University of Sao Paulo – Polytechnic School

A Course of Lectures in Geotechnical Engineering

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October 2016

4 – Parameters for Design

Topics

1 – Basic Soil Behaviour

2 – Geological Origins of Engineering Soils

3 – Simple Analyses with Pencil and Paper

4 – Parameters for Design

Fundamental components of an undergraduate course

4 – Parameters for Design

4.1 Basis of design

4.2 Parameters from description

4.3 Parameters from tests
principles and errors
basic laboratory and in situ tests
interpretation of shear tests

Before you start

What is critical?
- collapse or movement or seepage
- immediate or long term

What analyses are proposed?
- simple pencil and paper
- standard tables and charts
- numerical analyses

How will parameters be determined?
- from description and classification
- from in situ tests
- from laboratory tests

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Parameters and Factors

Structure	Critical Condition	Analysis	Parameter	Factor
Slope	Drained stability	Limit equilibrium	ϕ'_c u	$F_s = 1$
Foundation on clay	Drained settlement	Limit equilibrium	s_u (peak)	LF = 3
Foundation on sand	Drained settlement	Limit equilibrium	peak strength	LF = 3
Foundation	Drained settlement	Elastic	E' or M'	Relate to strain

Types of soil parameters

Universal – same for all soils

Material parameters – depend only on the grains

State dependent parameters – depend on the grains and current state

Methods for determination

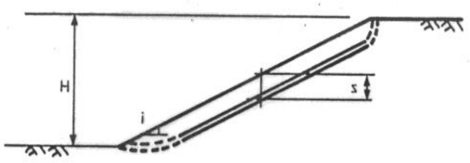
From description and classification

From laboratory tests

From in situ tests

Strength parameters for slopes

The long term (drained) state will nearly always be worse than a short term (undrained) state.



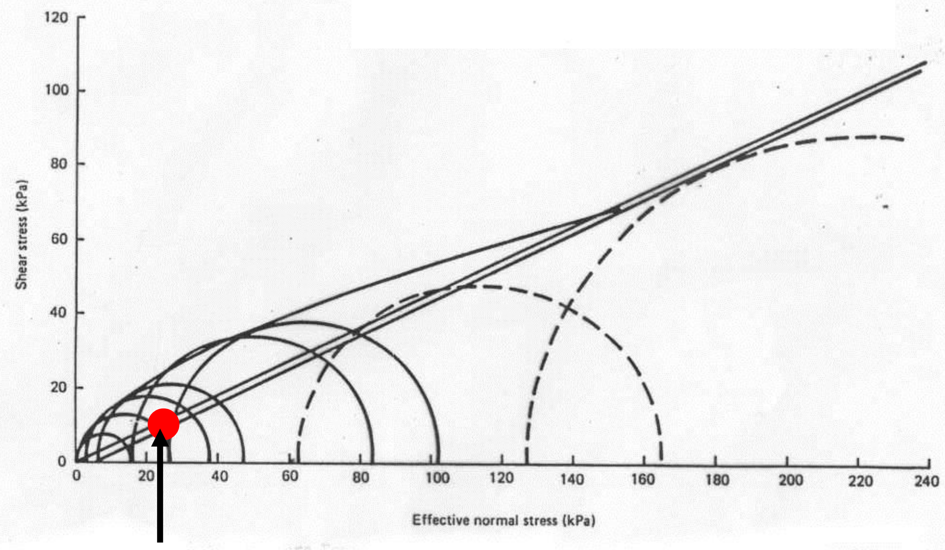
For a safe slope use:

