When or should ‘advanced’ laboratory testing be ‘routine’

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Geolabs Ltd

7/11/2012 - Doha

‘Routine tests’

- Atterbergs
- Particle size, density, specific gravity
- Compaction, CBR
- Shear box
- Triaxial
  - UU
  - CU
- Permeability
- IL oedometers, Rowe cells
- Ring shear

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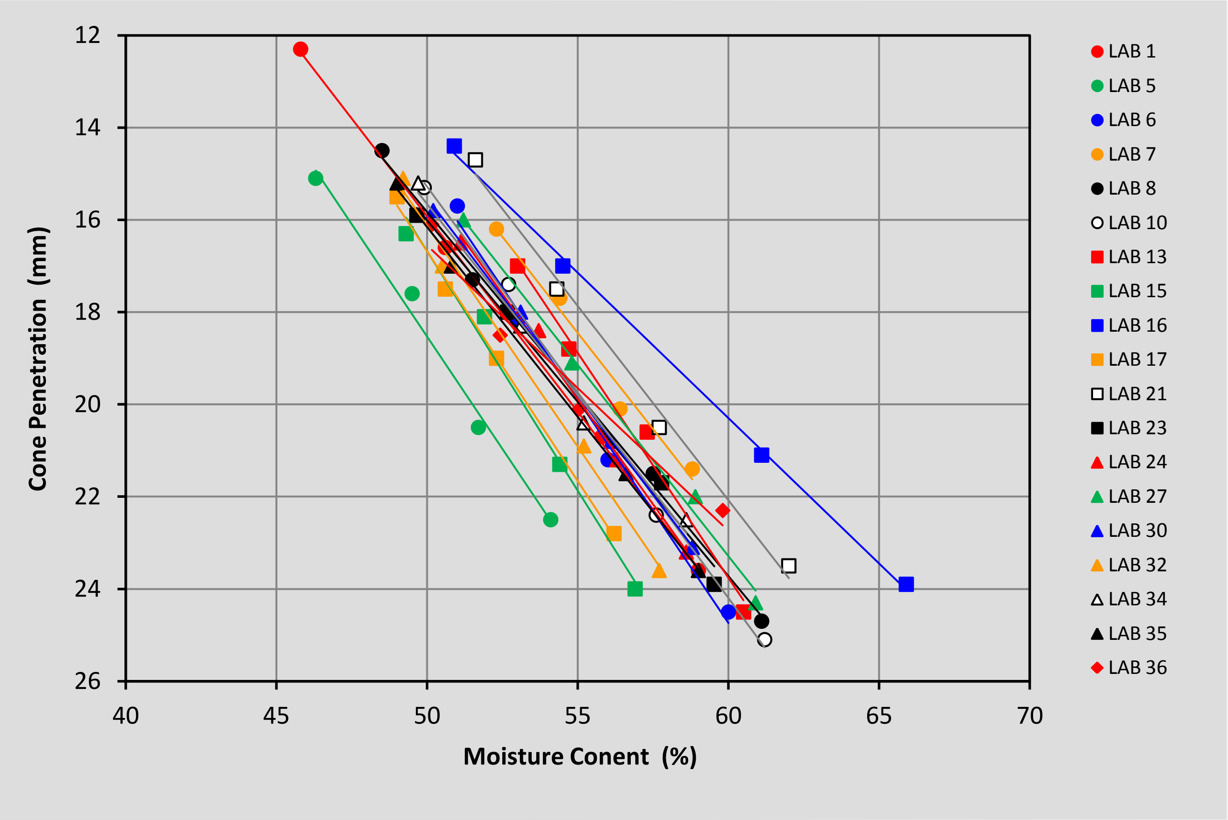
‘Routine tests’

- The profession often have trouble even getting these repeatable and of a consistent quality

Proficiency / Interlaboratory Comparison Testing Scheme



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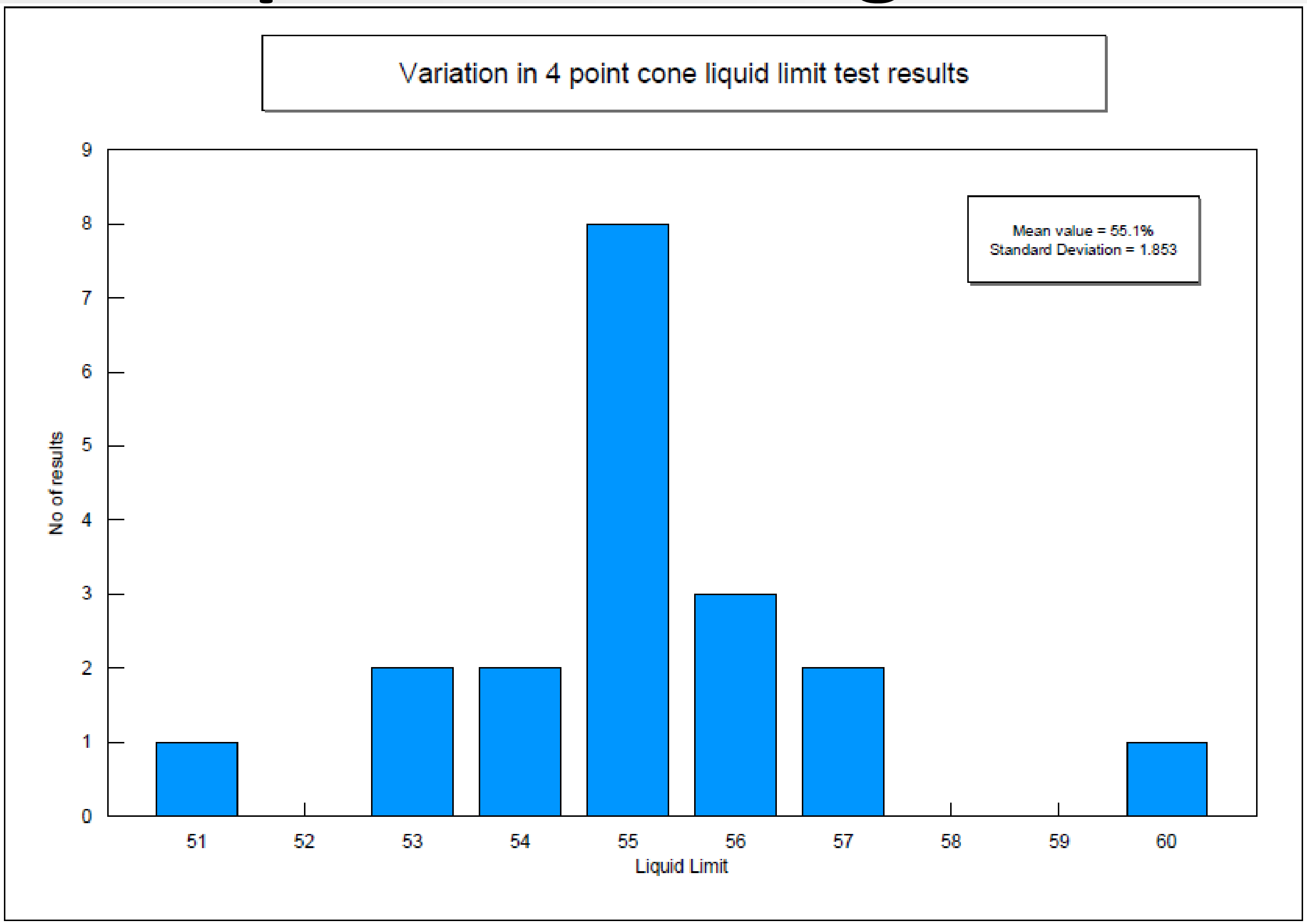
Proficiency / Interlaboratory Comparison Testing Scheme



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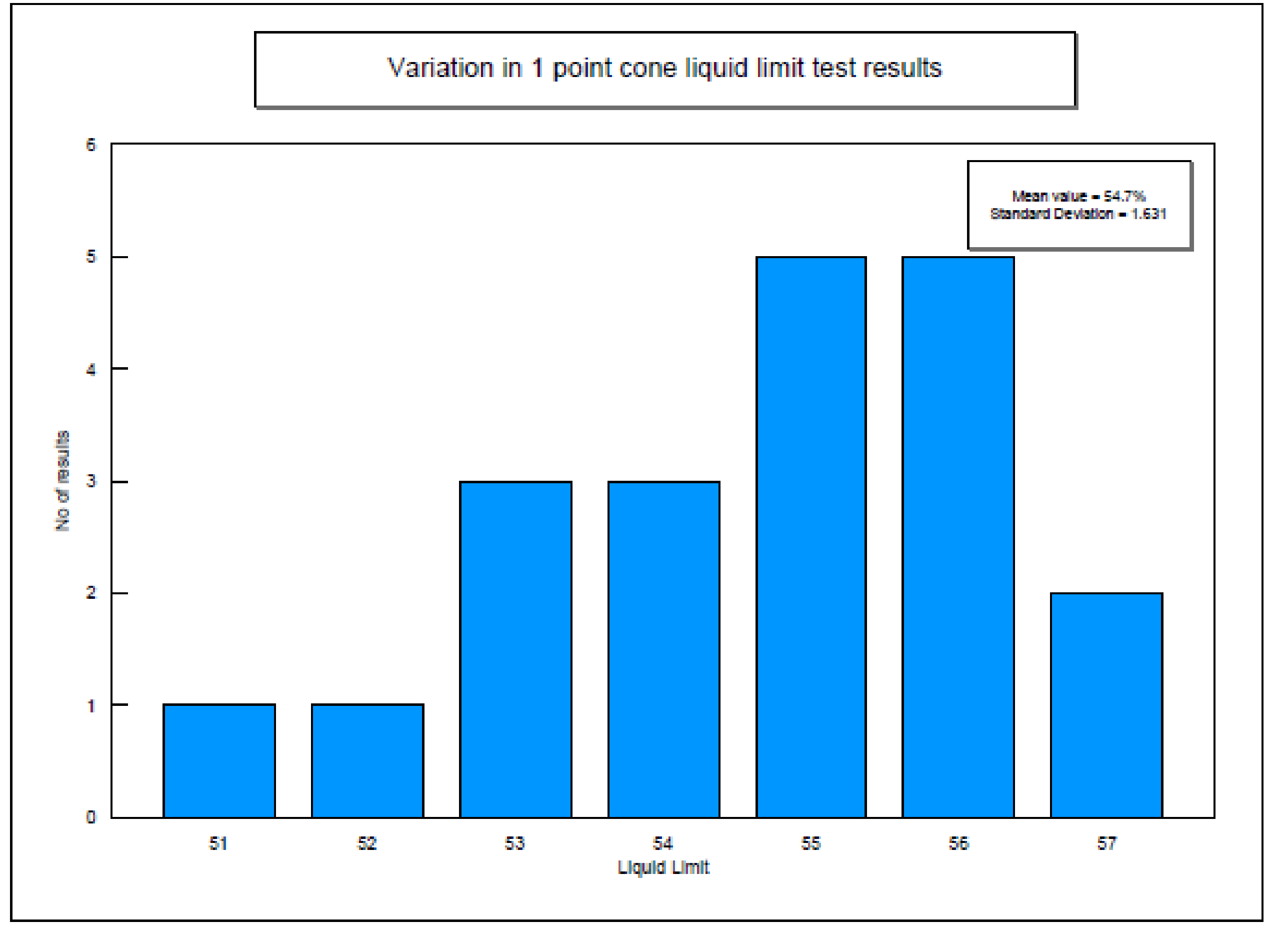
Proficiency / Interlaboratory Comparison Testing Scheme



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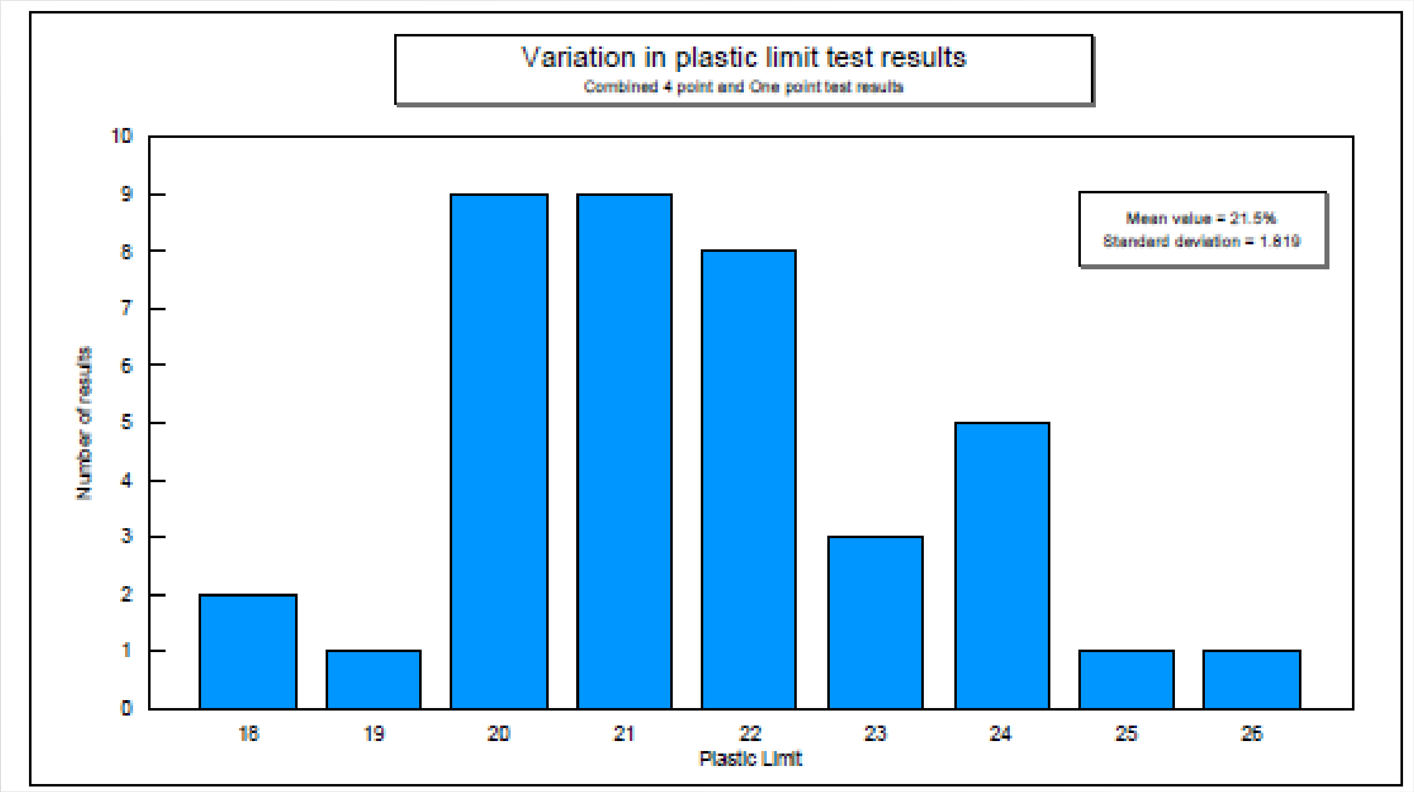
Proficiency / Interlaboratory Comparison Testing Scheme



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Advanced Tests

- Advanced triaxial, (a significant enhancement on the standard effective stress capability); including features such as local axial and radial strain, mid height pwp, piezobenders and anisotropic stress control (CAU)
- Cyclic triaxial
- Cyclic and static simple shear
- Resonant column
- Don’t forget the CRS oedometer
- And more

But first

- So you want to get reliable parameters for your design using laboratory testing!
- So you need samples, but not just any old samples, they need to be representative in terms of structure and composition
- Sample Quality!

Eurocodes (love them hate them)

- Recognises the need for sample quality

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Quality and QA

- Quality in sampling
- Quality in transport and storage
- Quality in preparation and testing
- Quality in reporting

- Quality throughout!!

- All rely on Quality in equipment and personnel!!!

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Samples

- Varying levels of disturbance!

Tube sampling

Sources of disturbance

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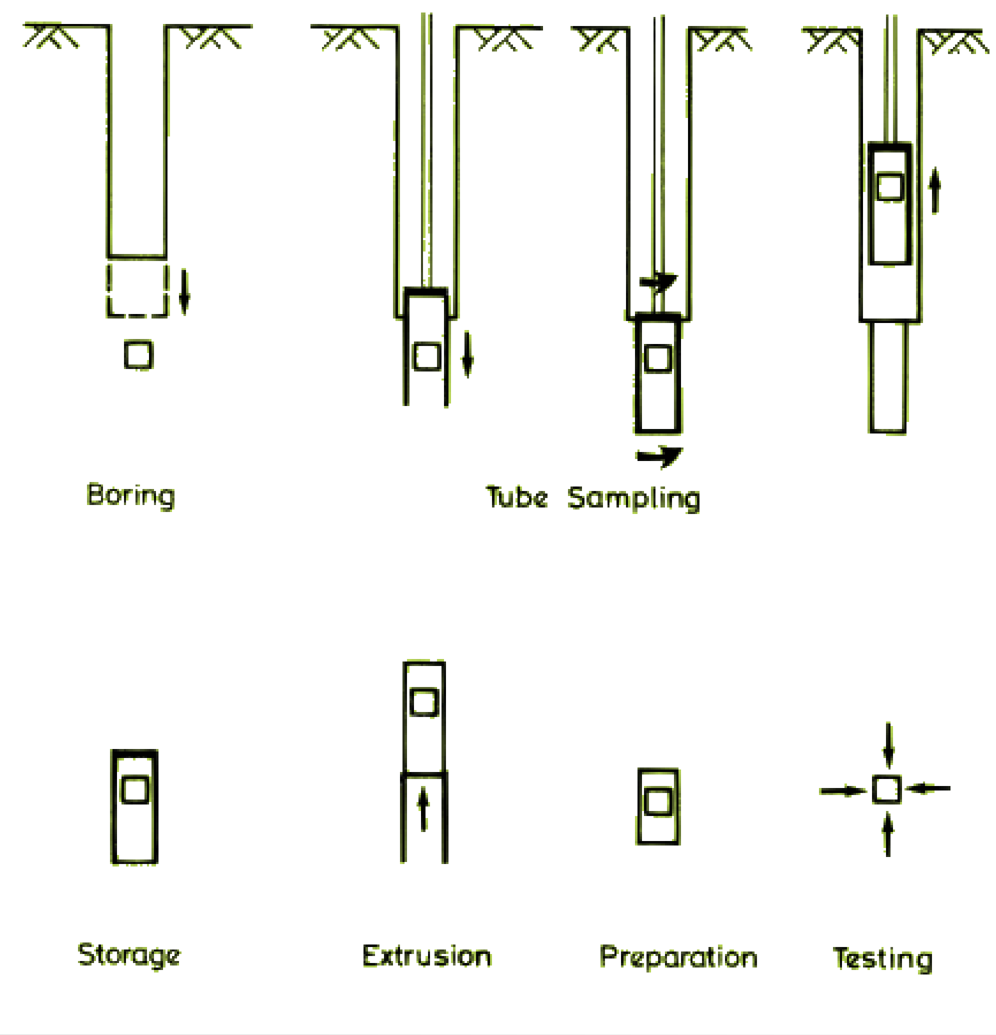
Stages in sampling and preparing soil specimen for laboratory test



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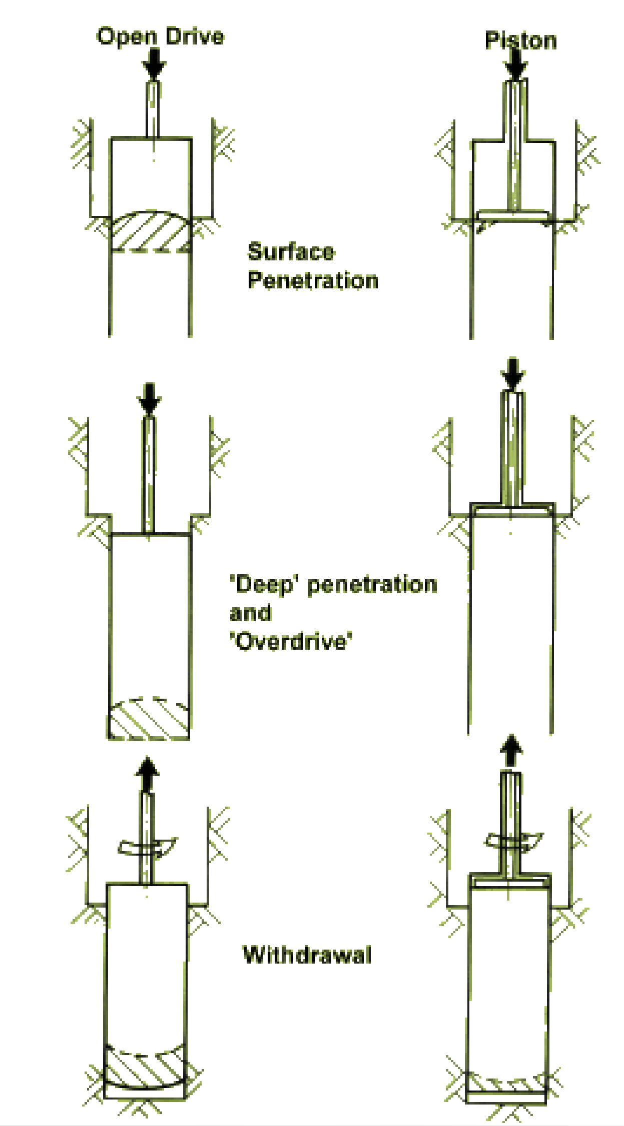
Sources of tube sampling disturbance



Open drive and piston

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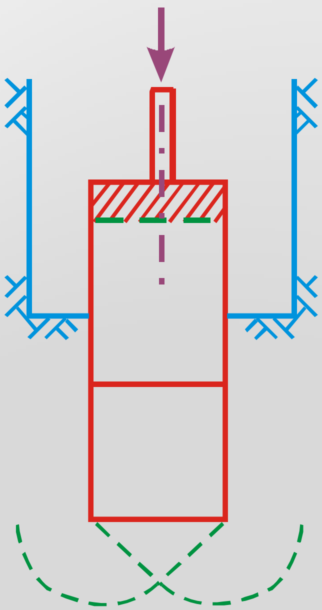
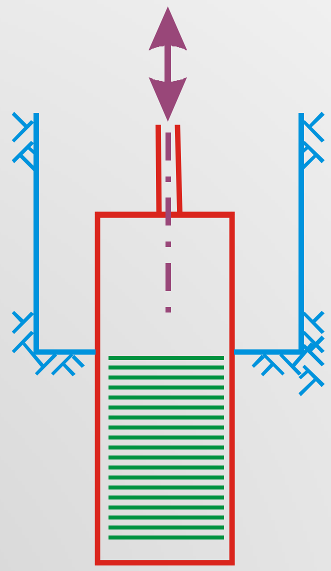
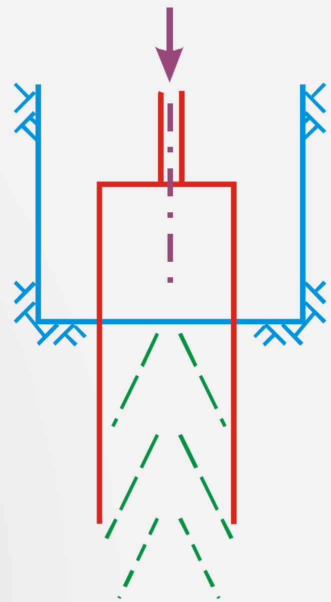
Sources of tube sampling disturbance



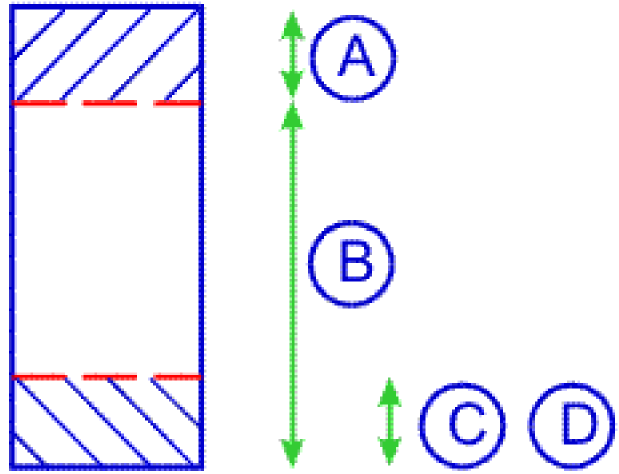
Plugging



Jarring



Indentation fractures



(A) Surface Penetration

(B) 'Deep' Penetration

(C) Over - driving

(D) Withdrawal

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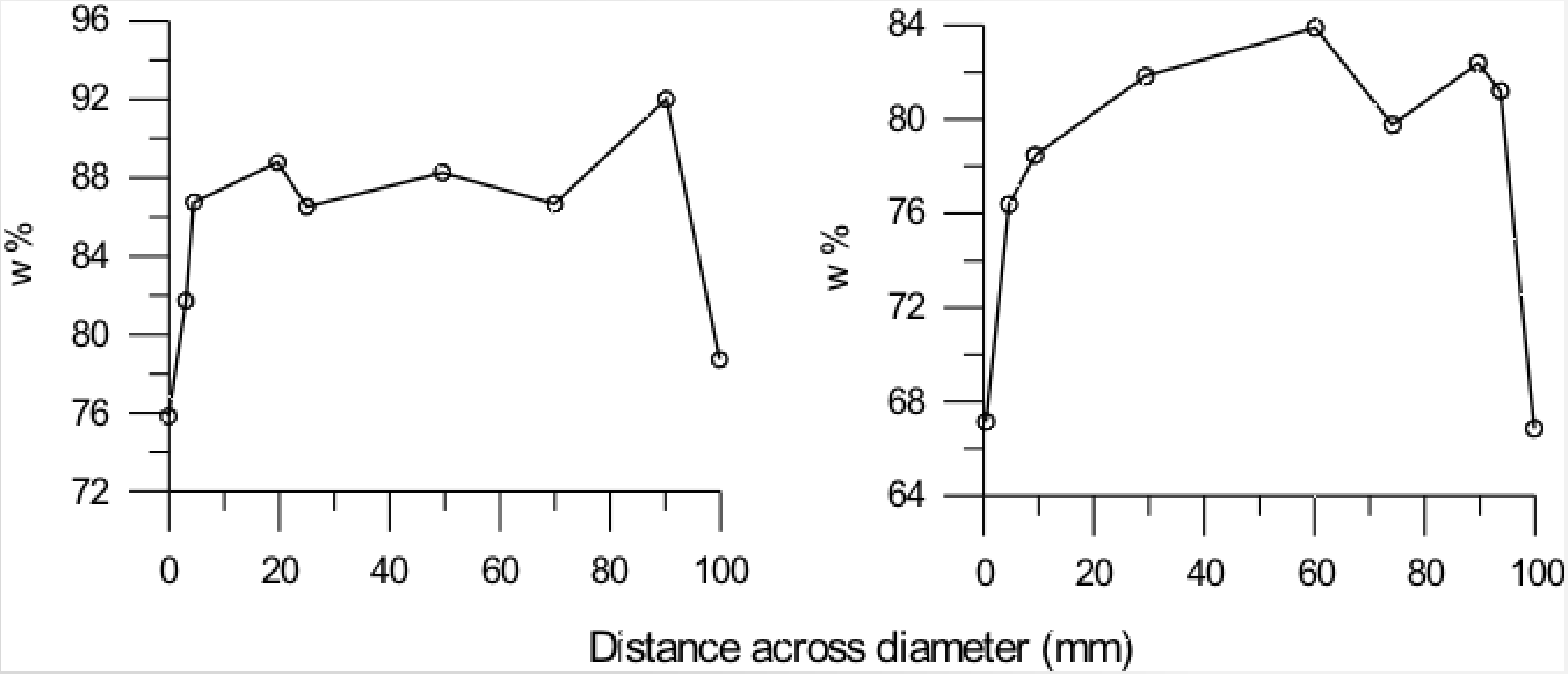
Measured water content distributions across the diameter of tube samples of soft clay



