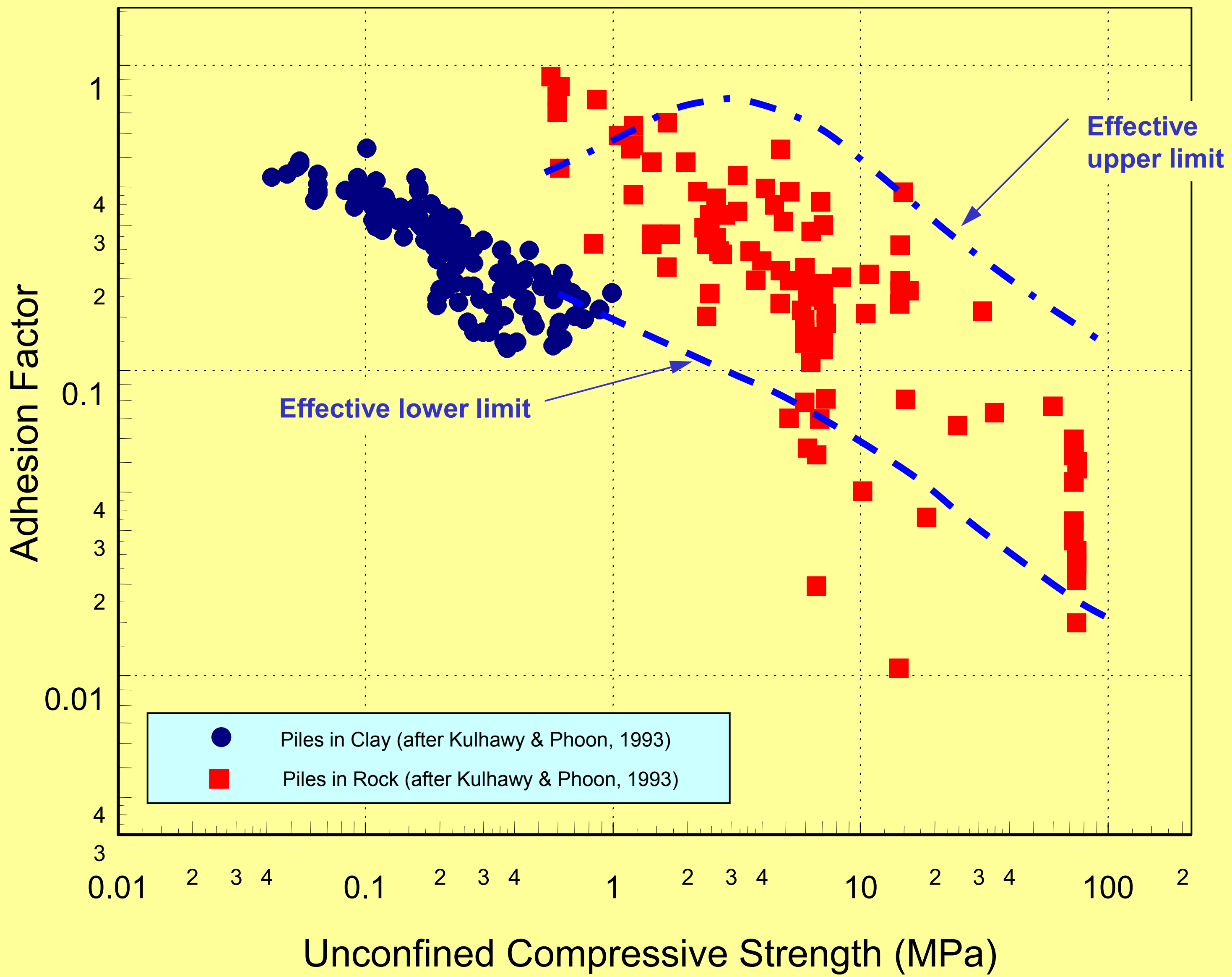


Associates

Back-calculated from pile load tests, λ = 50 mm



Does this explain the empirical load test data ?



Revisit : Paramete... Shaft Resistance

Rock

- type, structure, ...theri...
- strength
- stiffness

Construction

- socket diamete...
- socket roughne...
- socket cle...
- concrete ...
- contractor exp...

Affects normal stiffness and increase in normal stress with dilation

...t strength ...d stiffness

Major impact on interface behaviour wrt stiffness and strength of response

Aff... of ...ies, load ...ring between asperiti...

May impact on soundness and integrity of pile

Affects socket ... stiffness a... stress, asp... load sharing be...

...ction and interaction between asperities

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Summary

- Understanding shaft resistance is of prime importance to predicting rock socketed pile performance
- Shaft resistance is highly dependent on rock properties, socket roughness and construction effects. Socket diameter also has an impact.
- Be aware of differences between CNS laboratory testing performance and field socket performance
- Sockets should be roughened – "grooving" may not be advantageous"

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