ϕ'_{cv} and c' = 0

worst credible pore pressure

$F_s \geq 1.0$

Be careful of residual strength



Stress on the failure planes in the ground

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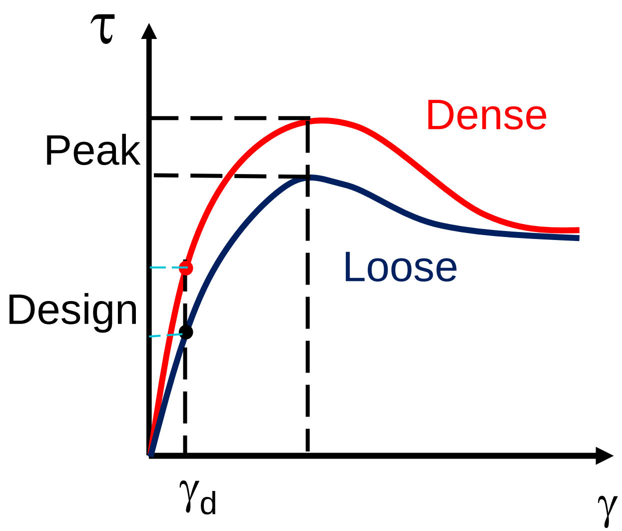
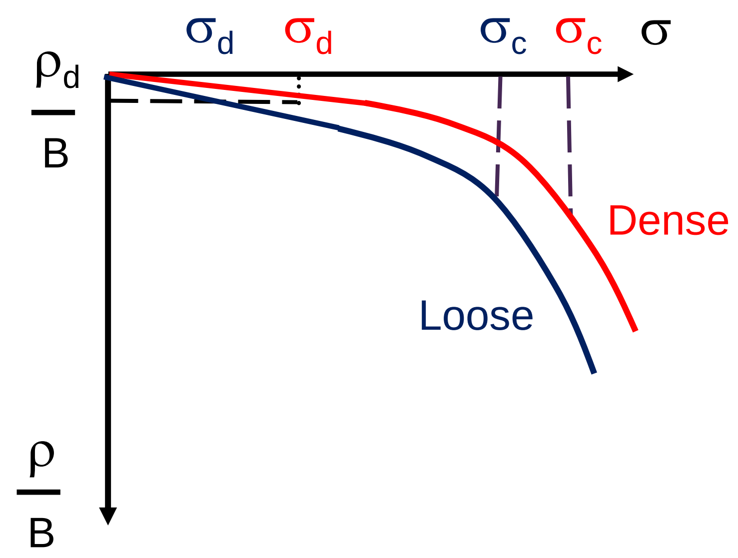
Strength for Limiting Foundation Settlement



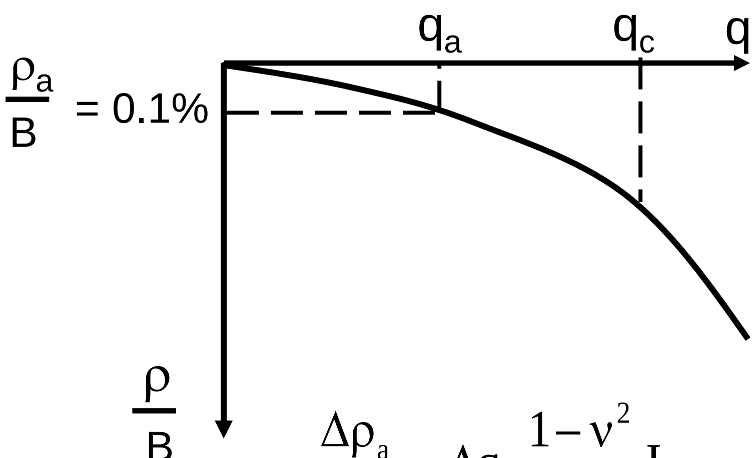
Laboratory test



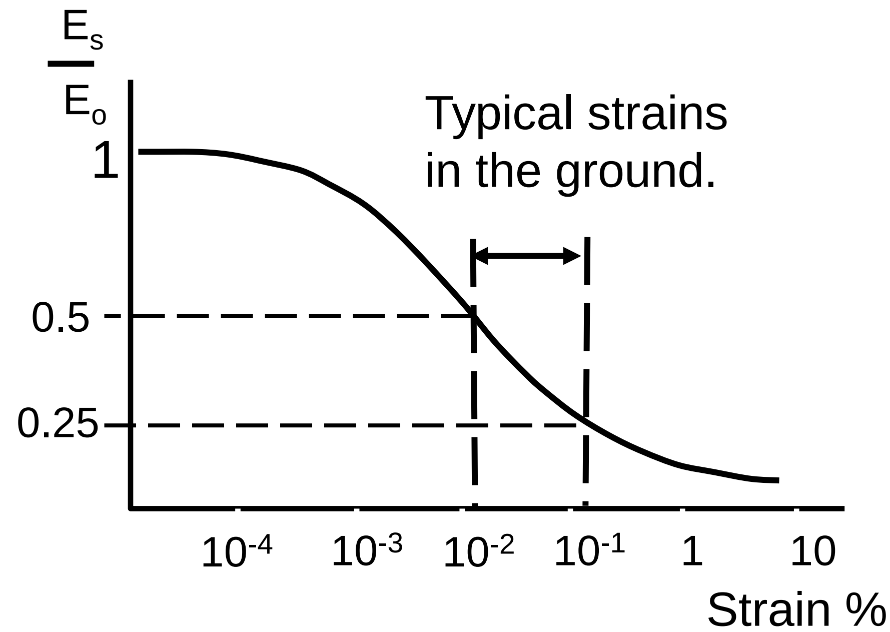
Foundation settlement

$$\frac{\tau_d}{\tau_p} = \frac{\sigma_d}{\sigma_c} =$$ Factor to limit settlement – based on peak strength = 0.3

Settlement of foundations – elastic analyses.



$$\frac{\Delta\rho_a}{B} = \Delta q_a \frac{1-\nu^2}{E} I_\rho$$



For a drained state: E' and ν'
For an undrained state: E_u and ν_u = ½

Select a value of E' or E_u related to the settlement and the mean strains in the ground

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Permeability and drainage.