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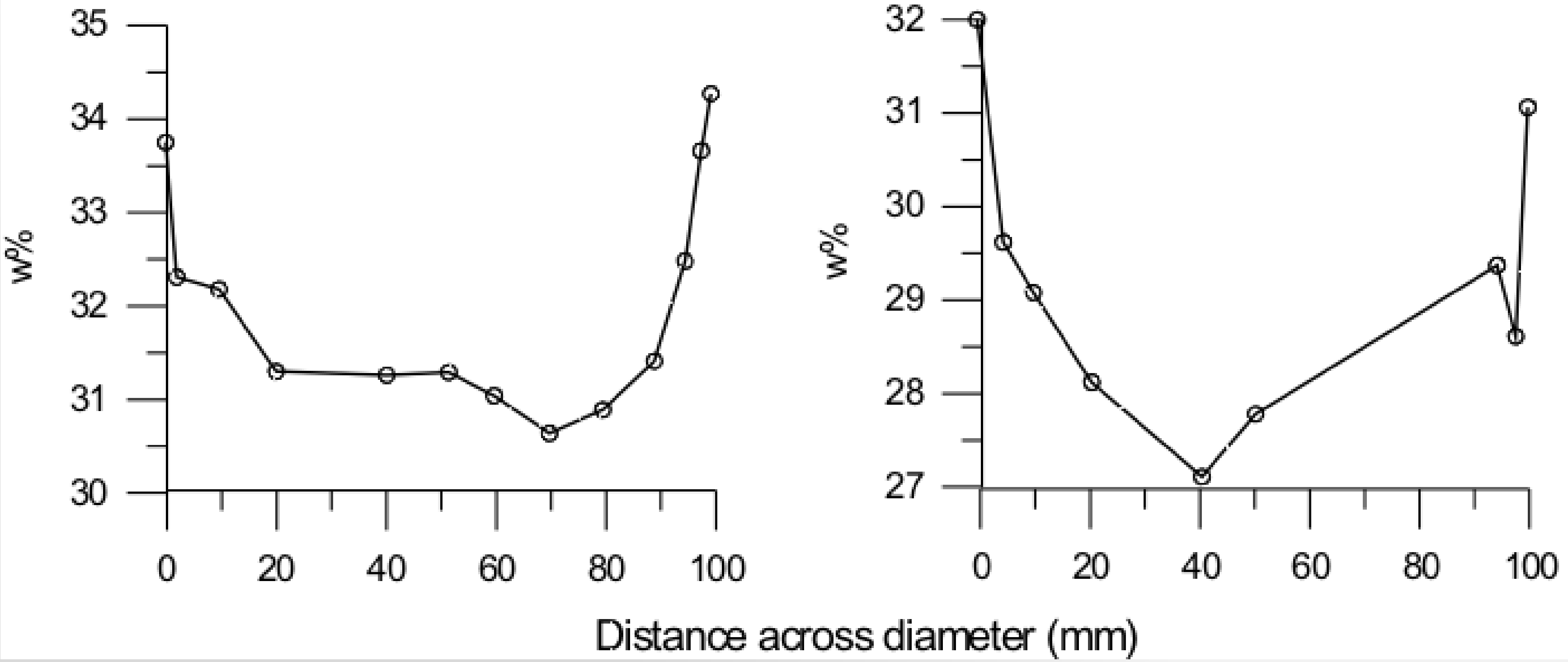
Measured water content distributions across the diameter of tube samples of heavily overconsolidated plastic clay



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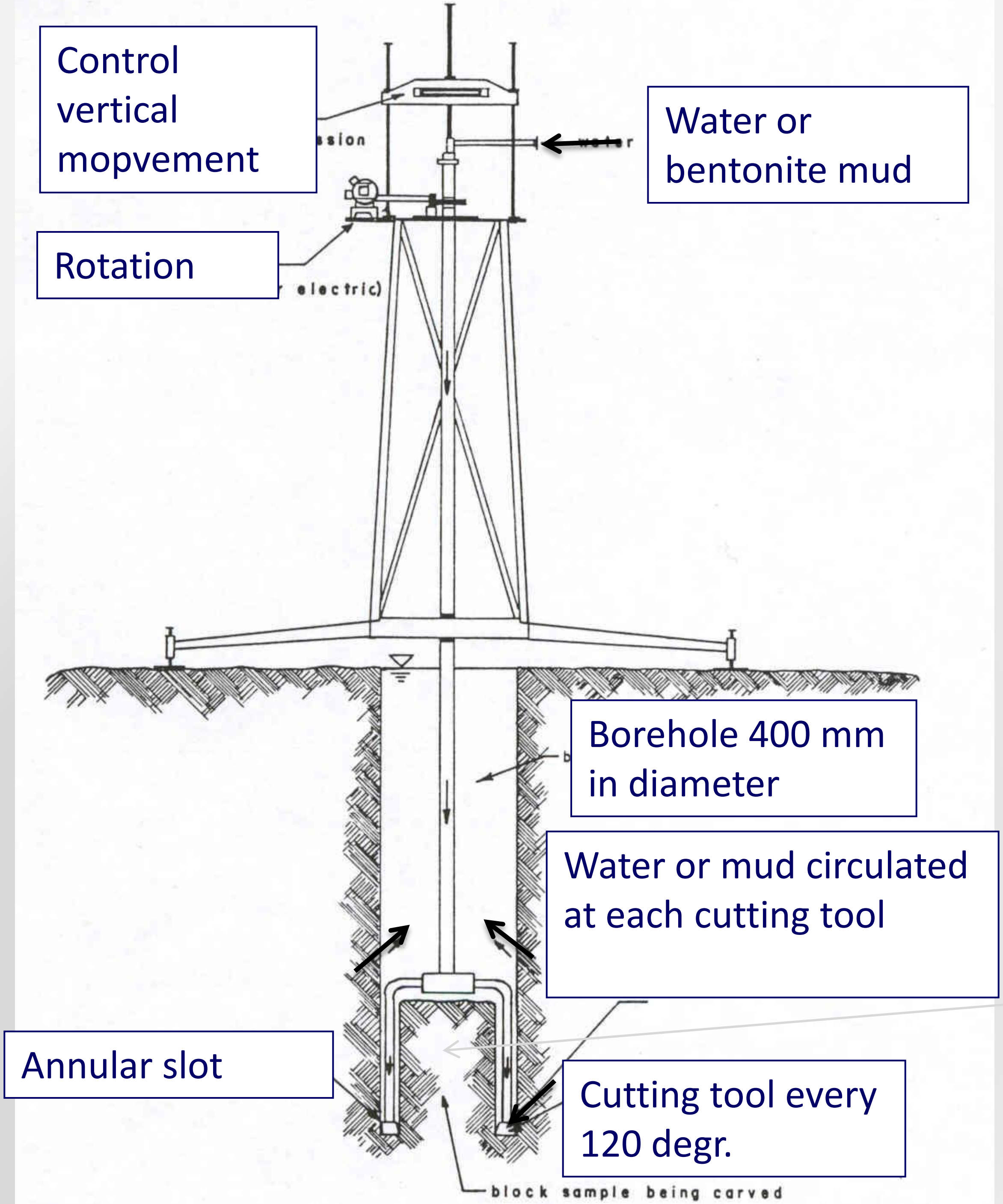
Sampling effects in soft clays

Canadian Sherbrooke block sampler



No tube sampling strains!!

Block sample being carved out

Block sampling with Sherbrooke sampler

Block sample cleaned and wrapped in plastic cling film

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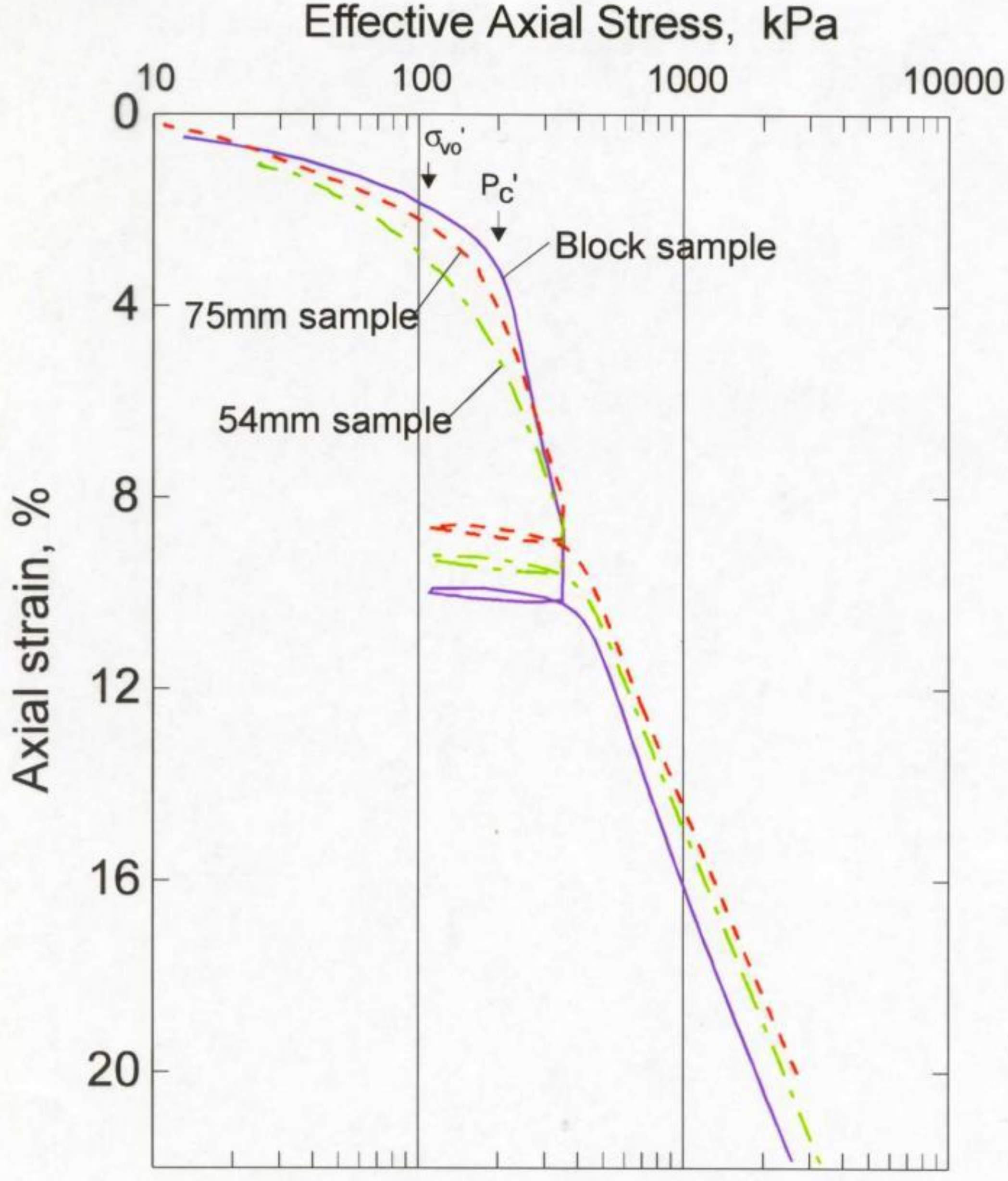
Effect of structure of natural clays

- All natural clays have developed *some* structure
- Degree of structure can be assessed by comparing behaviour of an undisturbed sample to that of a remoulded clay (eg. in oedometer tests)
- Soil structure is a result of several processes including, but not limited to: secondary compression, thixotropy, cementation, cold welding between soil particles (ageing--)
- Effect of sample disturbance is to partly or fully break down the structure of the soil sample – parameters measured by lab tests may not be representative for in situ conditions

Results of CRS tests



Lierstranda clay 12,3 m depth

Semilogarithmic scale

Clearly block sample gives a more stiff behaviour showing less sample disturbance

Better definition of preconsolidation stress, p_c'

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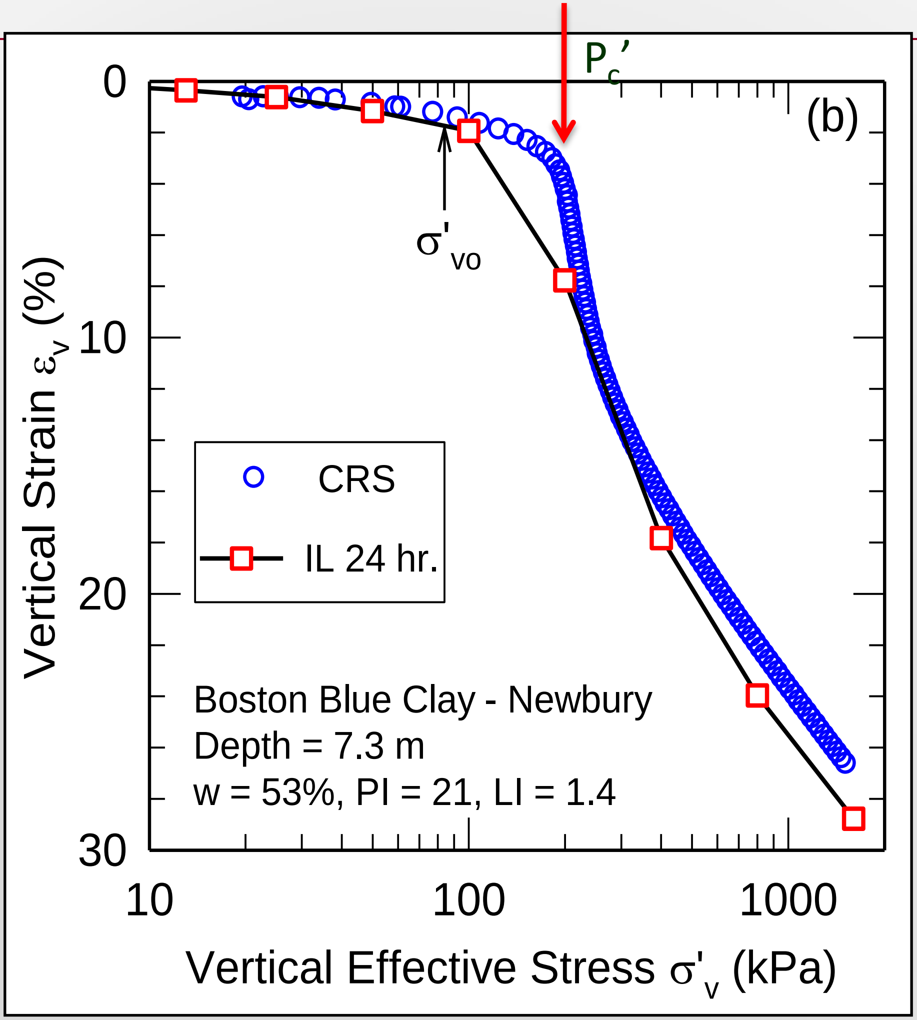
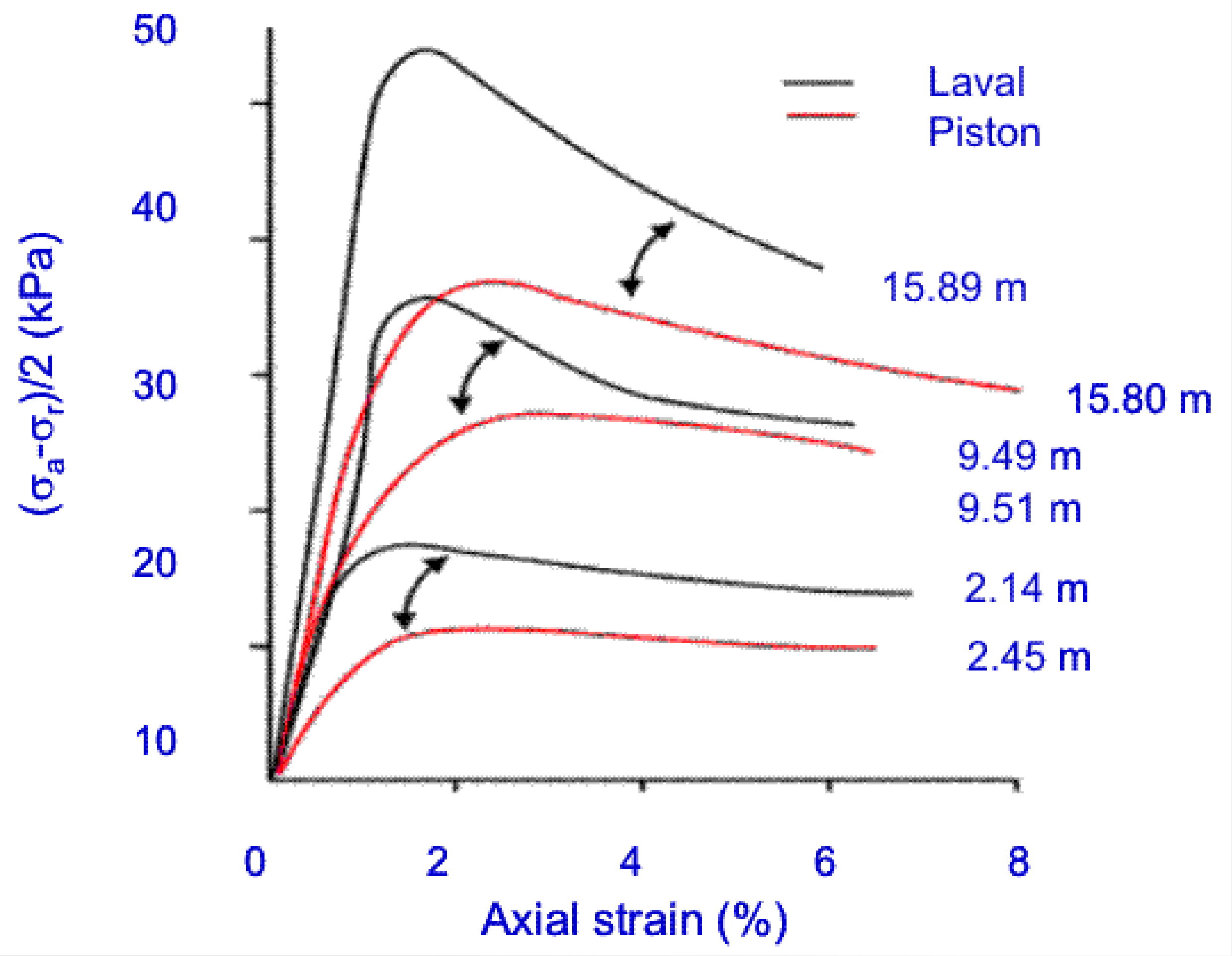
Comparison of IL and CRS Consolidation Data



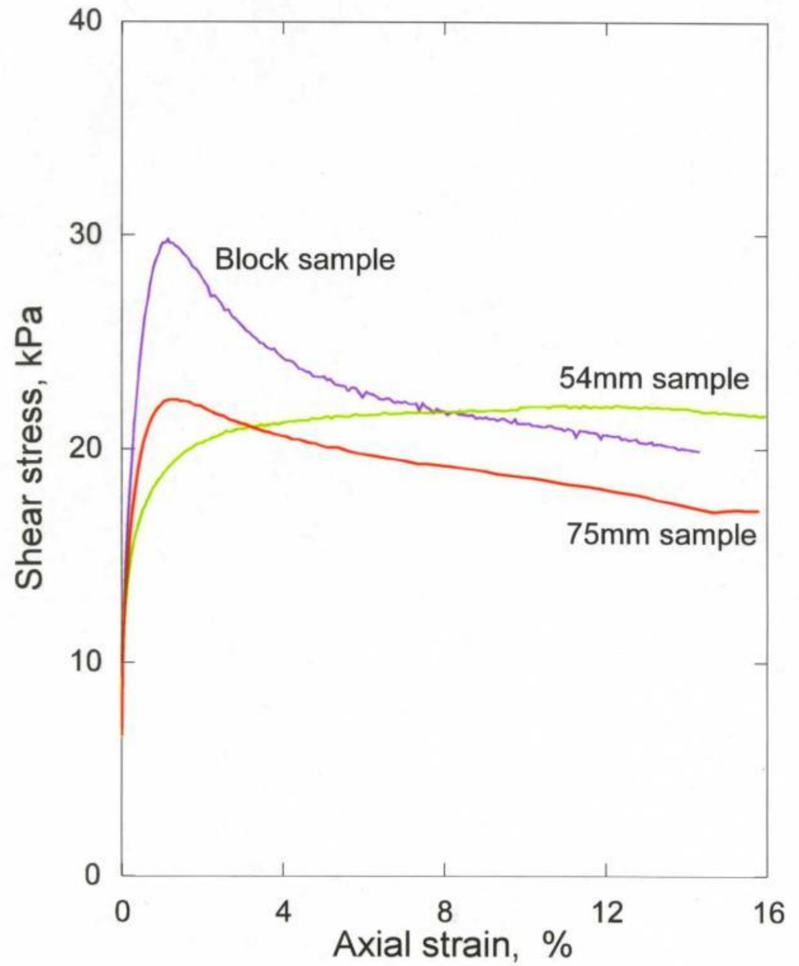
Better definition of preconsolidation stress, p_c', from CRS

UU triaxial compression tests on Laval and piston samples. Bothkennar Clay



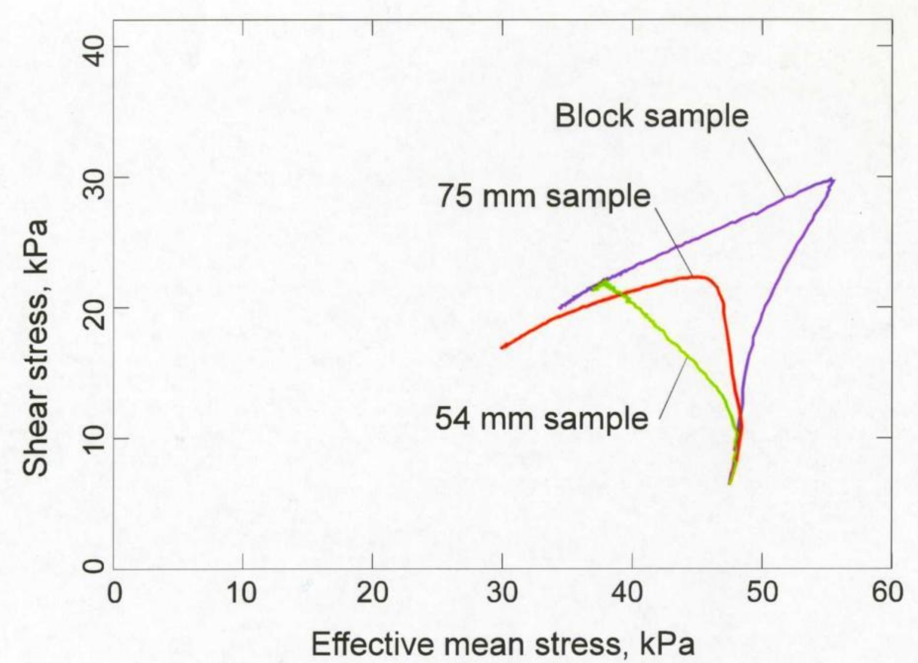
Strength and stiffness!!

Results from shearing phase of CAUC tests



Shear stress versus axial strain for CAUC tests at 6.1m depth.

Similar failure envelopes?



Stress path diagram

(Lunne et al, 2001)

Lierstranda clay from 6.1 m depth

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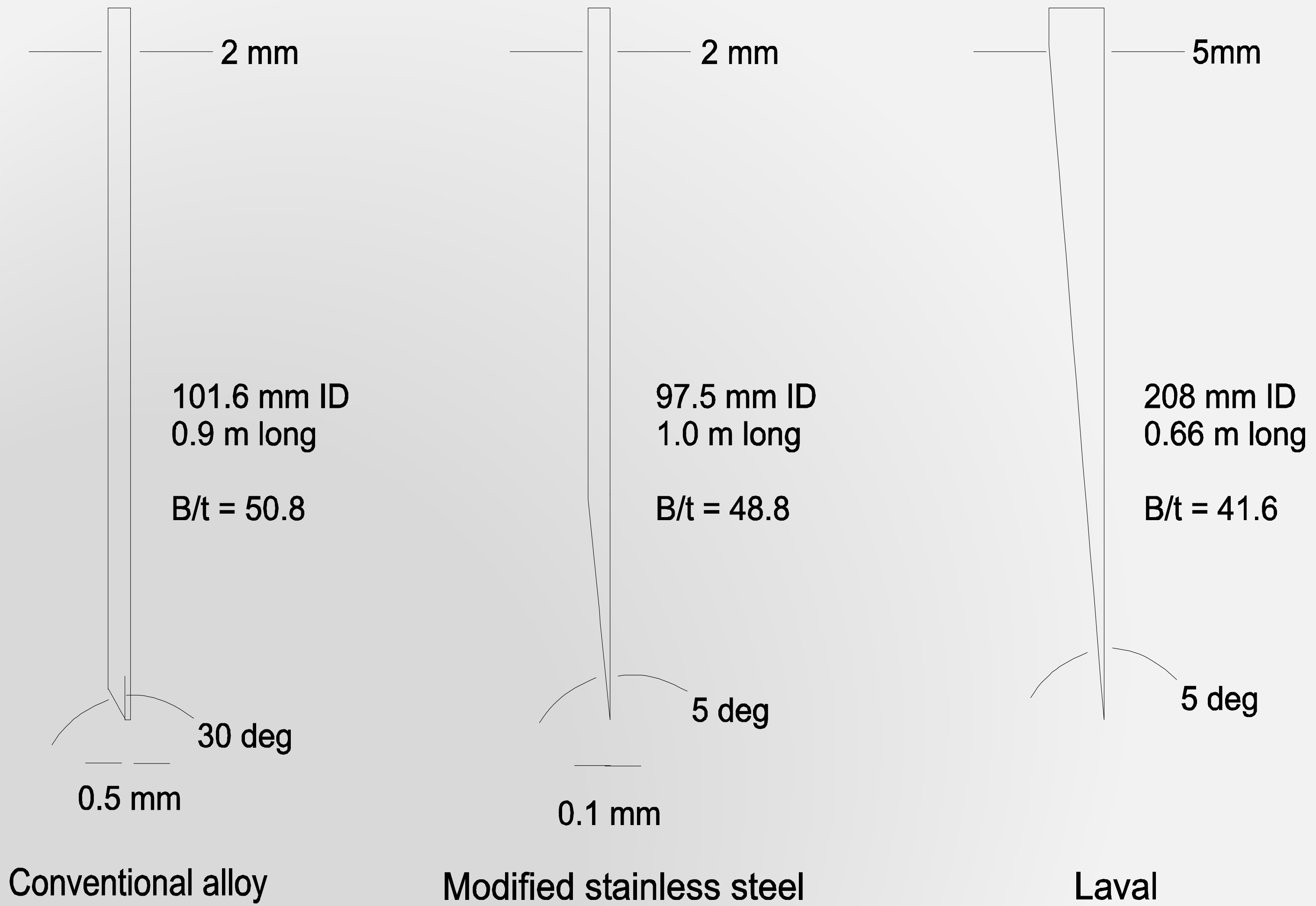
Sample tube geometries



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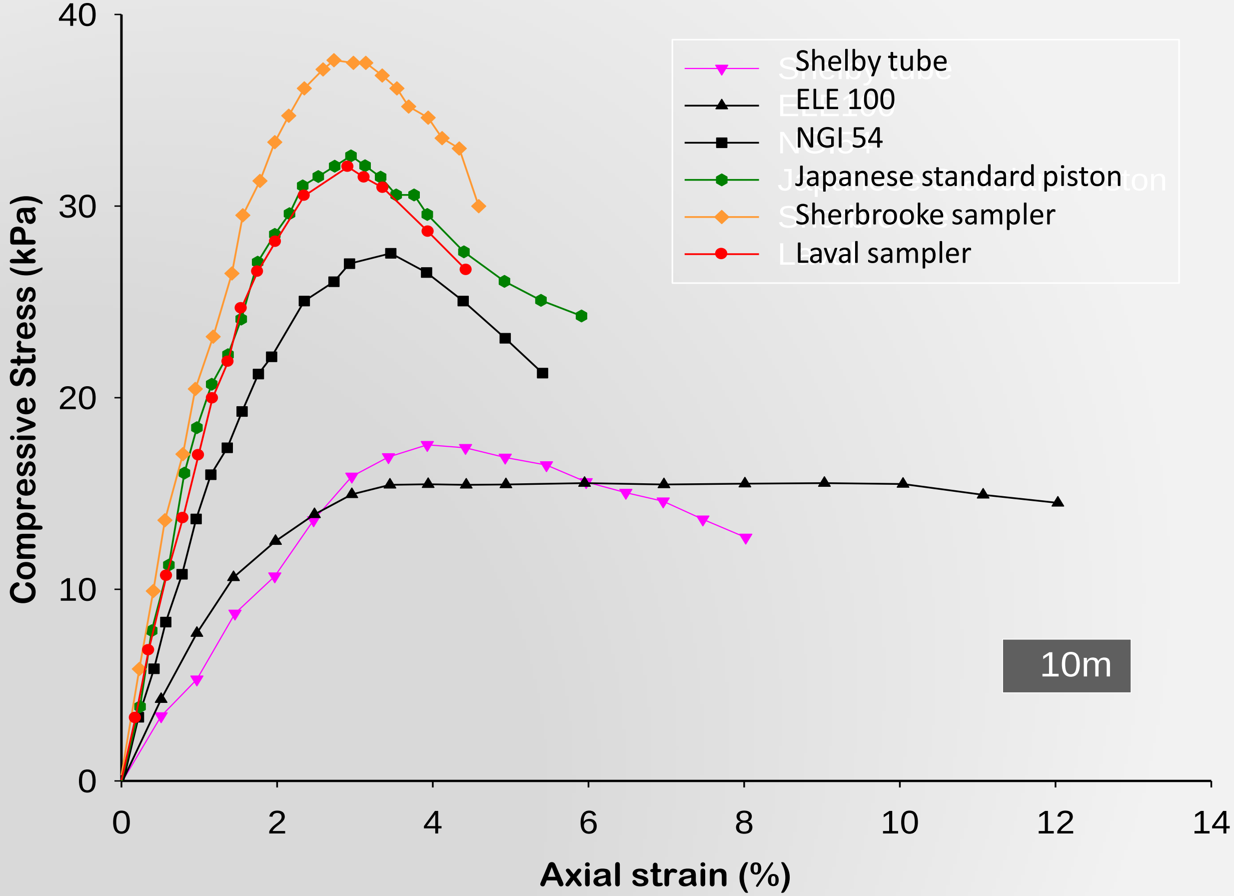
Unconfined compression tests on Ariake Clay (Tanaka and Tanaka, 1999)



What are YOU trying to test??

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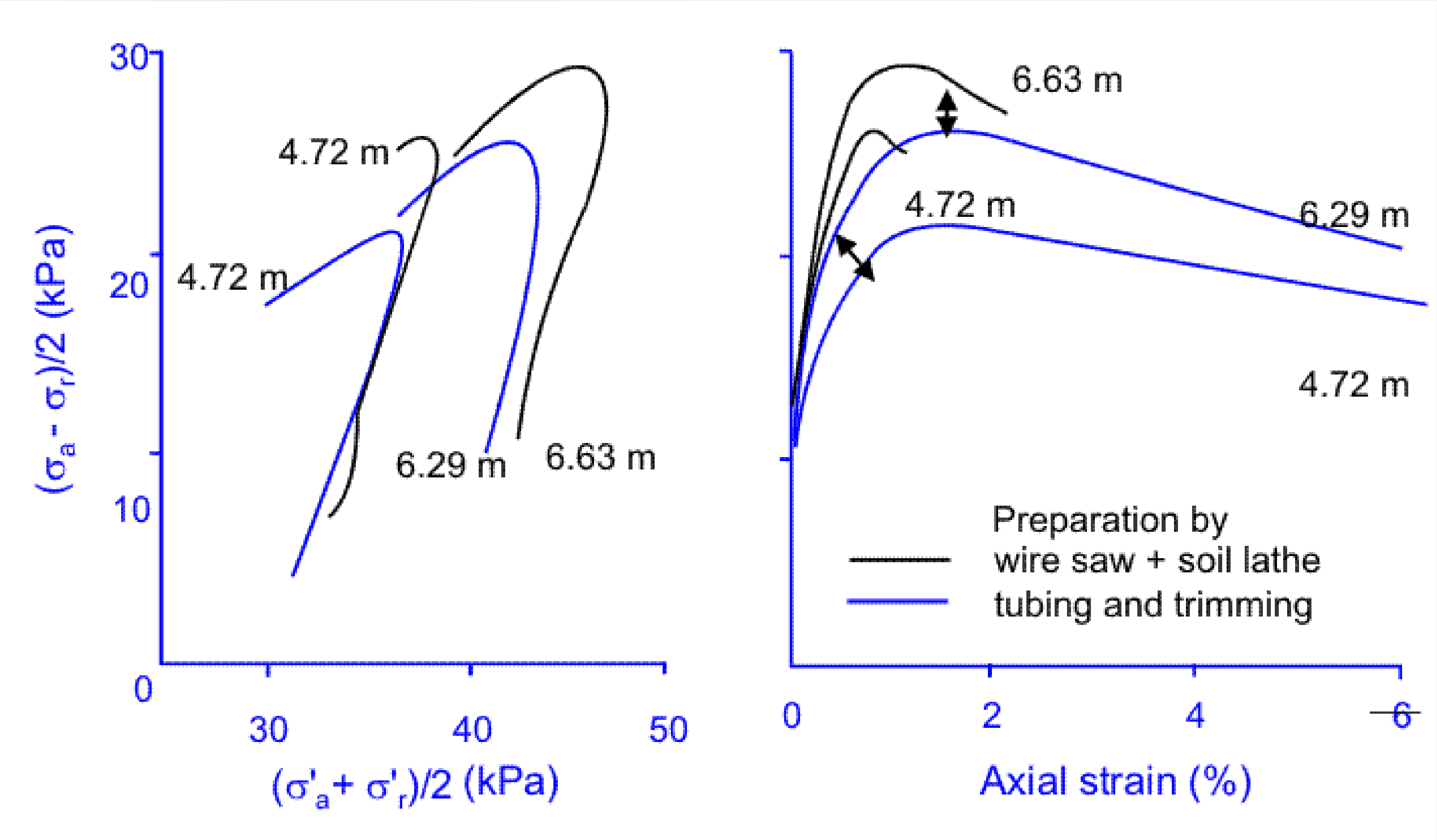
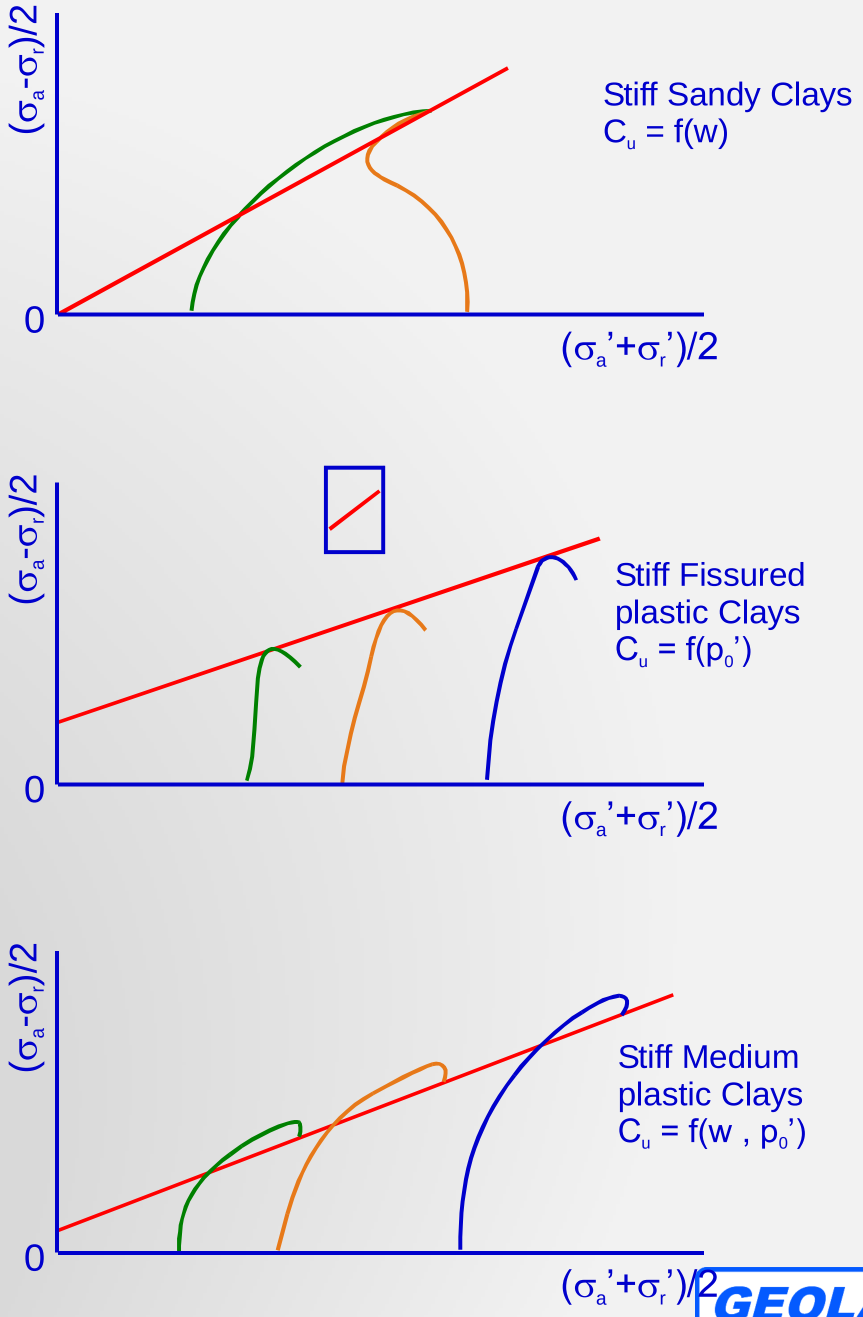
Disturbance during specimen preparation Bothkennar Clay



Sampling effects in stiff clays

Stiff clays: distinction on basis of unconsolidated undrained triaxial compression



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Conventional practice for sampling stiff plastic clays

- Shell and auger boring, dry hole, cased to cut off ground water entry
- Open drive tube sampling
- Unconsolidated undrained triaxial compression tests for stress-strain-strength

Invariably large scatter in strength and stiffness parameters variously attributed to:

- fabric
- sample disturbance
- stress relief
- sample size

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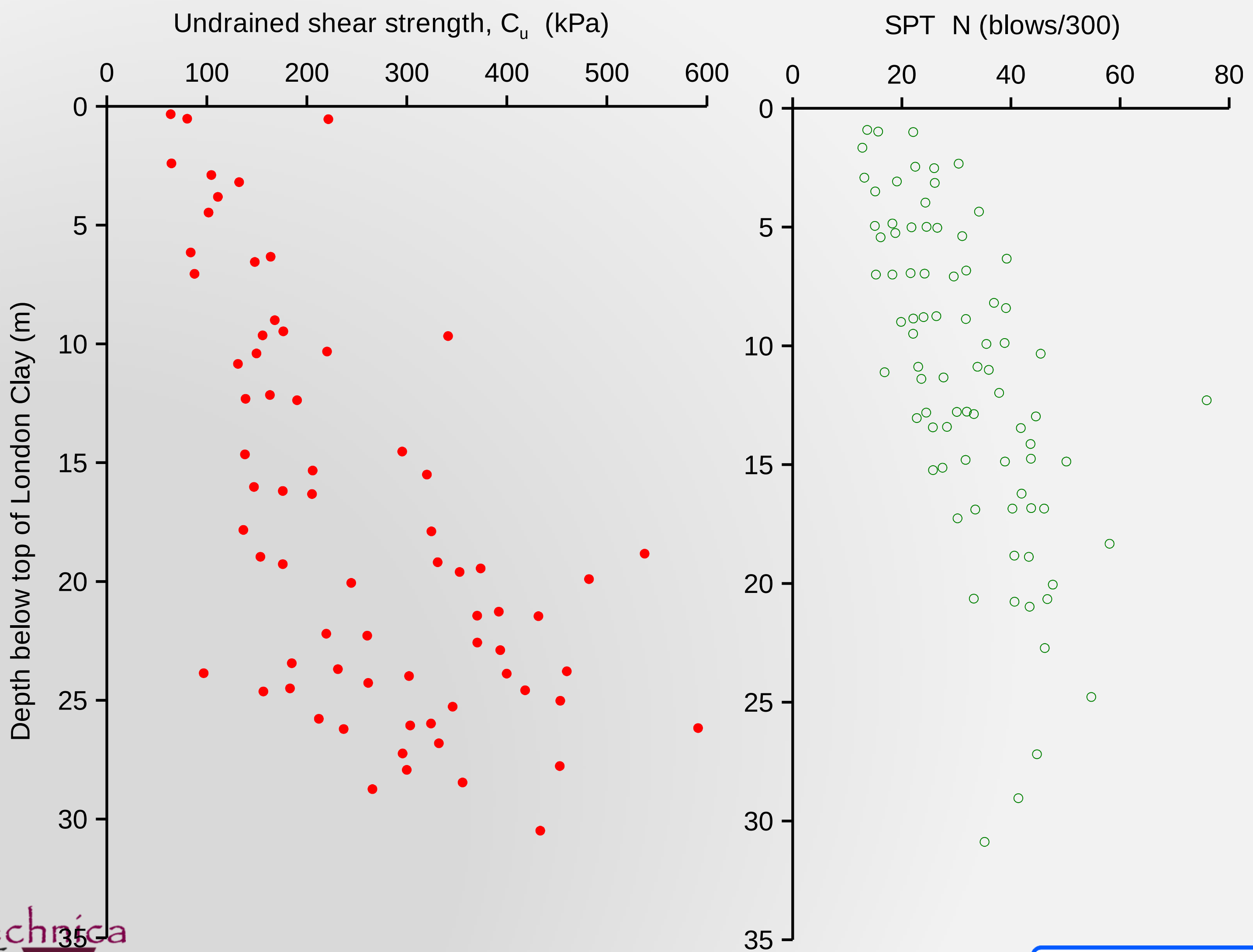
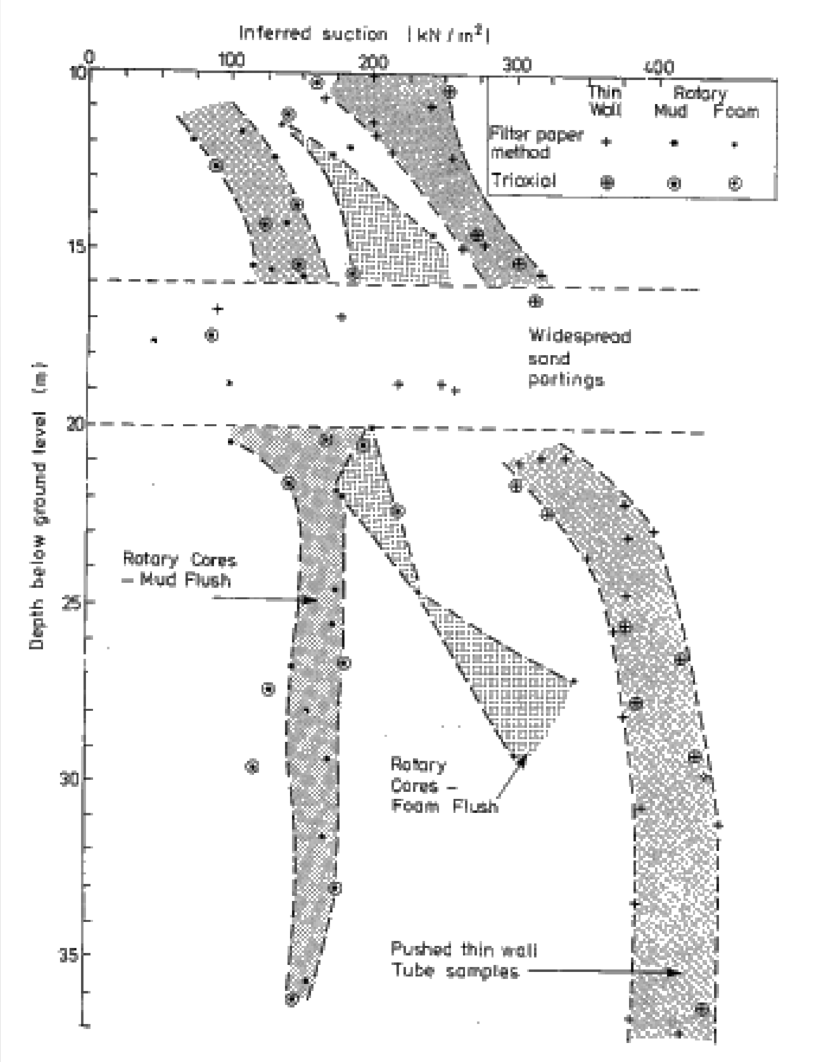
Results of conventional site investigation in London Clay



Initial effective stresses in rotary cores and thin wall tube samples of London Clay

Probably between rotary foam and pushed



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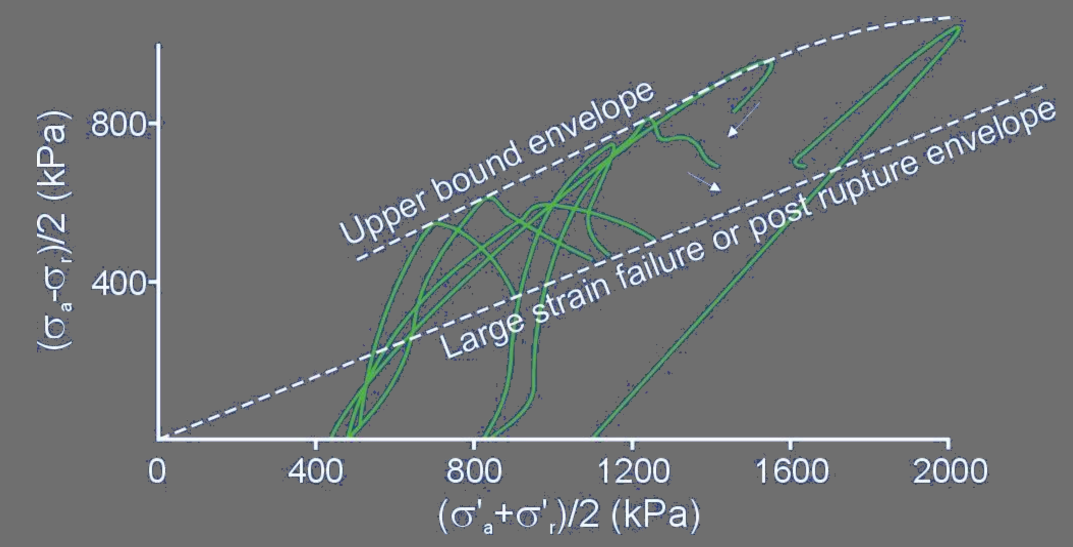
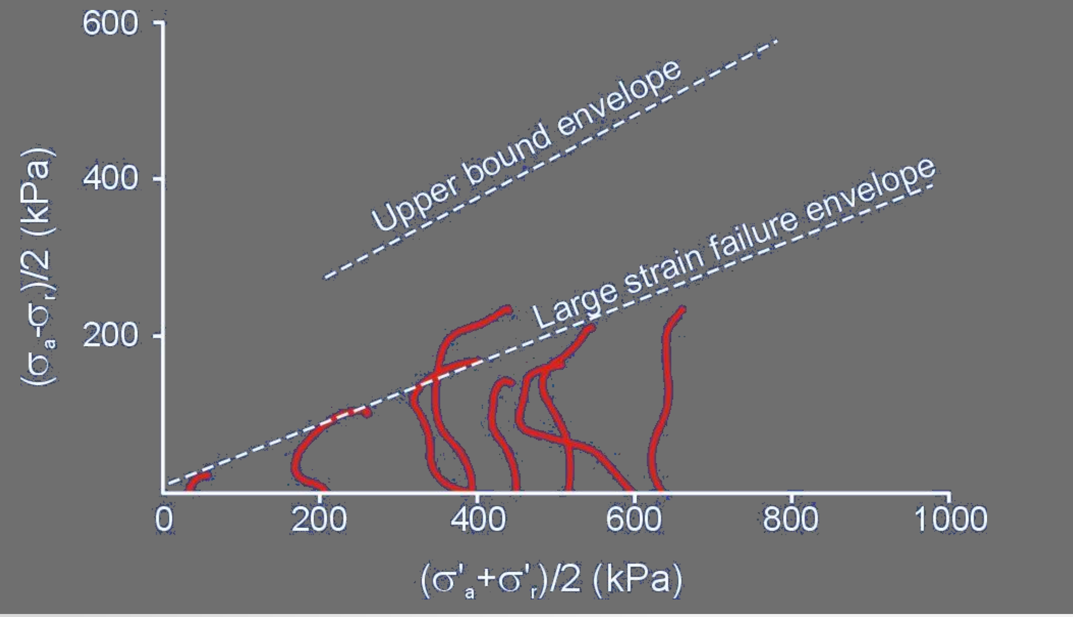
Effects of sampling method in UU triaxial compression tests on Upper Mottled Clay, Lambeth Group





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Evaluation of sample quality

Evaluation of sample quality

- Fabric inspection
- X- ray
- Comparison of tube sampling strains and yield strains
- Reconsolidation strains (esp in oed)
- Measurement of initial effective stress
- Comparison of in situ and laboratory measurements of shear wave velocity/dynamic shear modulus

How can we then reduce effects of sample disturbance?

- Use the best sampler possible for the project
- Careful sample handling and testing – recompression technique may to some extent "repair" the sample
- Trimming of sample to smaller diameter may help in some cases but can also damage sample if not undertaken with great care (tubing vs hand trimming).

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Sample disturbance effects

Conclusions:

- *Sample disturbance(SD) can be very significant!*
- Effect of SD is to partly or completely destroy structure
- SD has significant effects on deformation and strength characteristics as measured in oedometer and triaxial tests
- $\Delta e/e_o$ is a consistent measure of SD for soft clays
- SD effects can best be minimized by carefull choice of drilling and sampling methods
- Sample handling and consolidation techniques may reduce SD effects

In situ tests will also give essential input to choice of soil design parameters, but will not eliminate need for sampling and laboratory testing

- So we have good quality sample!

Advanced Tests

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- Cyclic triaxial
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Applications

Advanced Tests

- Advanced triaxial, (a significant enhancement on the standard effective stress capability); including features such as local axial and radial strain, mid height pwp, piezobenders and anisotropic stress control (CAU)
- Cyclic triaxial
- Cyclic and static simple shear
- Resonant column
- Don’t forget the CRS oedometer
- And more

Shearing Tests

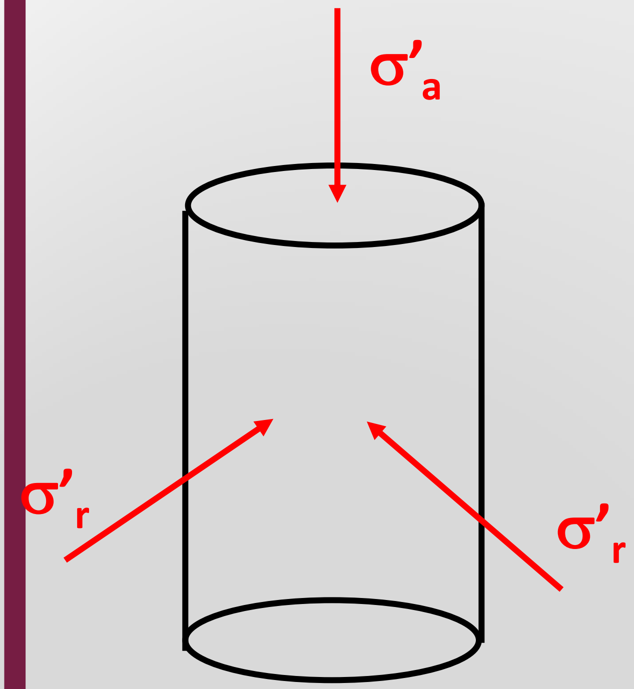
- we often have conflicting requirements of our tests:

Strength – need large strains with minimum restraint while maintaining uniform stresses & strains in sample

Stiffness – need to apply and measure very small stress/strain changes

- triaxial apparatus is fairly unique in its ability to perform both functions

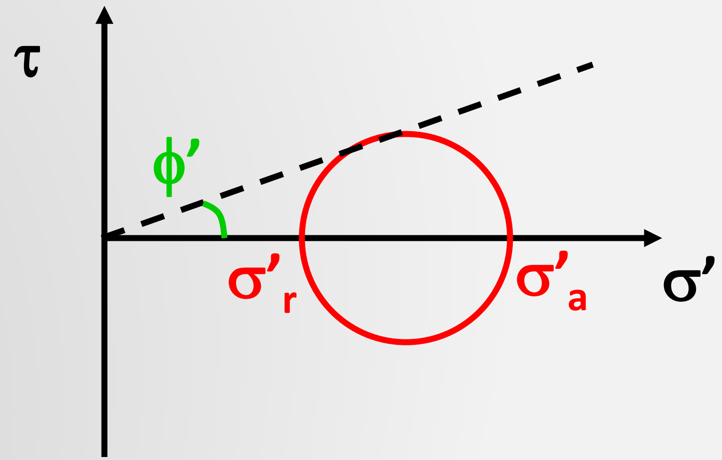
Triaxial Test



Advantages

- **drainage can be controlled**
- **complete stress state is known**

(σ_a, σ_r, and U) and can be controlled



Disadvantages:

- **axi-symmetric loading – soil parameters depend on mode of loading**

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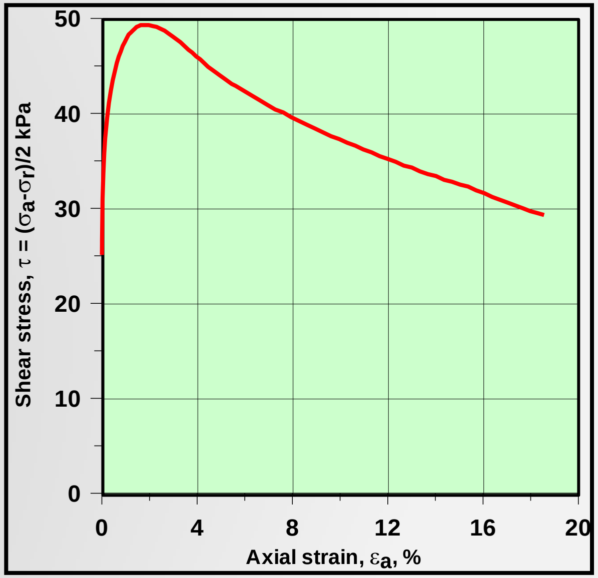
Triaxial testing CAUC



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The most basic and useful geotechnical test

We now have

Excellent equipment that allows us to,

- control:
  - Axial stresses
  - Radial stresses
  - Closed loop
- measure:
  - Accurate axial displacements
  - Radial displacements
  - Mid ht pore pressures
  - Small strain stiffnesses in varying directions
  - Volume changes

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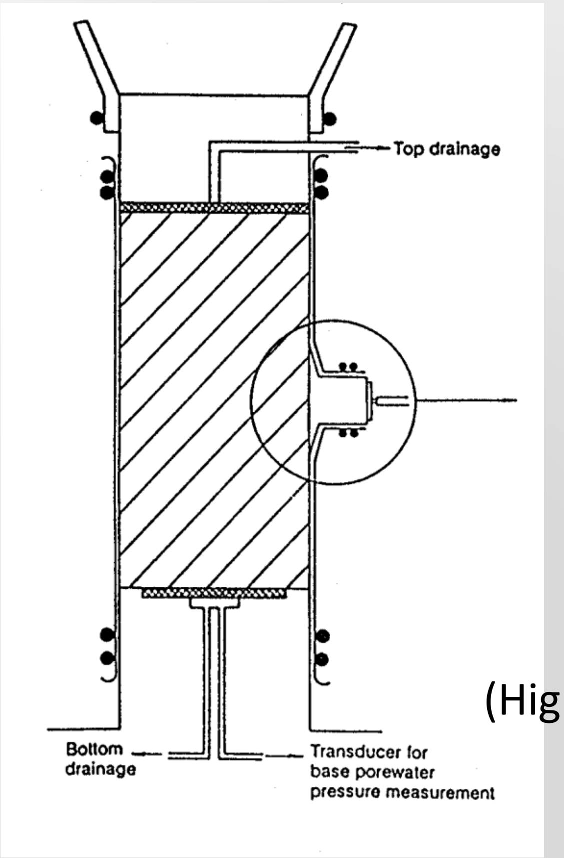
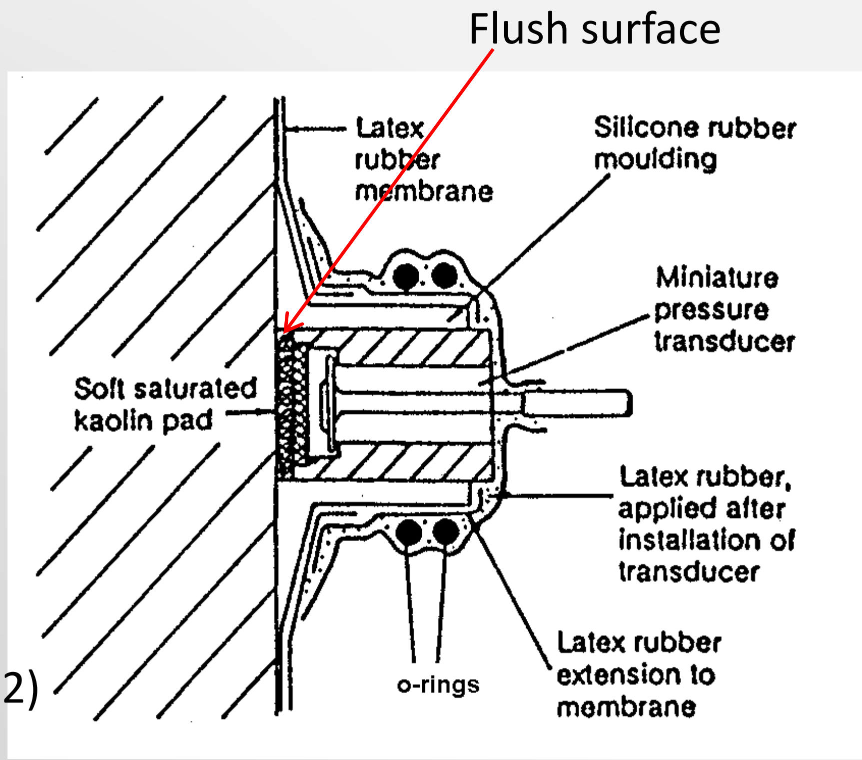
Mid-height pore pressure measurement





(Hight, 1982)

- **use without lateral filter paper will lengthen tests considerably**

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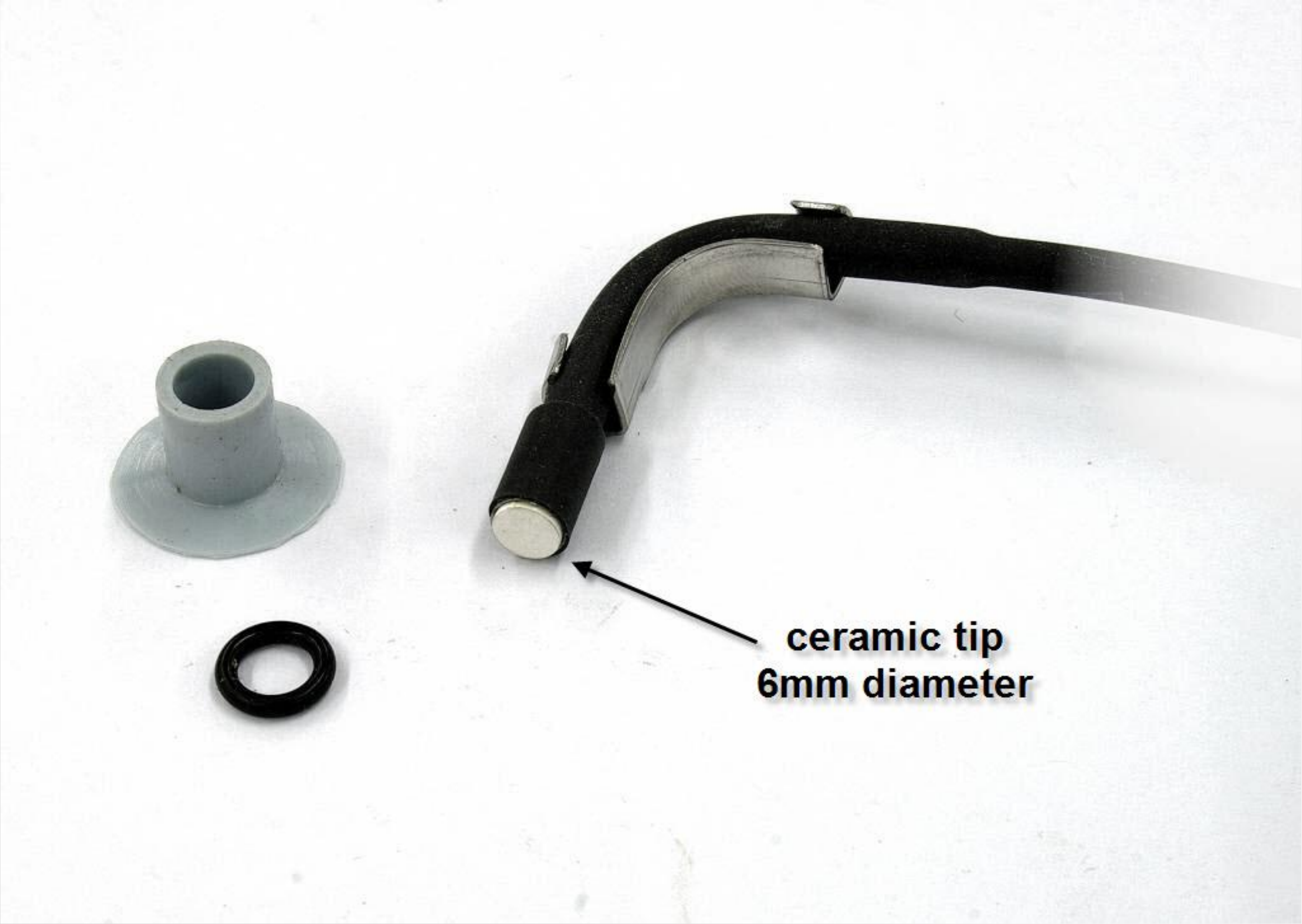

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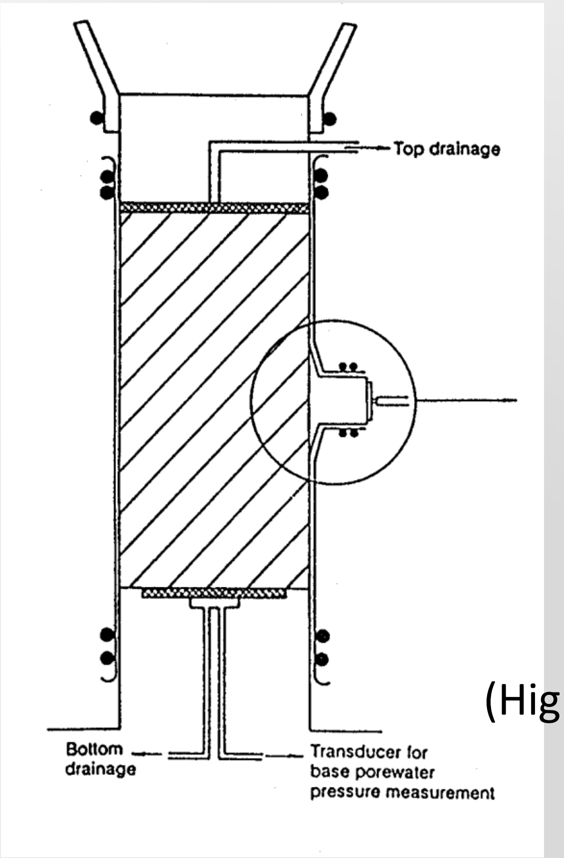
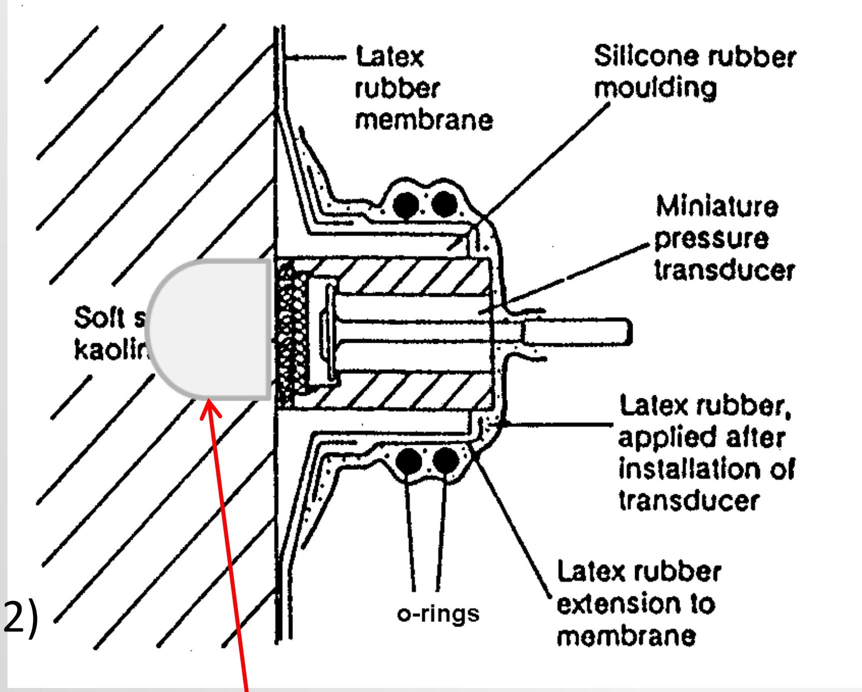
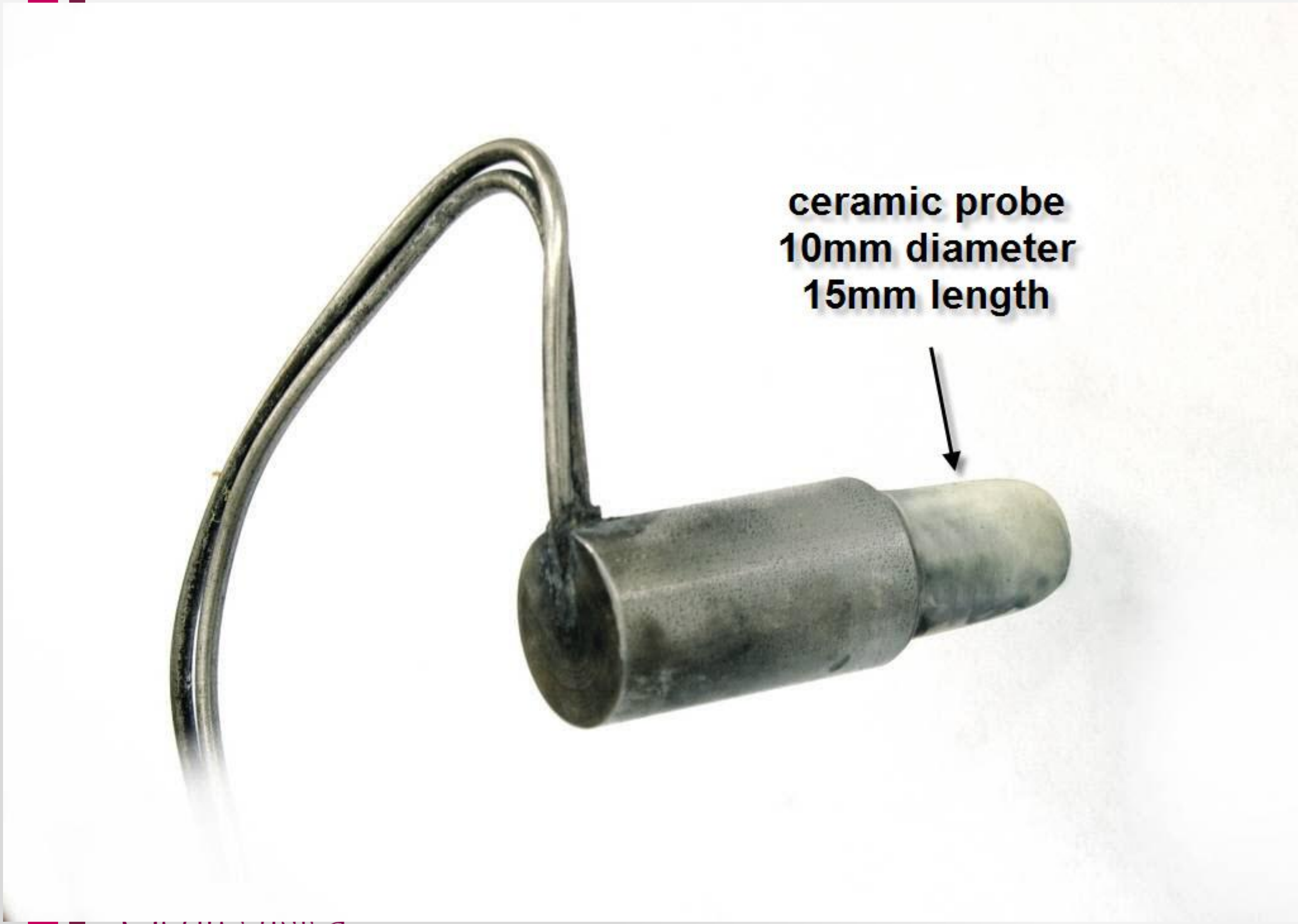
Mid-height pore pressure measurement



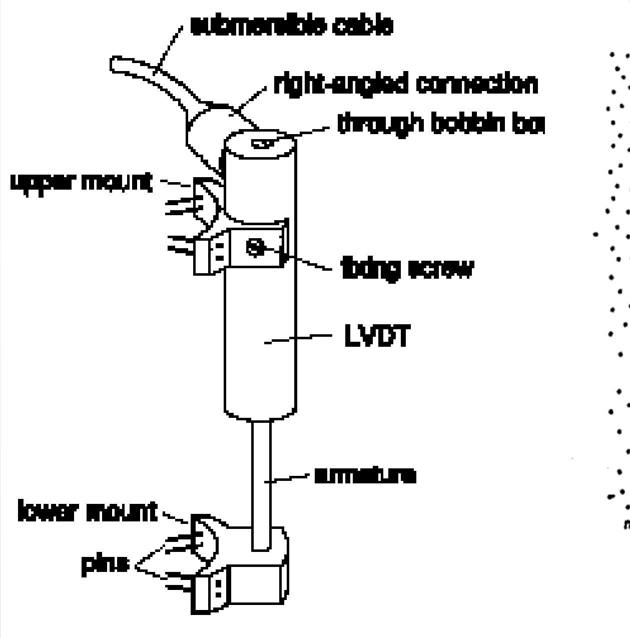
(Hight, 1982)



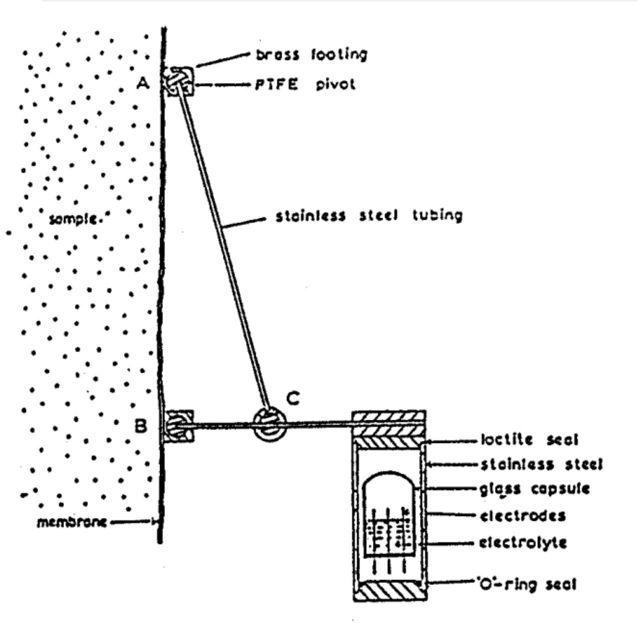
Prebore hole
and push in probe


ceramic probe
10mm diameter
15mm length

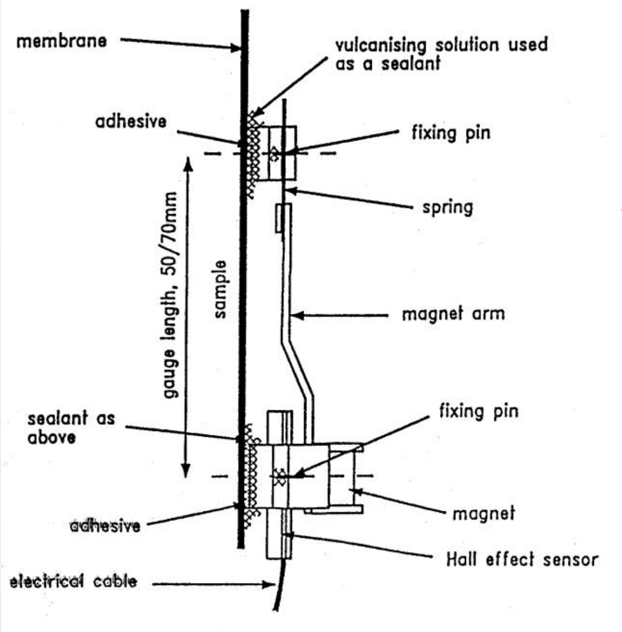
Local Strain Measurement - Axial



LVDTs
(Cuccovillo & Coop, 1997)



(Jardine et al., 1984)



Hall Effect
(Clayton & Kathrush., 1986)

- most accurate
- difficult to mount

- sensitive to rigid body rotation of sample – need to take average of two readings on opposite sides of sample
- cannot be used for ε_r

- accurate
- relatively easy to mount

- transducers generally only glued to membrane – pins no longer used

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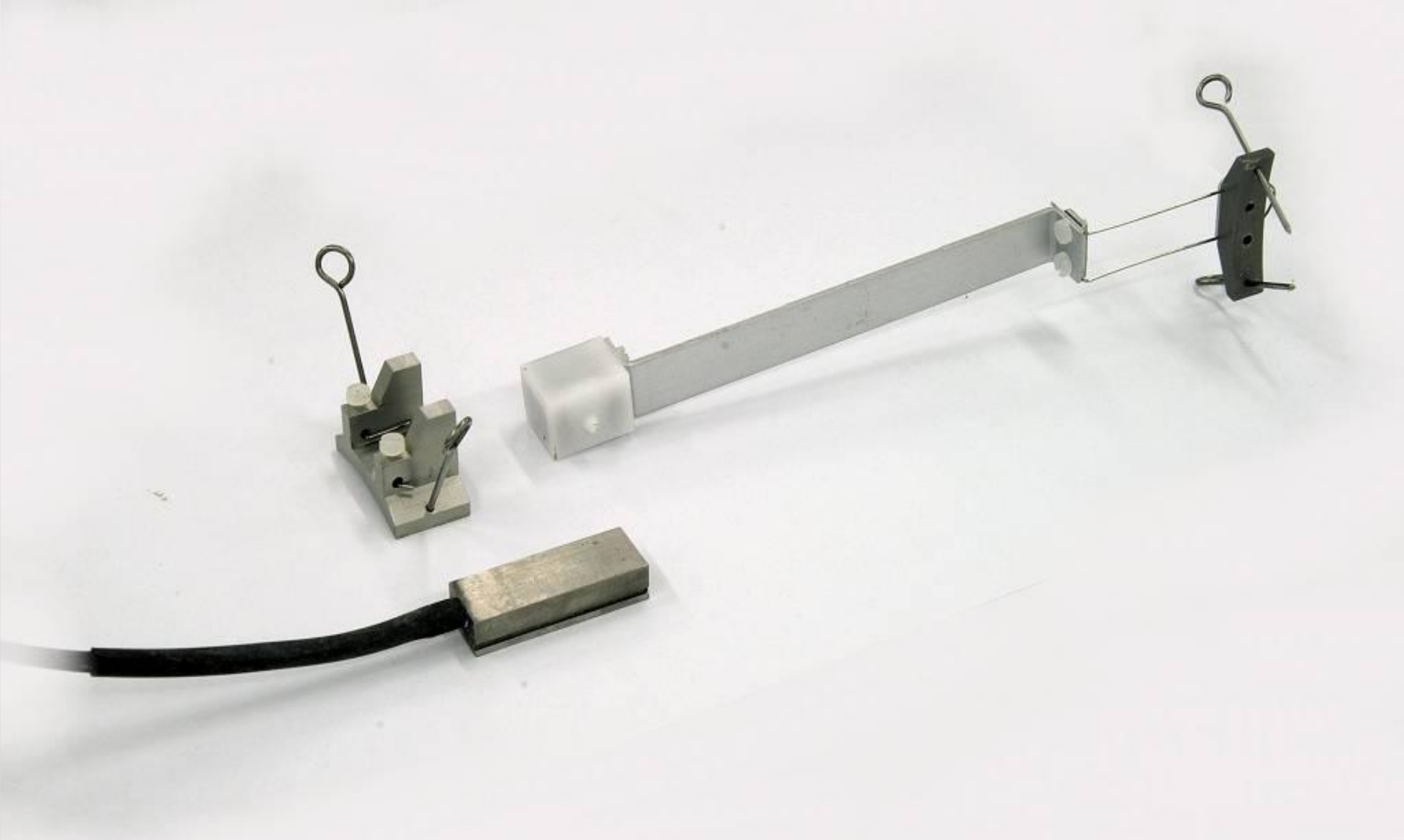

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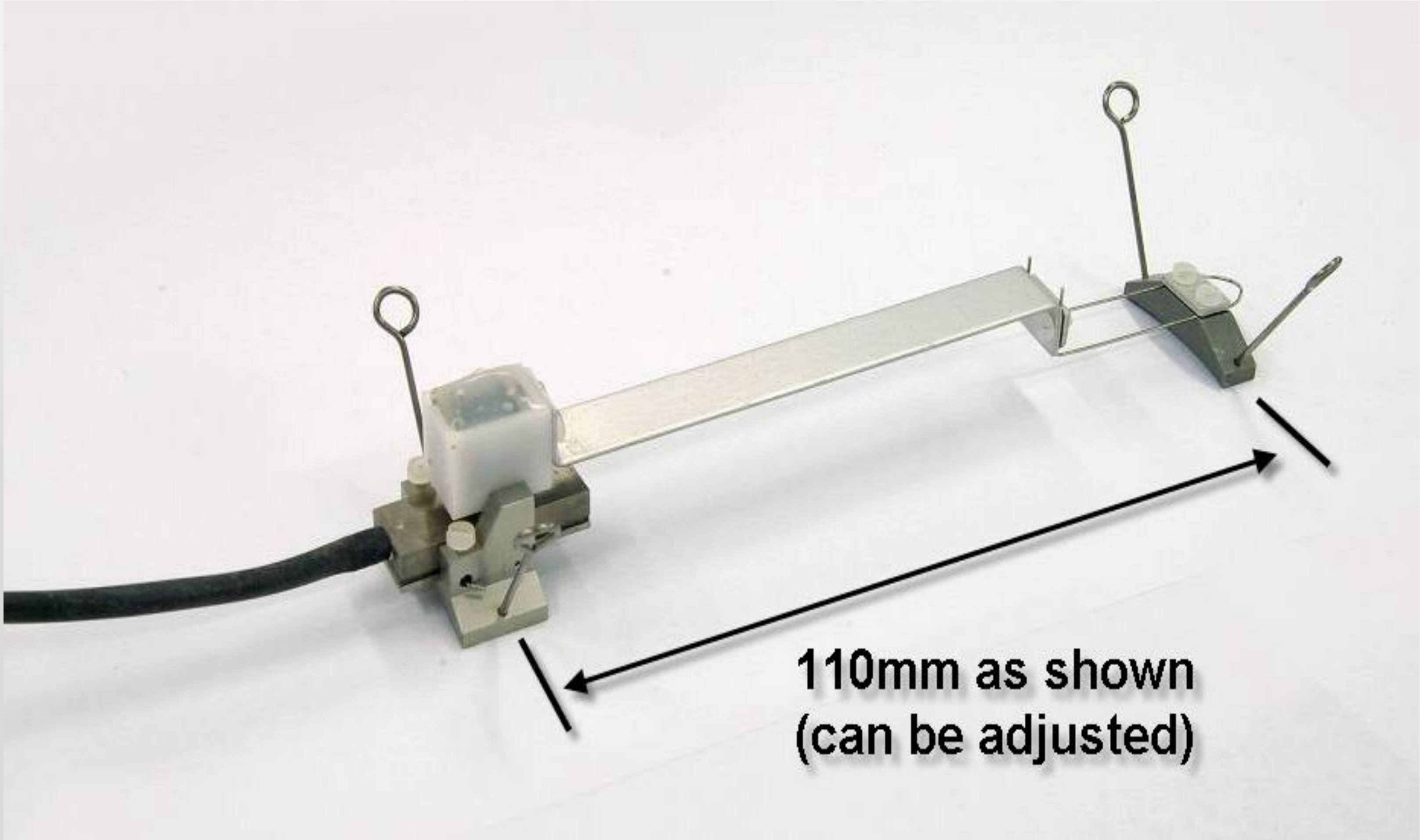
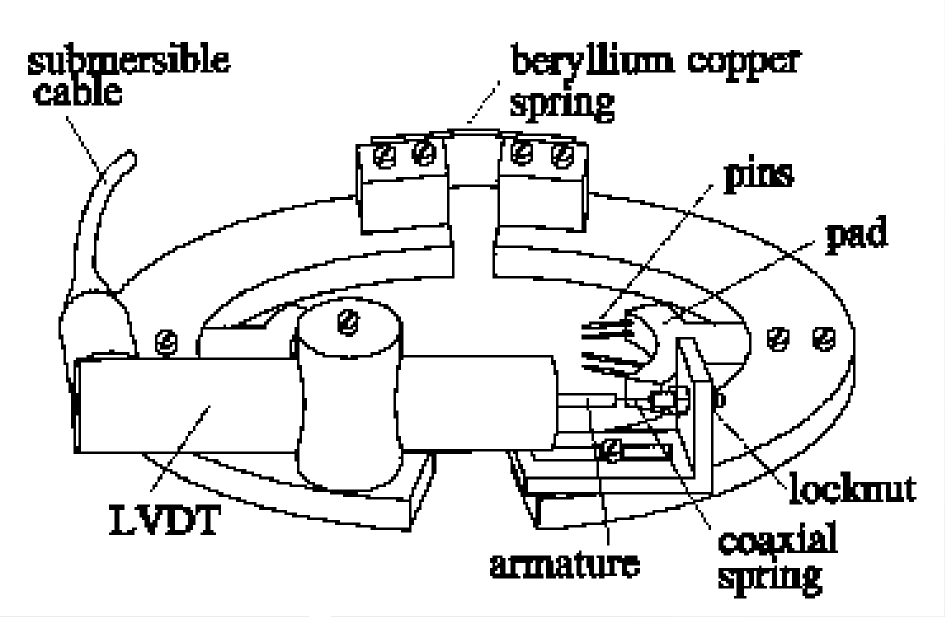
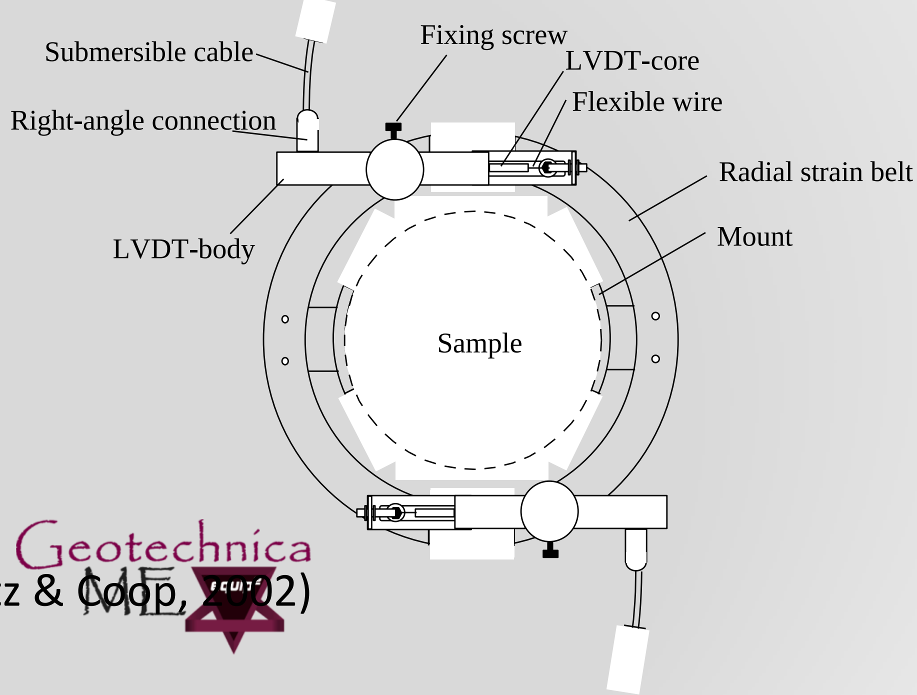


Resolution – 0.0003mm

Local Strain Measurement - Radial





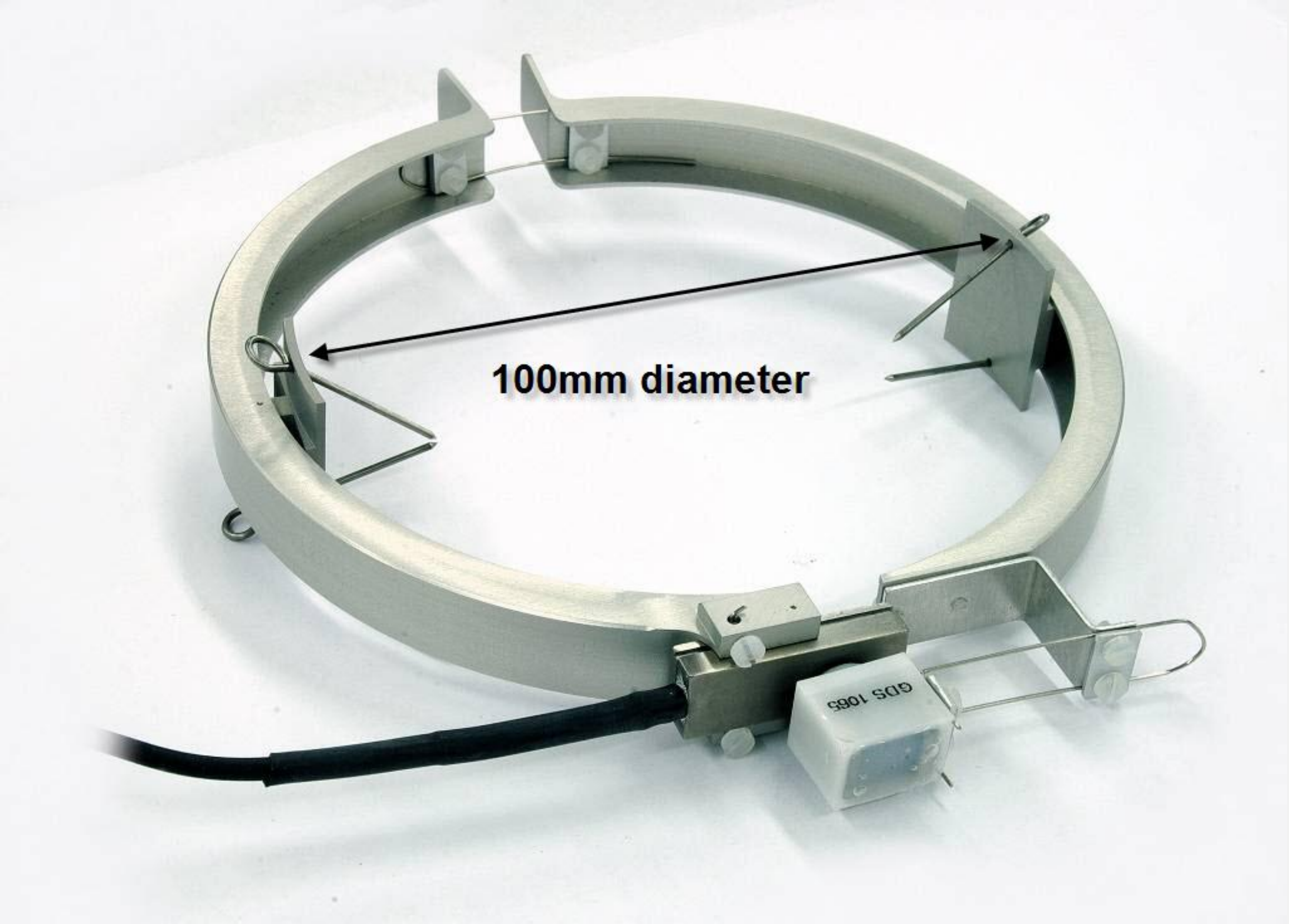
- single LVDT version or Hall effect

- double LVDT or Hall effect version

- allows larger ε_r
-difficult to mount

-BUT SPACE

(Klotz & Coop, 2002)

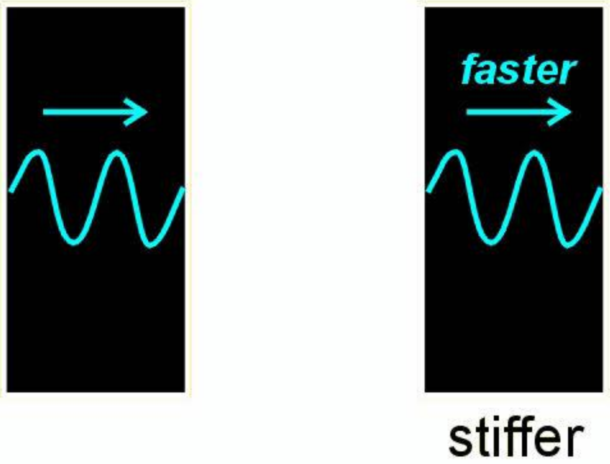


Resolution – 0.0001 – 0.0002mm

Stiffness: dynamic

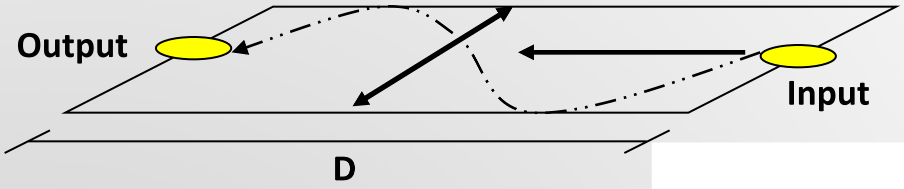
Dynamic Shear Modulus, G_{max} =

density x (shear wave velocity)^2



Bender Elements

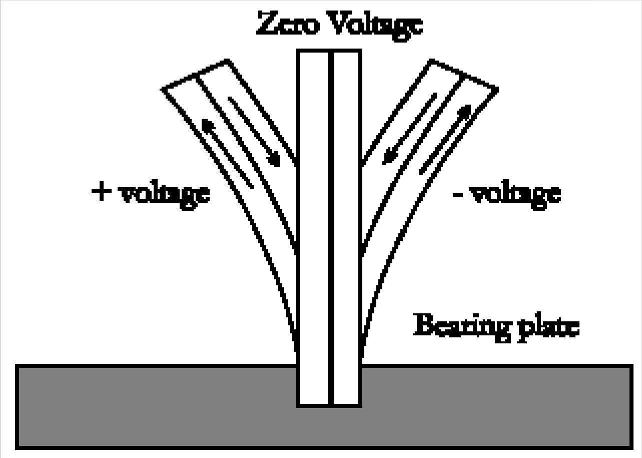
➢ **shear plane wave travelling through an elastic isotropic or cross-anisotropic medium – measure elastic shear stiffness, G_0**



$$v = D/t_{arr}$$

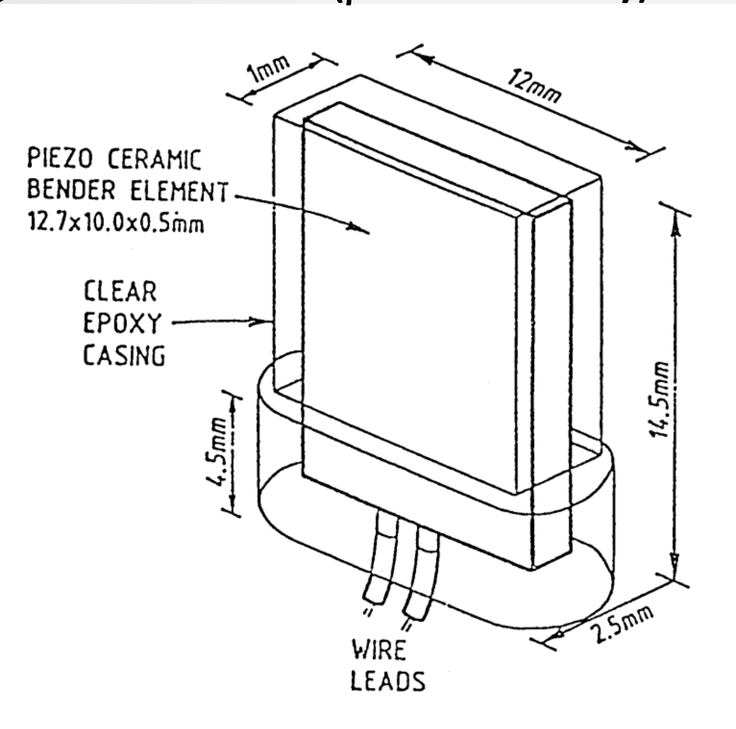
$$G_0 = \rho v^2$$

(ρ = mass density)



Piezoelectric Bender Elements

Kramer (1996)



(Dyvik & Madhus, 1985)

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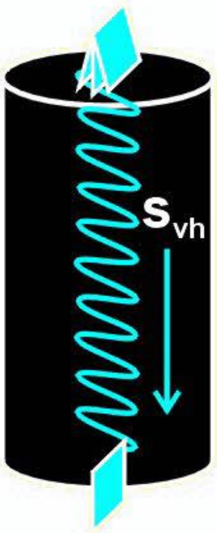
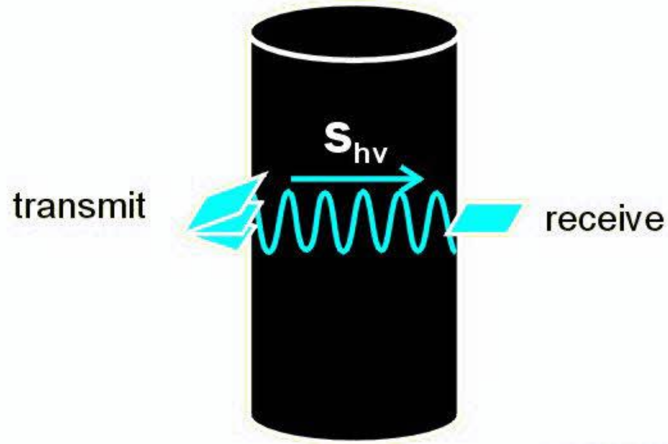
Shear Wave Velocity - S_{vh}



Shear Wave Velocity - S_{hv}



propagated horizontally
polarised vertically

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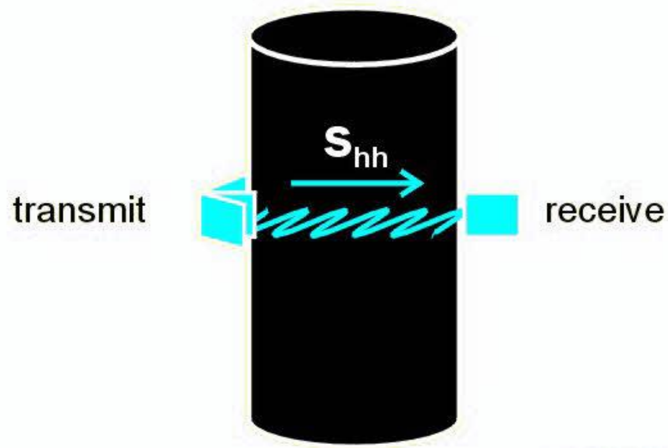
Shear Wave Velocity - S_{hh}



propagated horizontally
polarised horizontally

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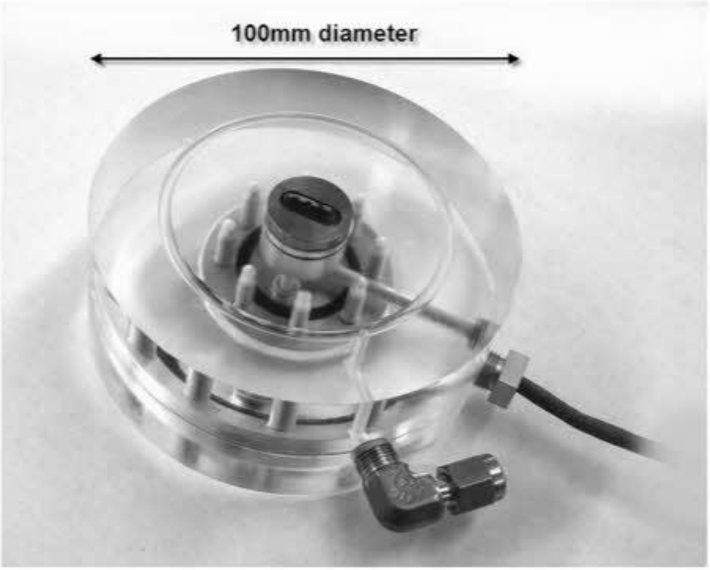
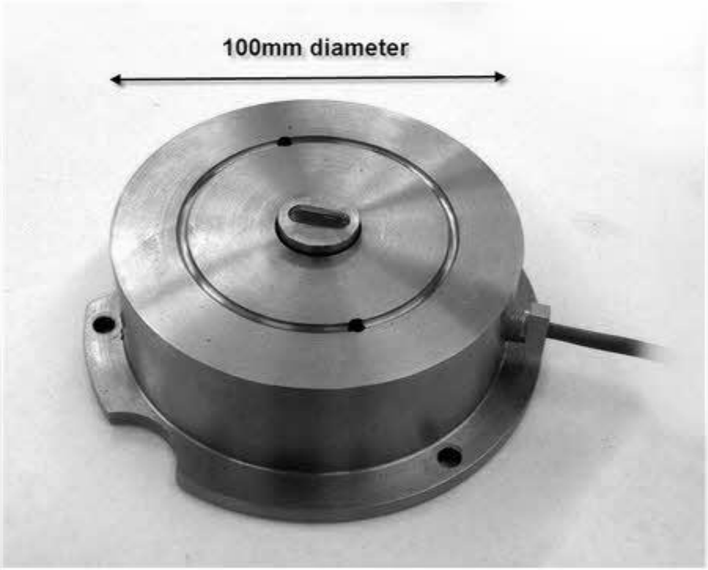
Piezo Bender Elements

top cap



base pedestal



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Piezo Bender Elements

top cap

base pedestal

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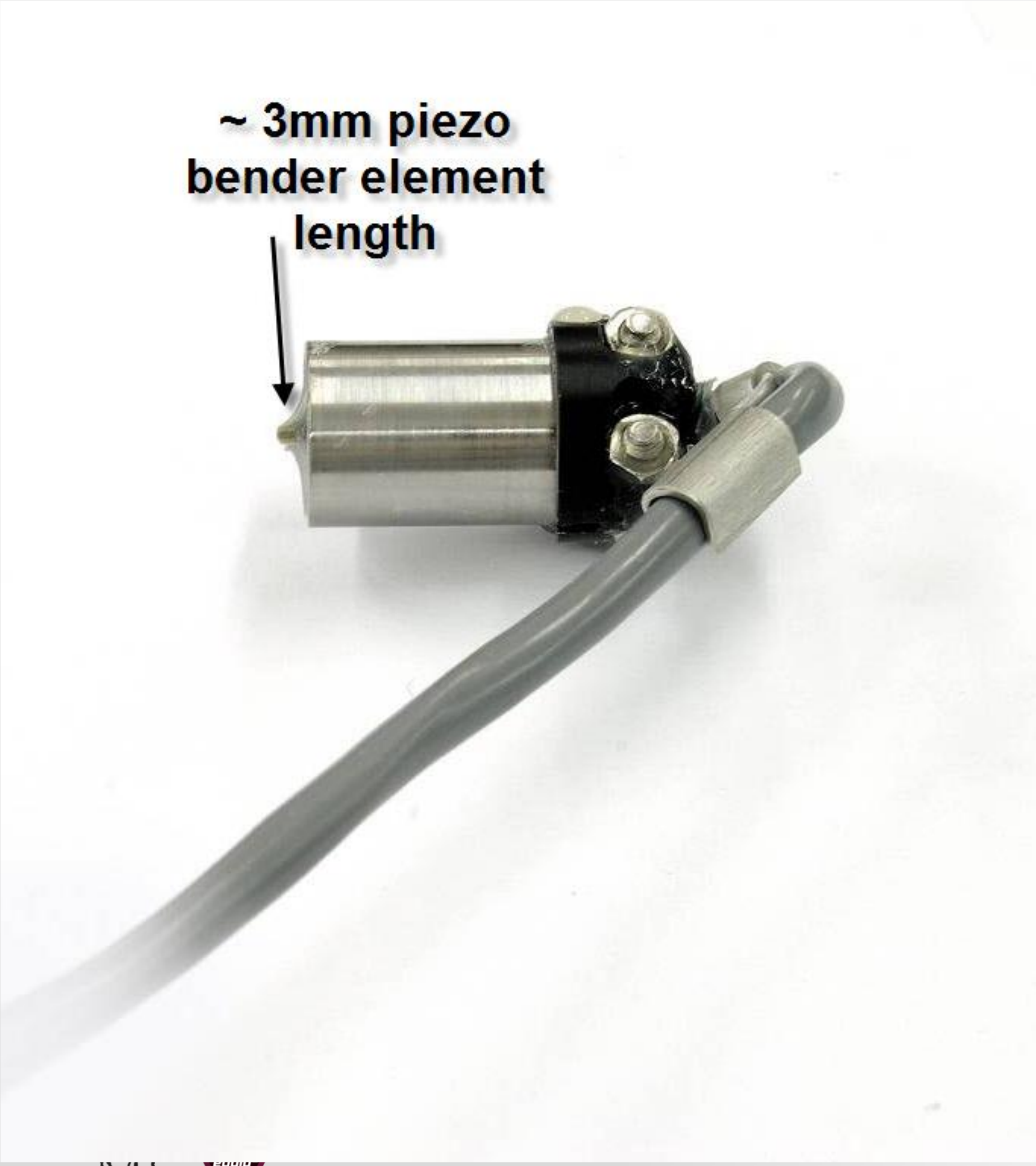

Lateral benders

Lateral benders

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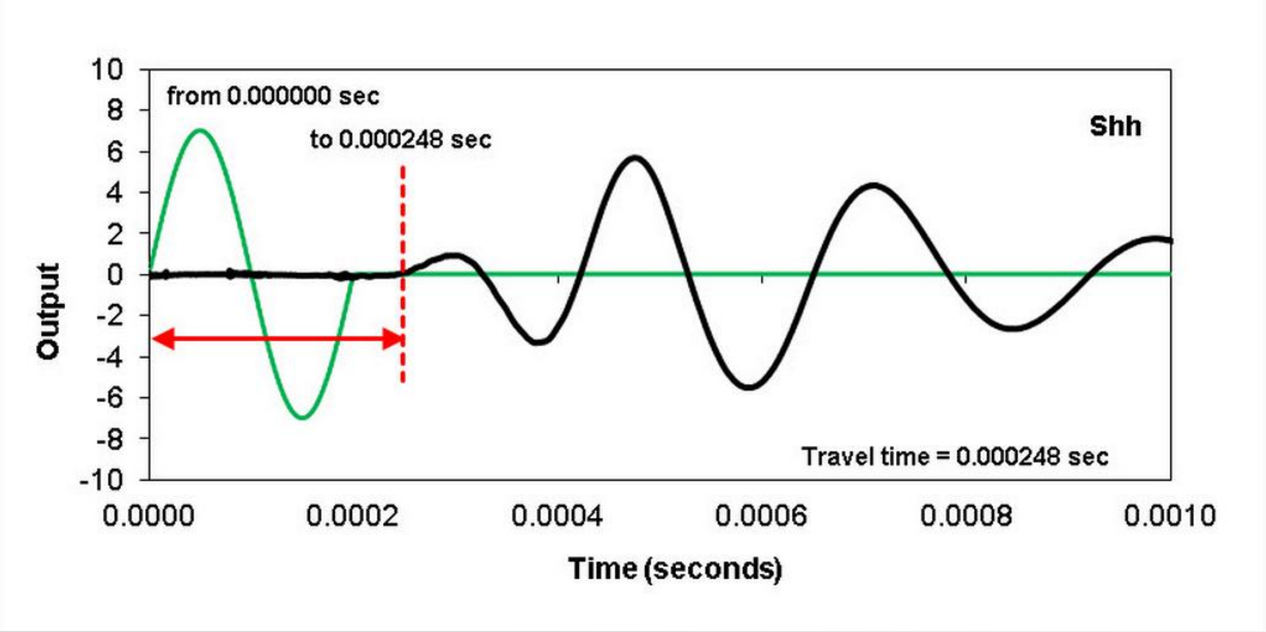
Piezobender trace



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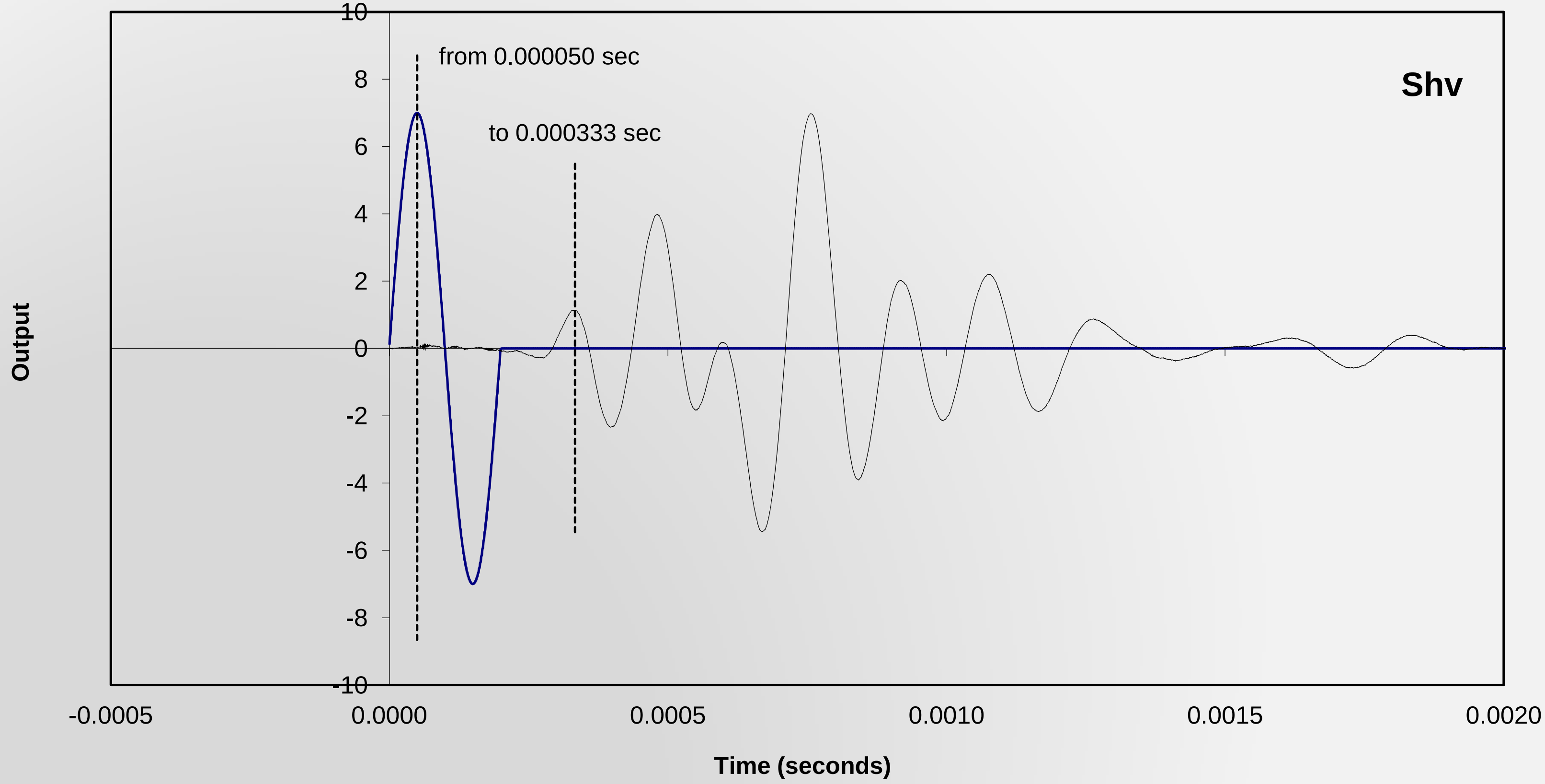
First Arrival



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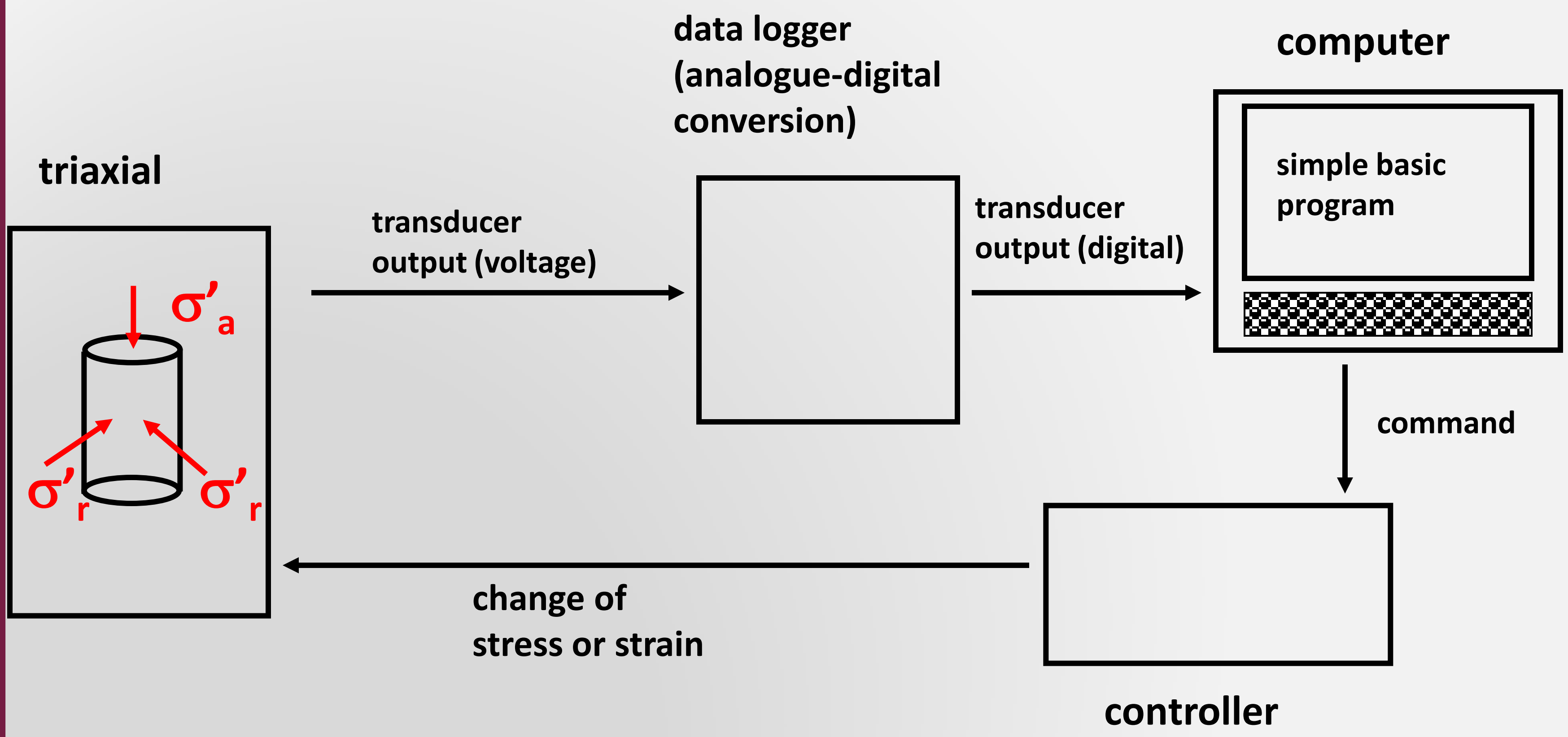
Control of triaxial tests: feedback loop



- automated control of tests much less common than data-logging

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Setting it all up

not much space

Setting it all up

not much space

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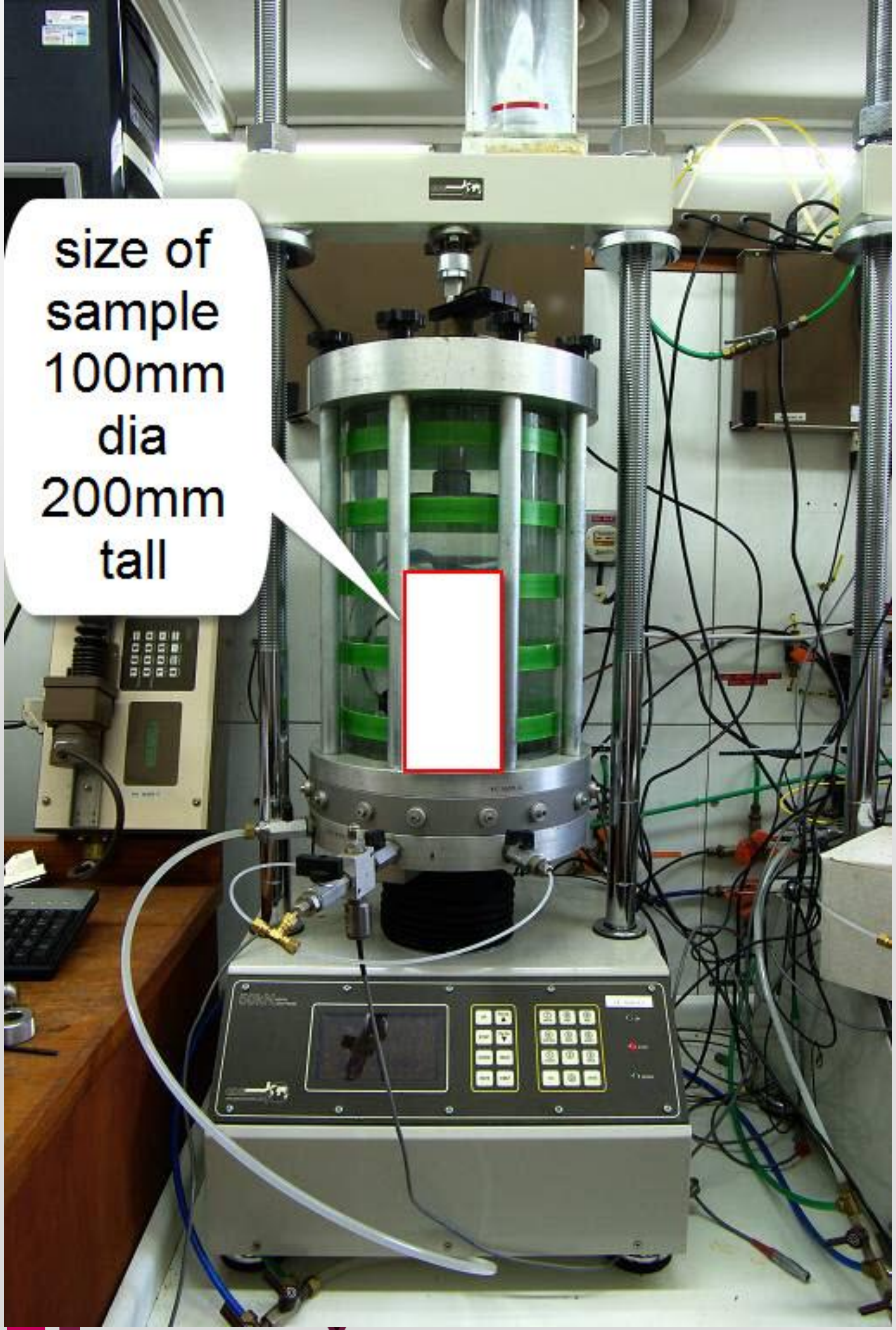

Larger cells

more space, large strains

id 220mm (165)

Anisotropy of Elastic Stiffnesses: Cross-Anisotropic Soil

- **behaviour defined by the following parameters:**

E'_V = vertical Young's modulus
E'_H = horizontal Young's modulus → **5 independent parameters**
ν'_{VH} = Poisson's ratio for influence of $\Delta\sigma'_V$ on $\Delta\varepsilon_H$
ν'_{HV} = Poisson's ratio for influence of $\Delta\sigma'_H$ on $\Delta\varepsilon_V$
ν'_{HH} = Poisson's ratio for influence of $\Delta\sigma'_{H1}$ on $\Delta\varepsilon_{H2}$ or $\Delta\sigma'_{H2}$ on $\Delta\varepsilon_{H1}$
G_{VH} = shear modulus in vertical plane
G_{HV} = shear modulus in vertical plane
G_{HH} = shear modulus in horizontal plane

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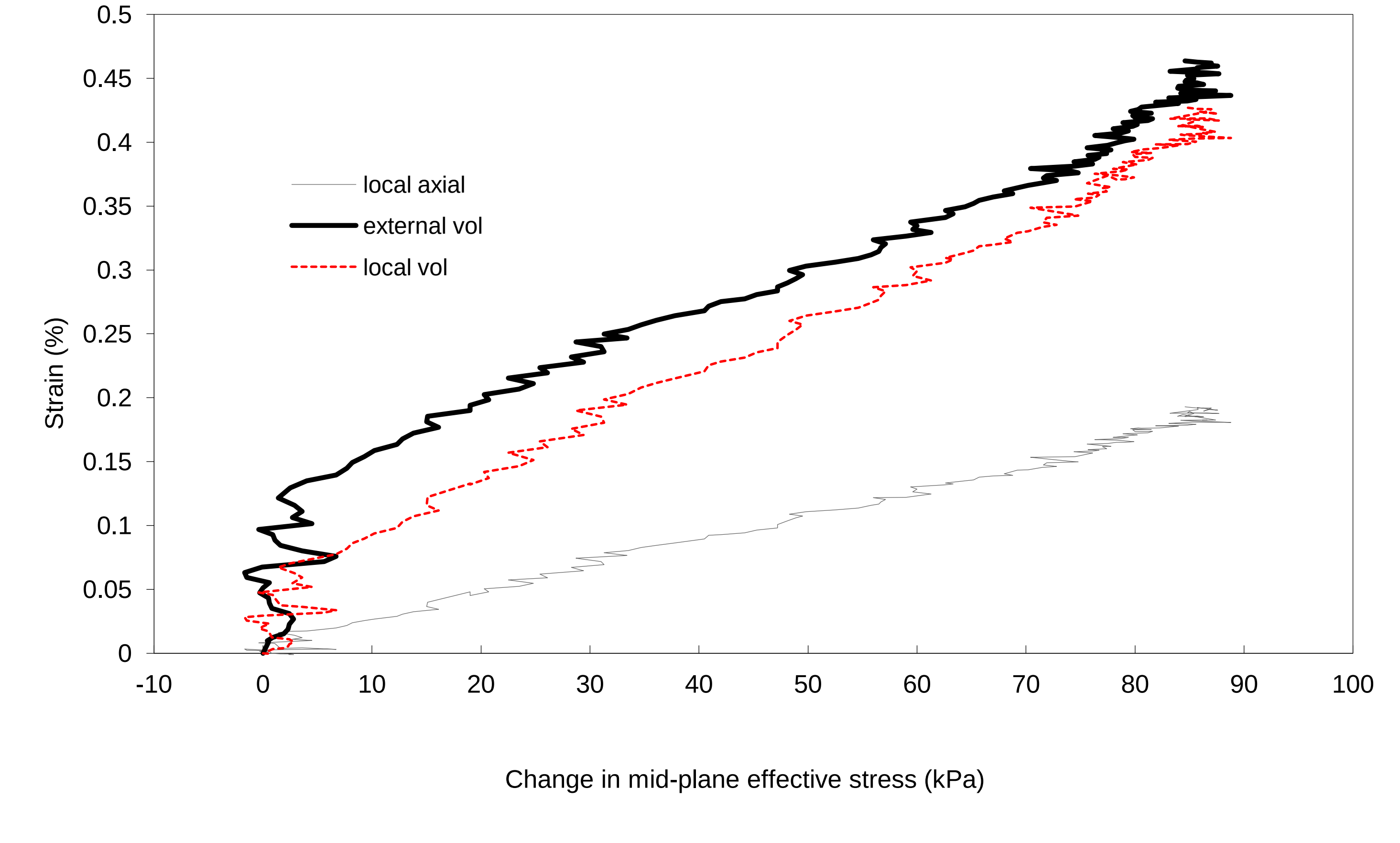
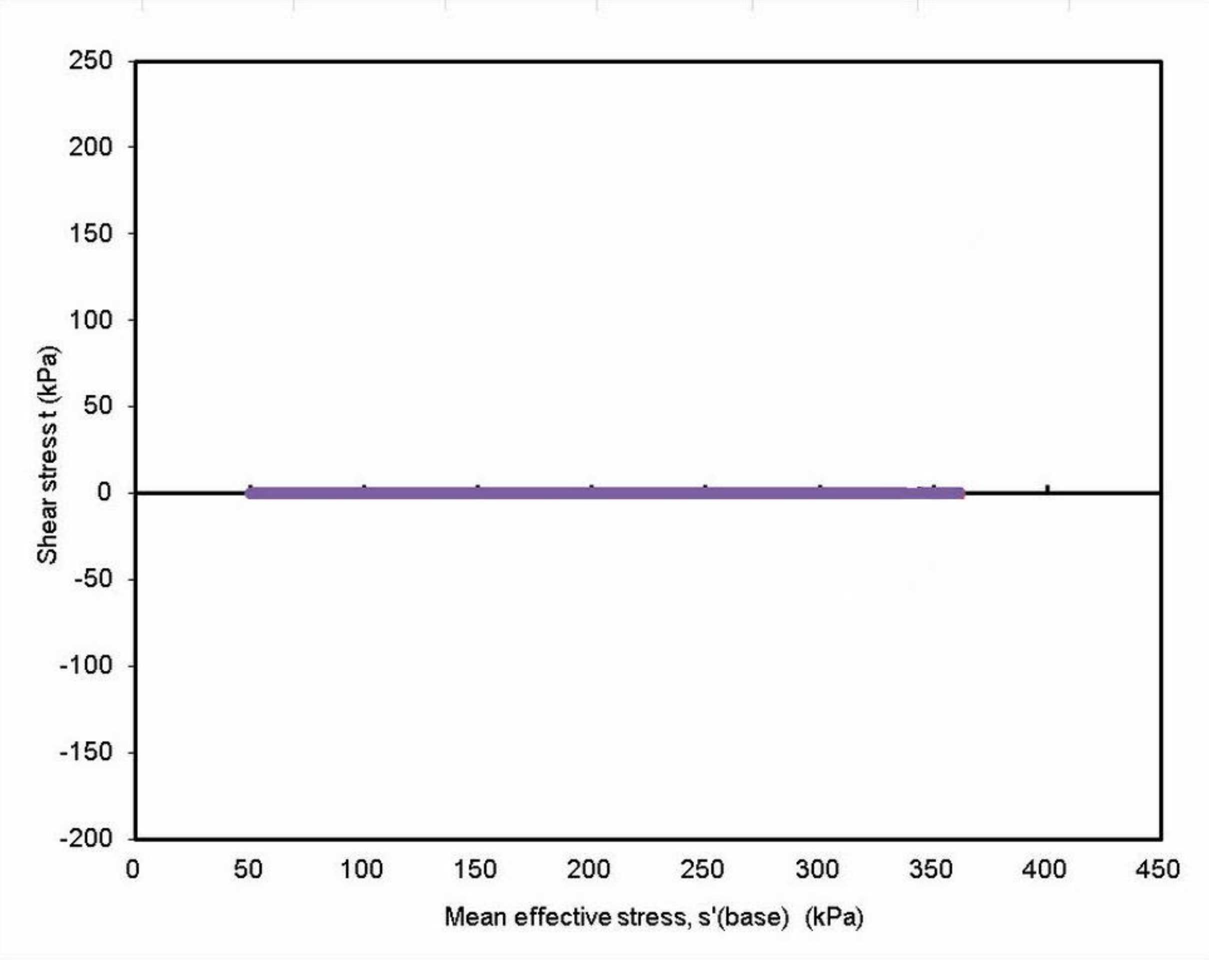
Strains during a stage



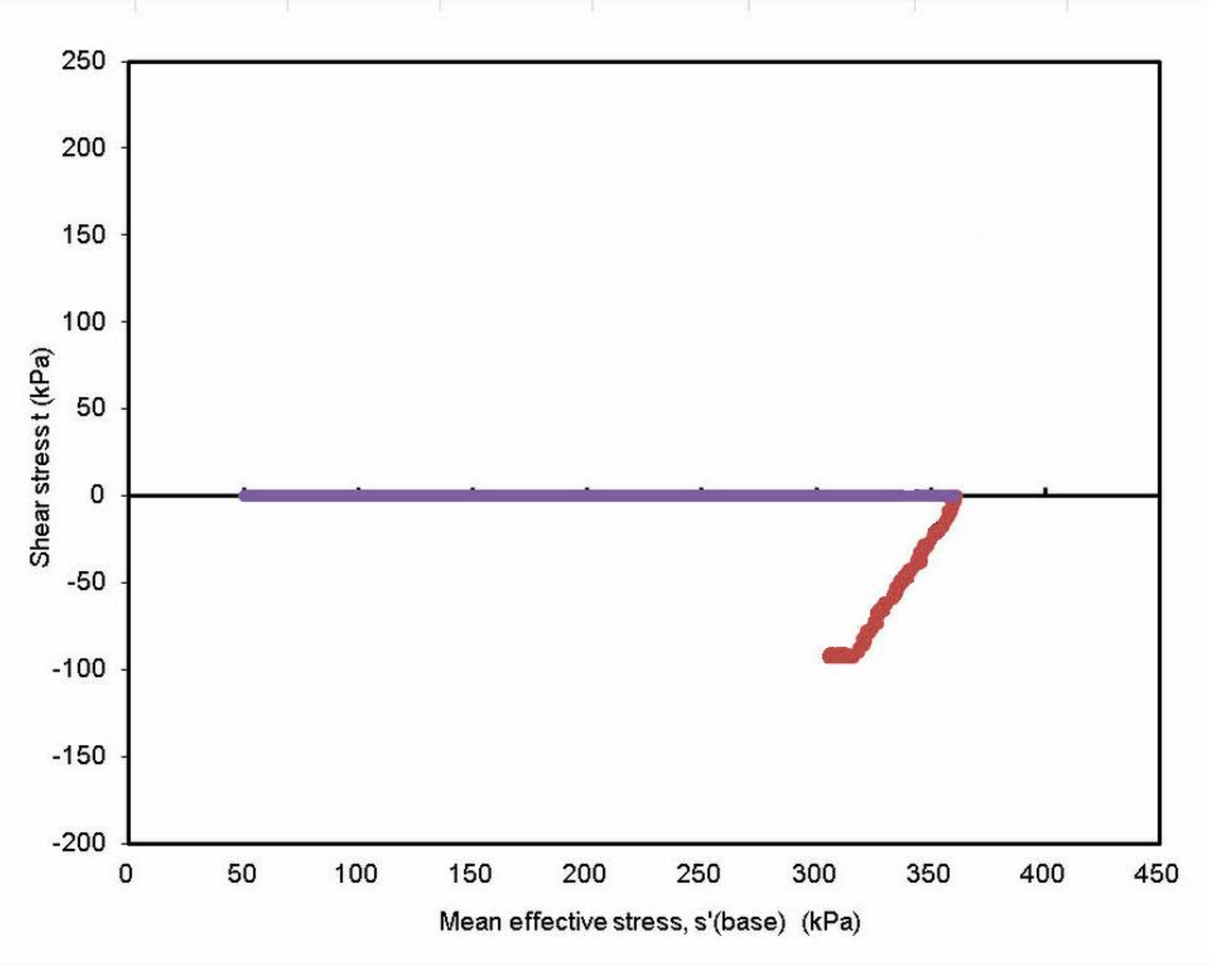
Stress Path

Isotropic Consolidation



Stress Path

Anisotropic Consolidation



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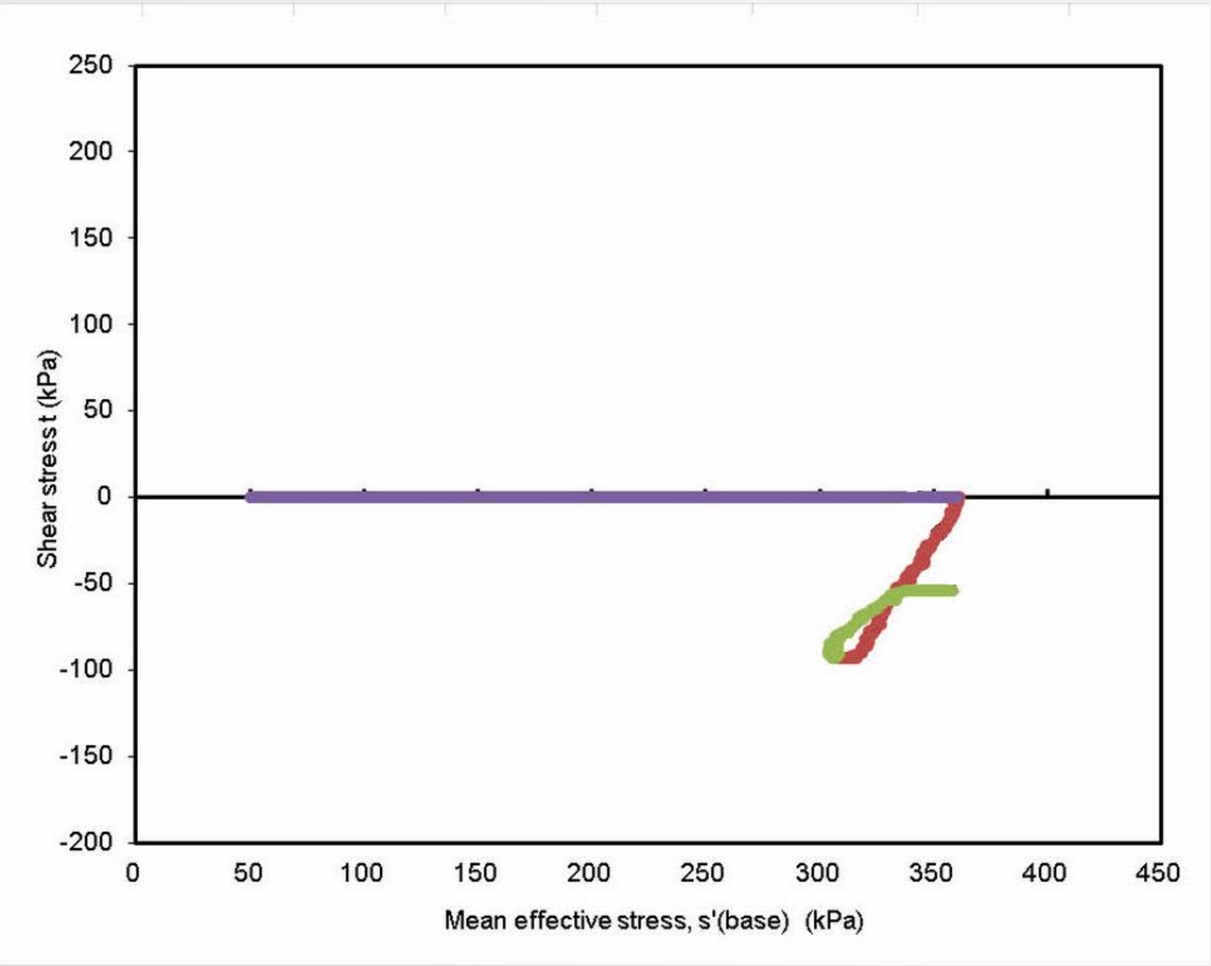
Stress Path

2nd Anisotropic Consolidation



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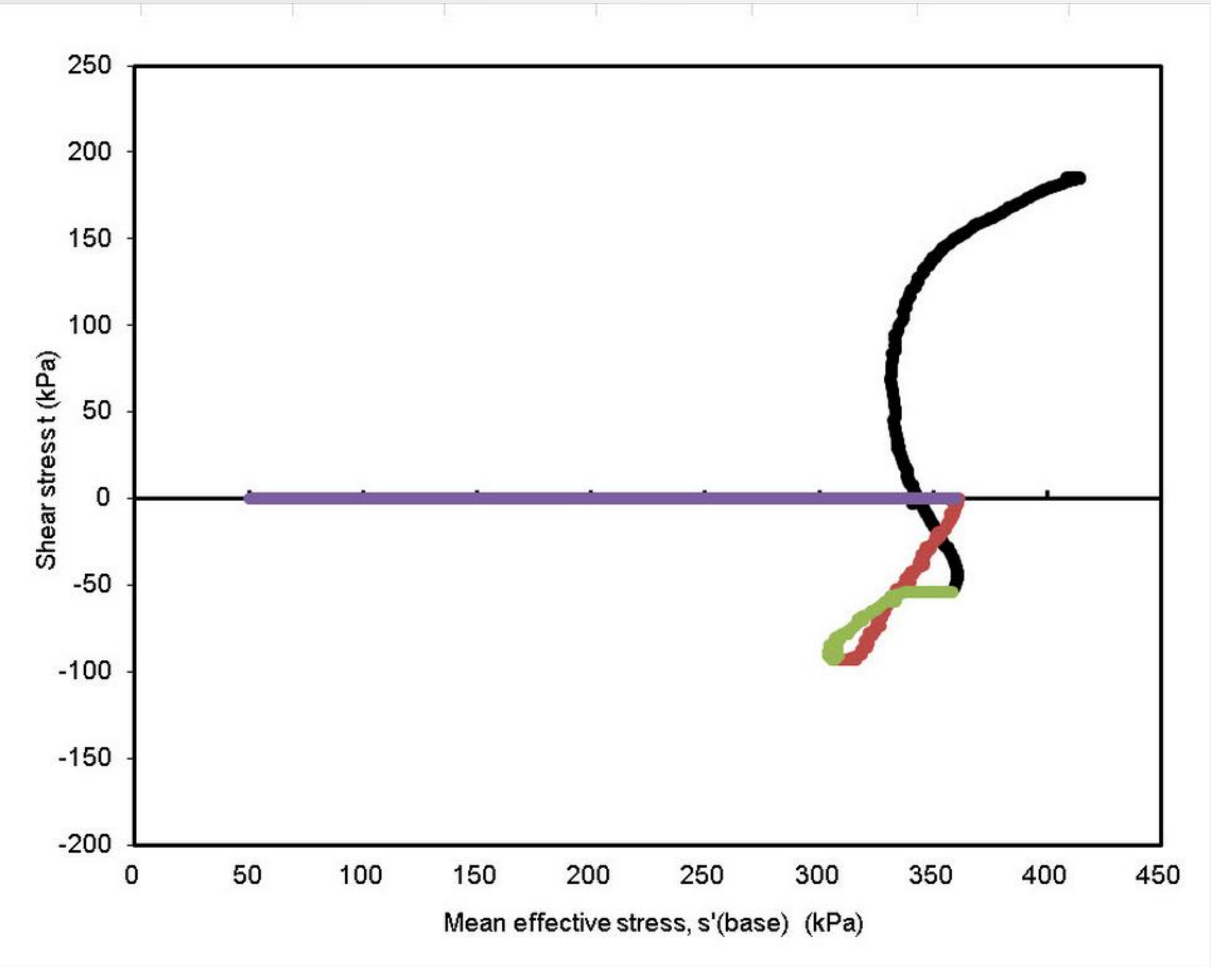
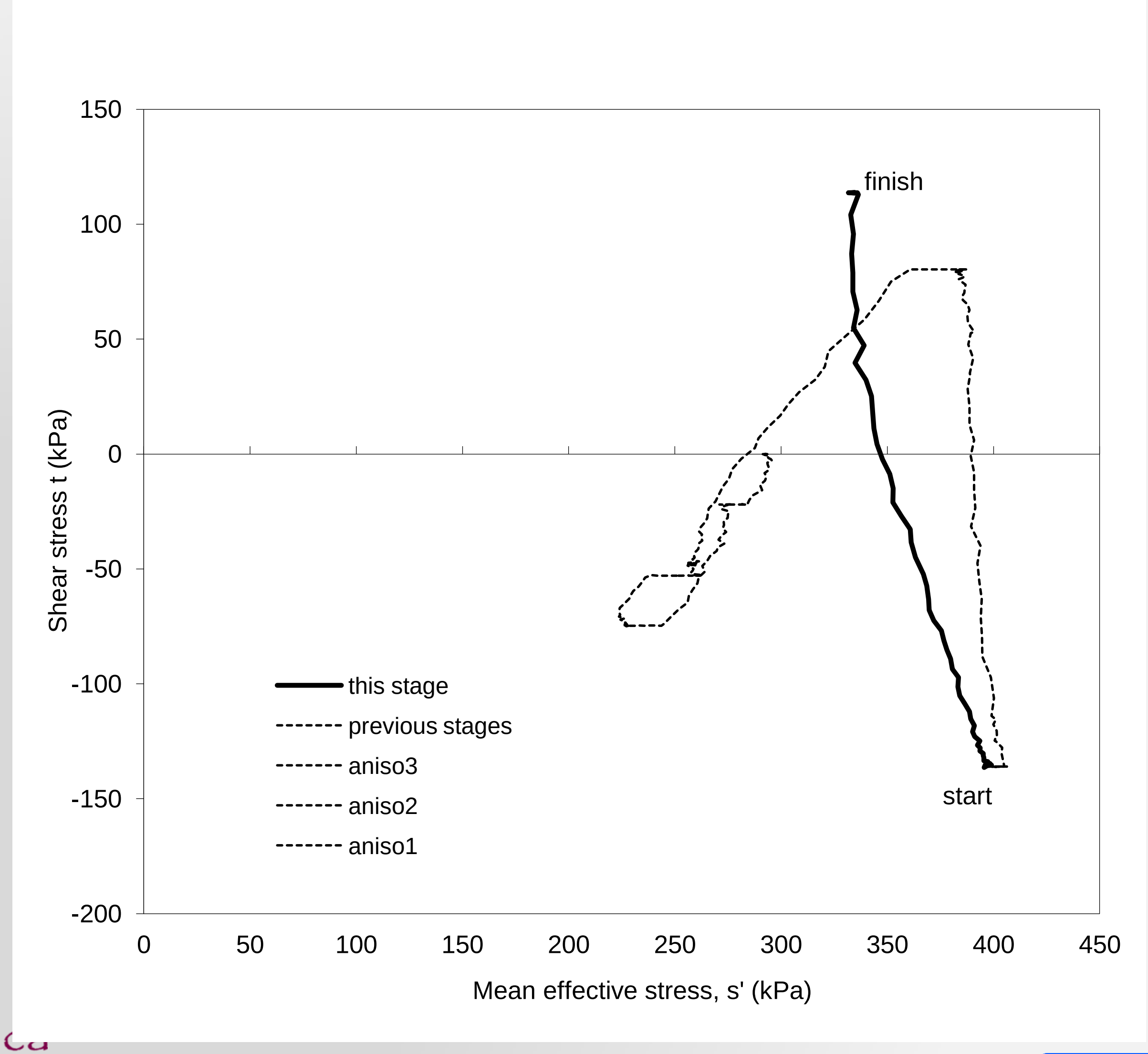
Stress Path

Shearing



Stress path of a test



Geotechnical MEX equipe
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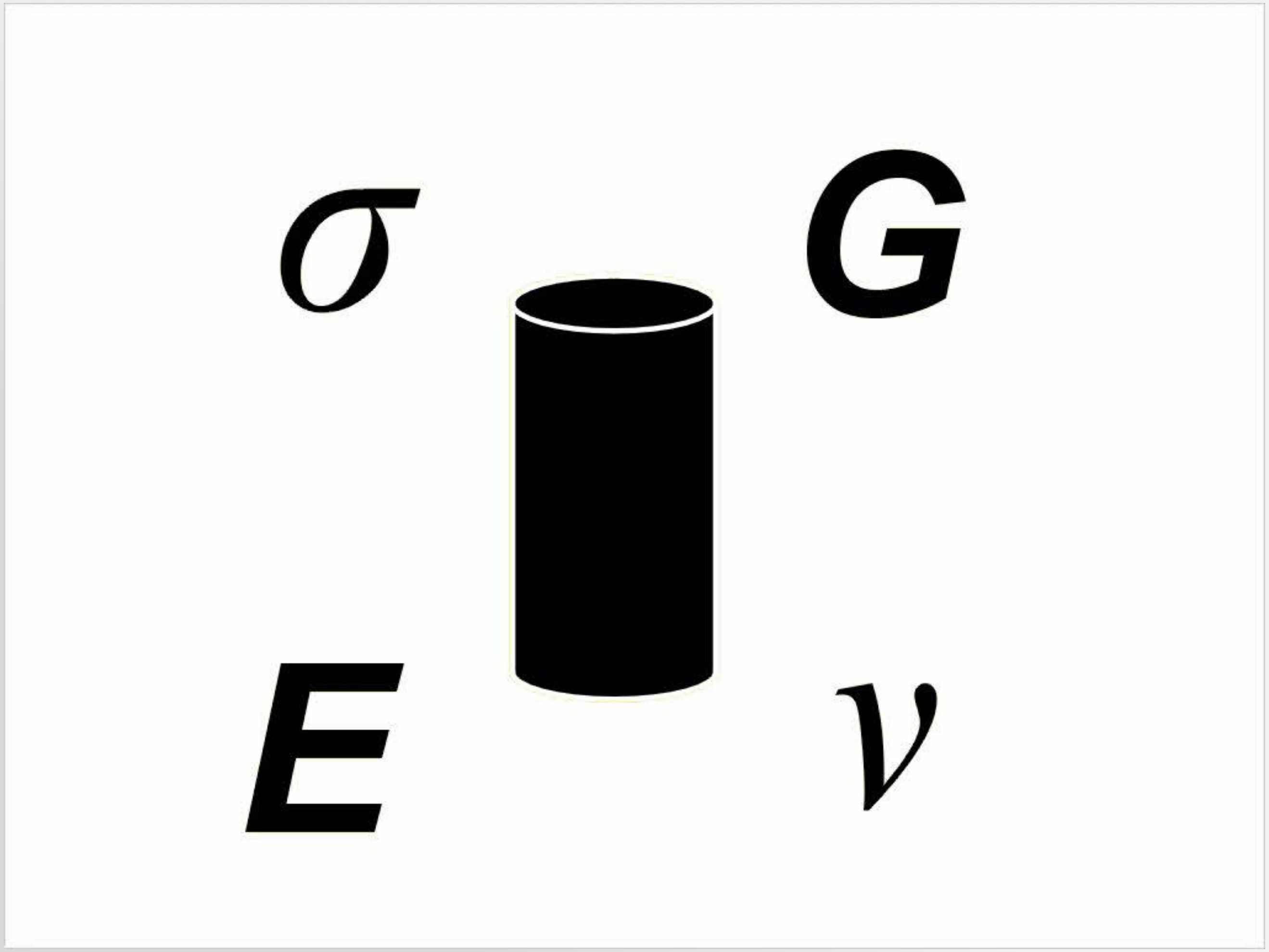
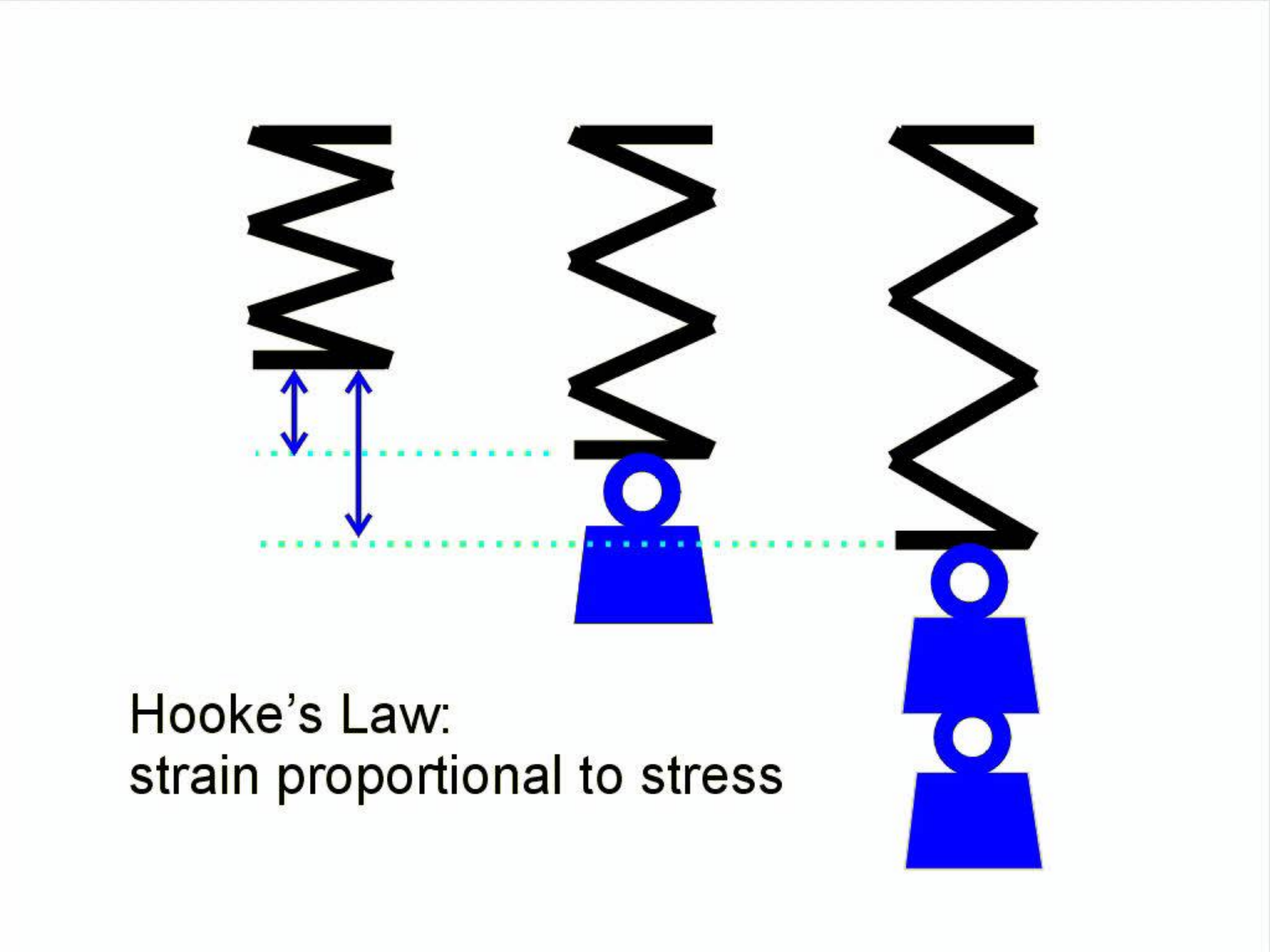
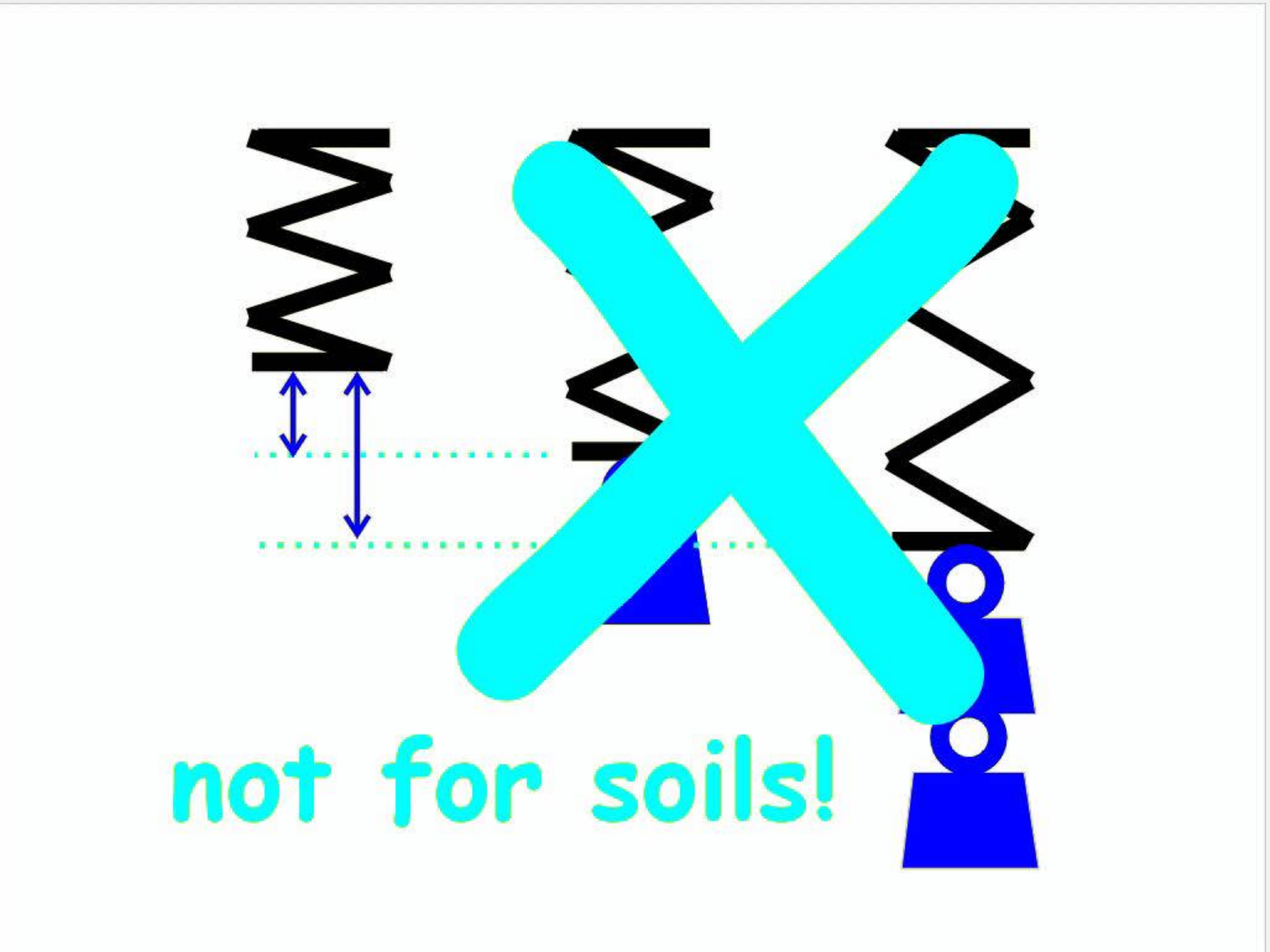
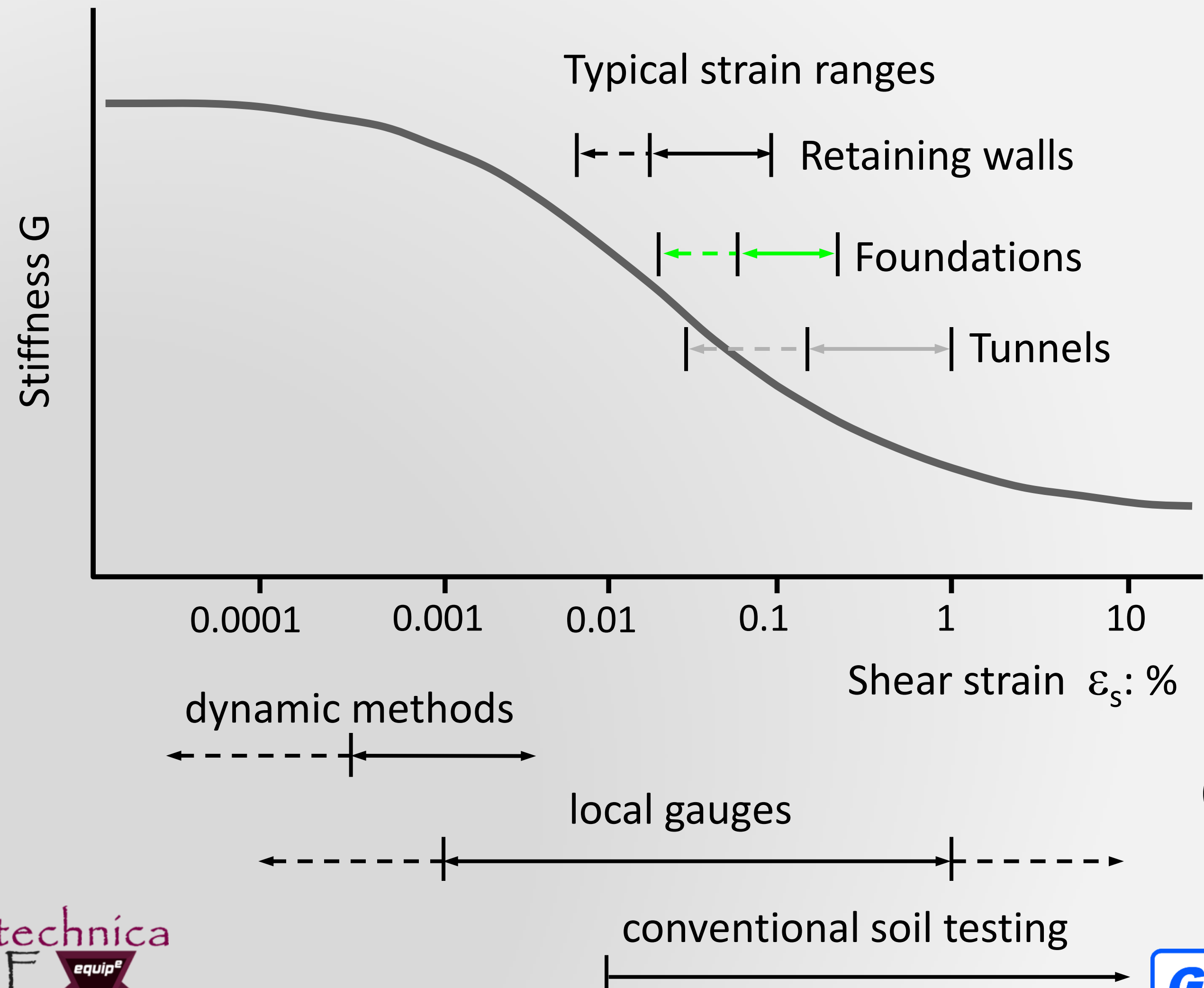


Measurements allow for different orientations


Hooke's Law:
strain proportional to stress


not for soils!

Measurement of Stiffness



(Atkinson, 2000)

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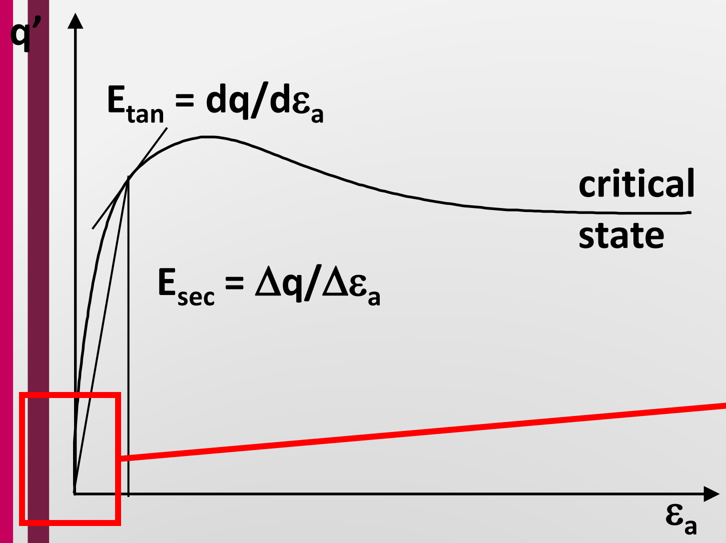
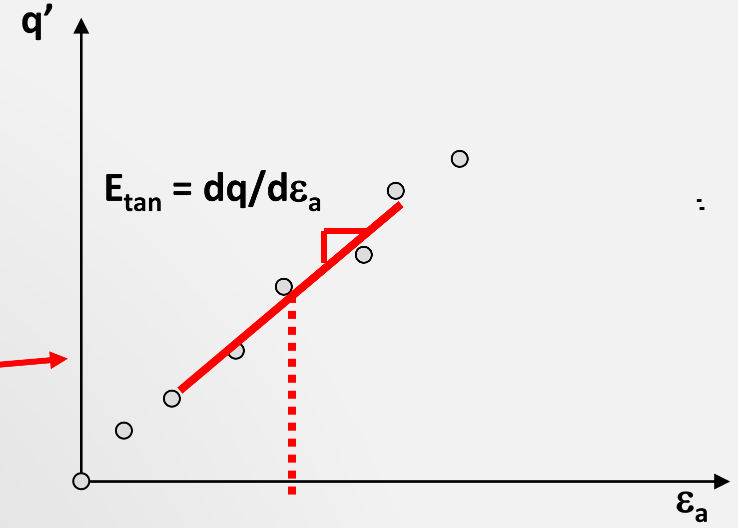
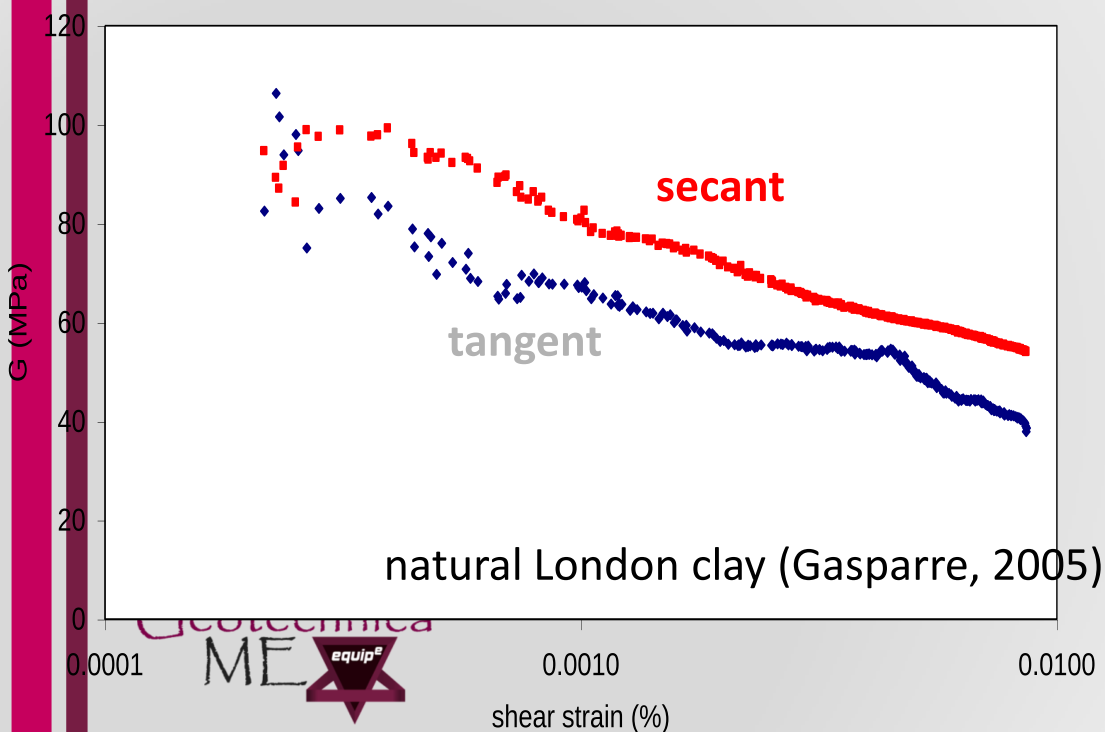


calculation of tangent stiffnesses



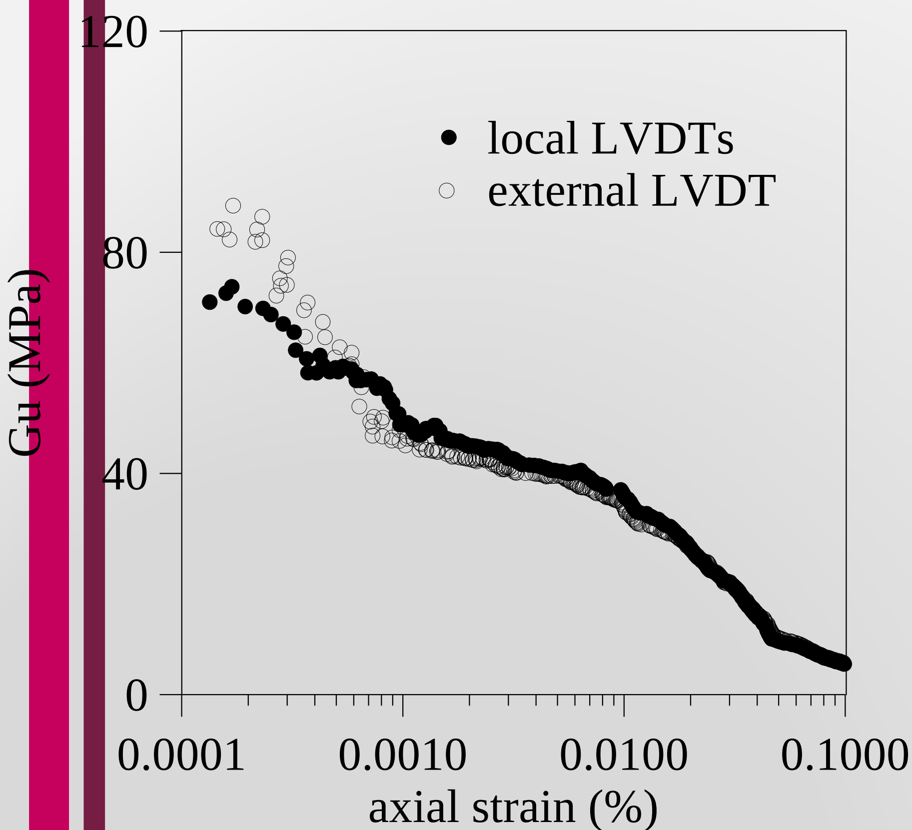


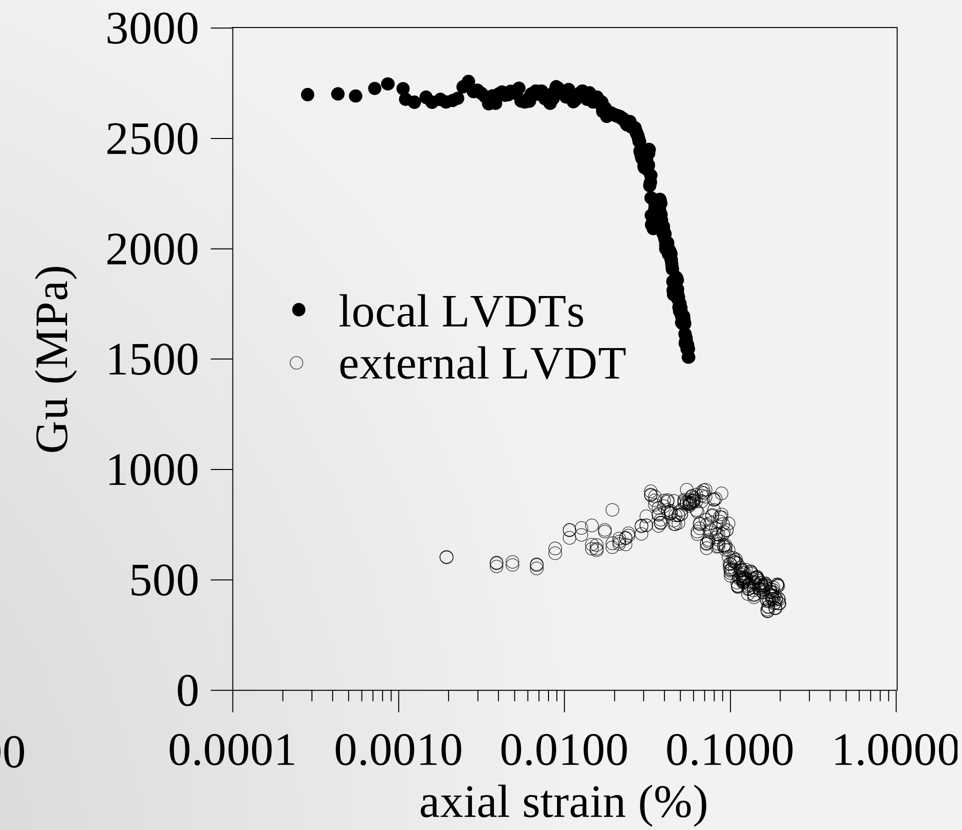
natural London clay (Gasparre, 2005)

- gradient over odd number of points
- No. of points in regression depends on No. of number data points recorded (use a fixed strain interval)
- plot stiffness against strain at central point

- **tangents always more scattered than secant at small strains (also have more meaning)**

Measurement of Stiffness – Examples of Tangent Stiffnesses



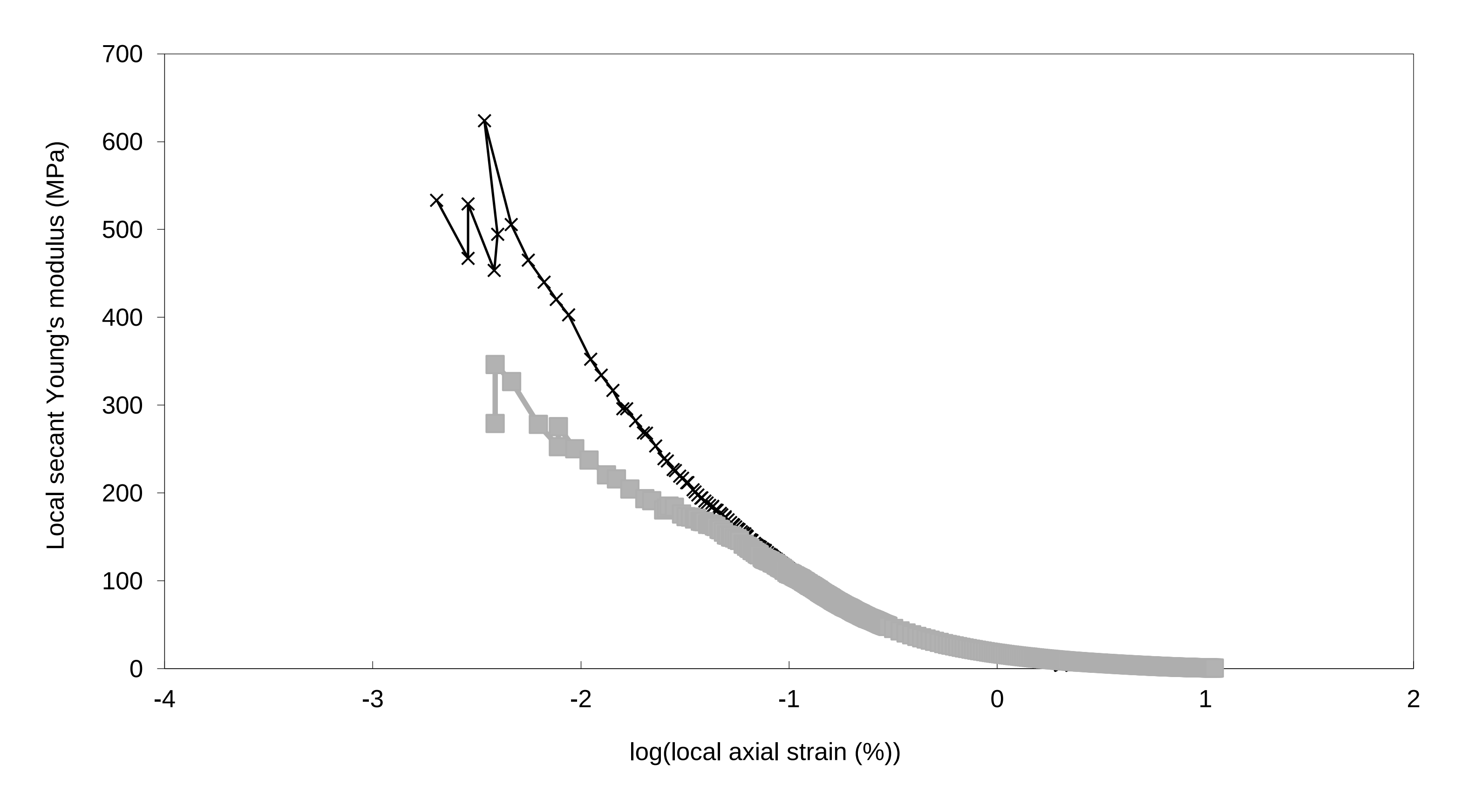


- reconstituted kaolin – low G

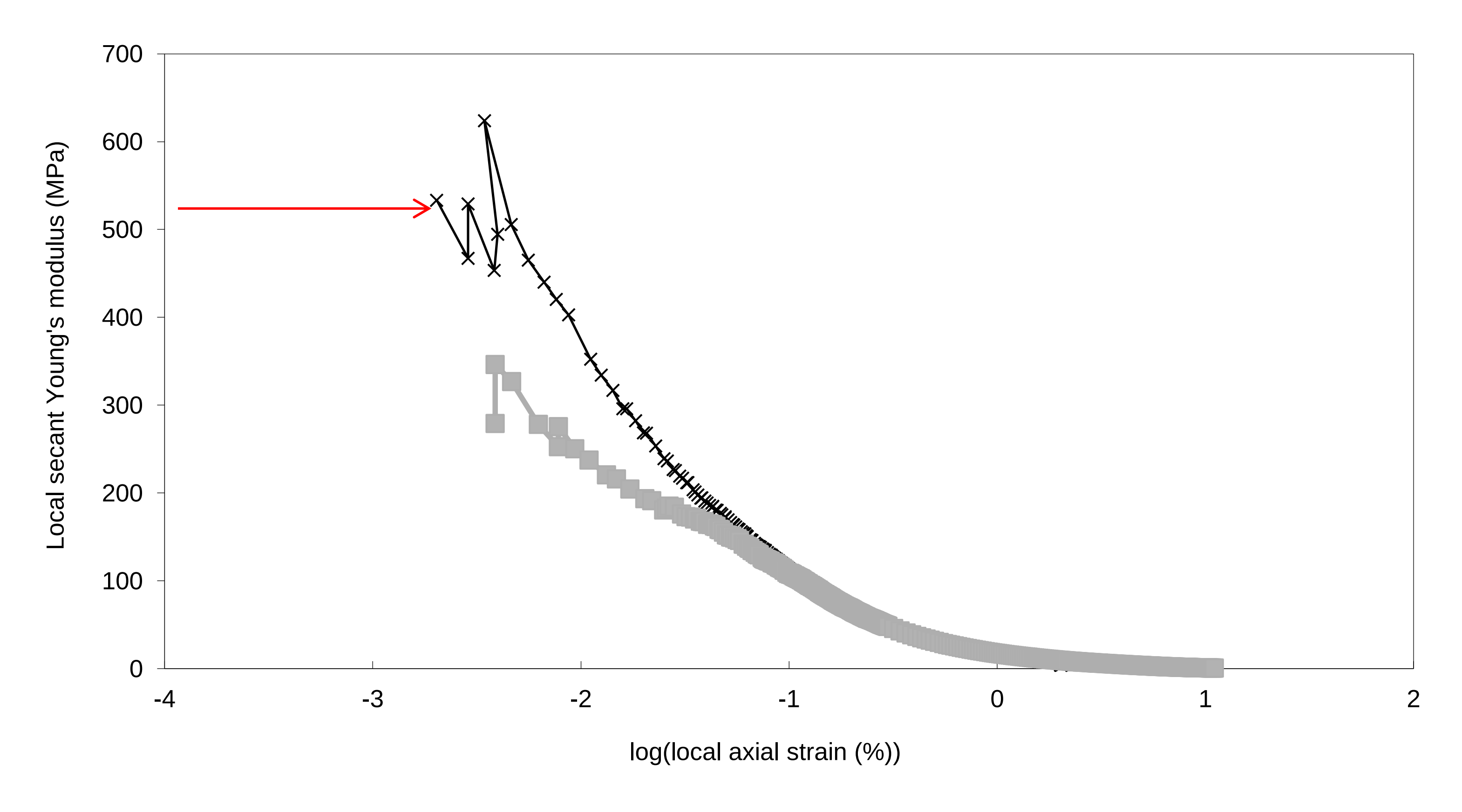
- natural Greensand – very high G
- suction cap used & compliance correction made
- strains prior to shearing small

(Cuccovillo & Coop, 1997)

Stiffness, local and external



Stiffness, local and external



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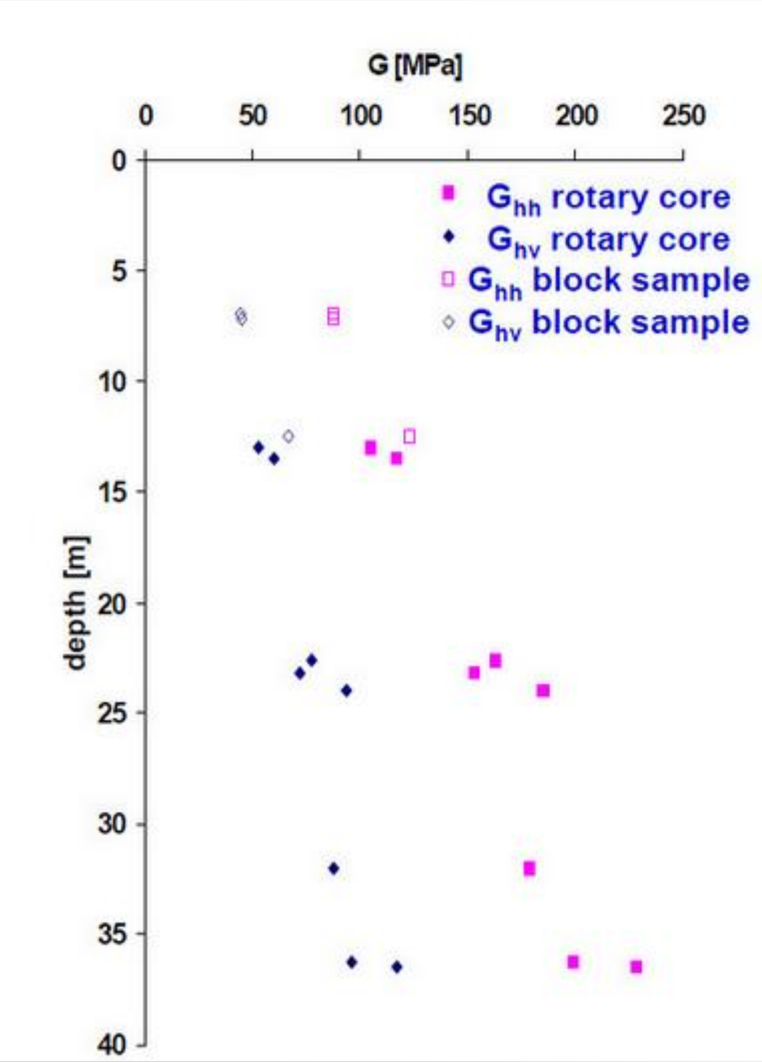
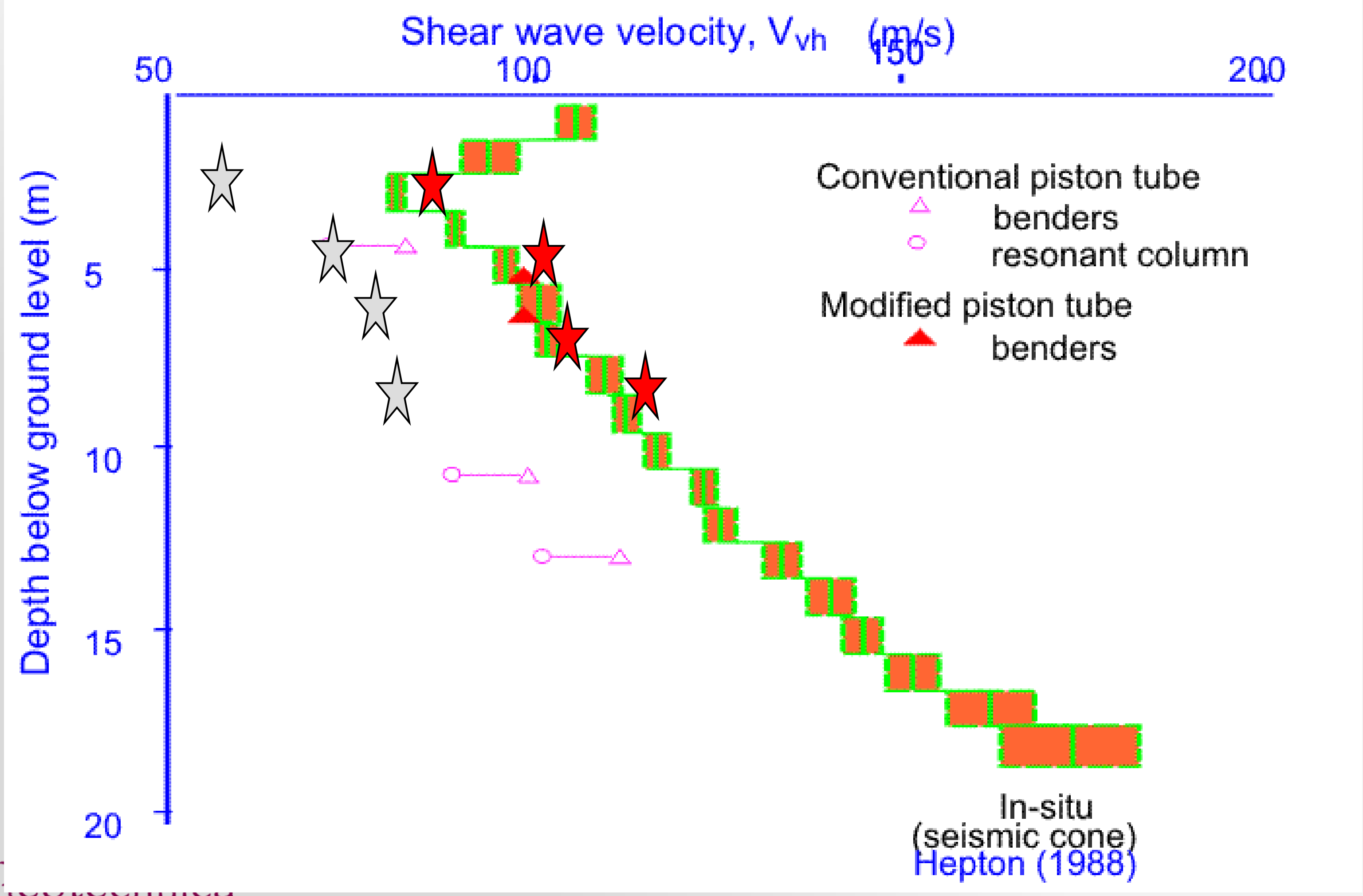
Anisotropy in London Clay



Gasparre (2005)

Sample quality assessment based on shear wave velocity



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Black Red Magenta Yellow Green Blue Cyan Brown White
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0 cm 1 2 3 4 5 6 7 8 cm
Project Name: TOOTING
Project No: GEO / 80050
Borehole No: BH1
Sample No: 018
Depth (m): 8.70 - 9.00

Using the equipment for Poisson's ratio and small strain stiffness of rock

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Where have we come in 25+yrs??

Is it new or just commercially viable?

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Summary

- there is much that can go wrong in conducting and interpreting tests
  But it can be done
- we should conduct and interpret tests within a chosen and appropriate theoretical framework
- level of complexity of tests should be appropriate to theoretical framework and design method
- You need to know what you are specifying and what can be realistically achieved, commercial vs research
- You need to have confidence is those performing the tests

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Value for money

I must say - thanks

- I wish to acknowledge the help from
  - David Hight
  - Tom Lunne
  - Matthew Coop

For some of the slides contained in this presentation

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Conclusions!

- Rubbish in – Rubbish out!
- Quality in – Quality out (hopefully/possibly)

Conclusions!

- We now have a new level of testing available to us which I believe should be consider ‘routine (advanced) testing’ for use when projects warrant it and samples are of the right quality.

- Particularly relevant for modelling and in ‘serviceability’ situations

Available for consultancy

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And finally

Thank you for your attention

Contact – jpowell@geolabs.co.uk