Very difficult to measure and very large range

Soil	Sizes	k m/s	Time for flow of 1m
Gravel	>2mm	$>10^{-2}$	<1 minute
Sand	2mm to 0.06mm	10^{-2} to 10^{-5}	
Silt	0.06 to 0.002mm	10^{-5} to 10^{-8}	
Clay	<0.002mm	$<10^{-8}$	>3 years

Principles of Design.

For stability: CS strength + F_s = 1.

For movement: peak strength + L_f = 0.3

or E related to strain.

Drainage: sand and gravel - drained

silt and clay - undrained

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Soil Description.

The nature of the grains.

Material parameters.

State: stress and water content.

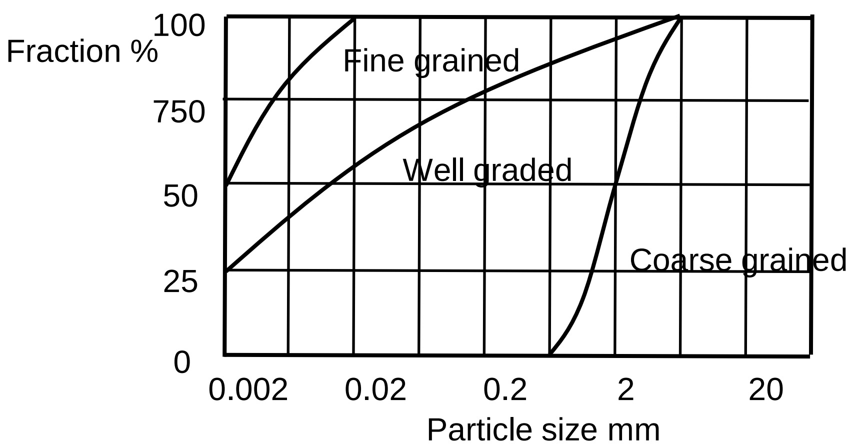
State dependent parameters.

Structure, fabric, bonding.

Description of the grains

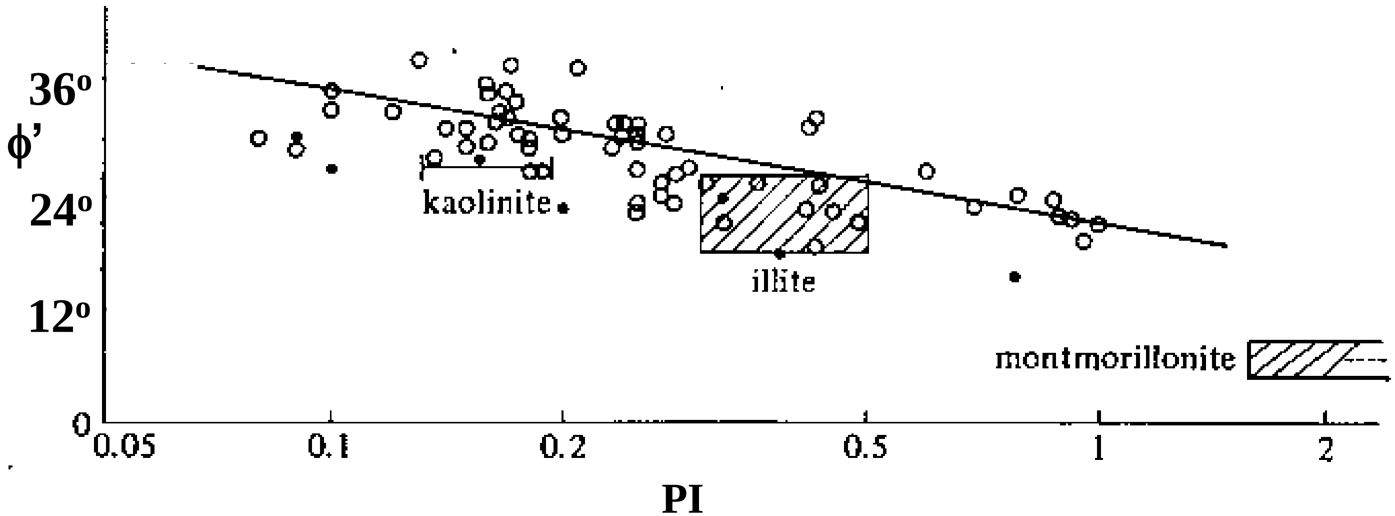






Grading
Mineralogy
Grain shape
Plasticity
Bonding

Critical state friction angle ϕ'_{cv}



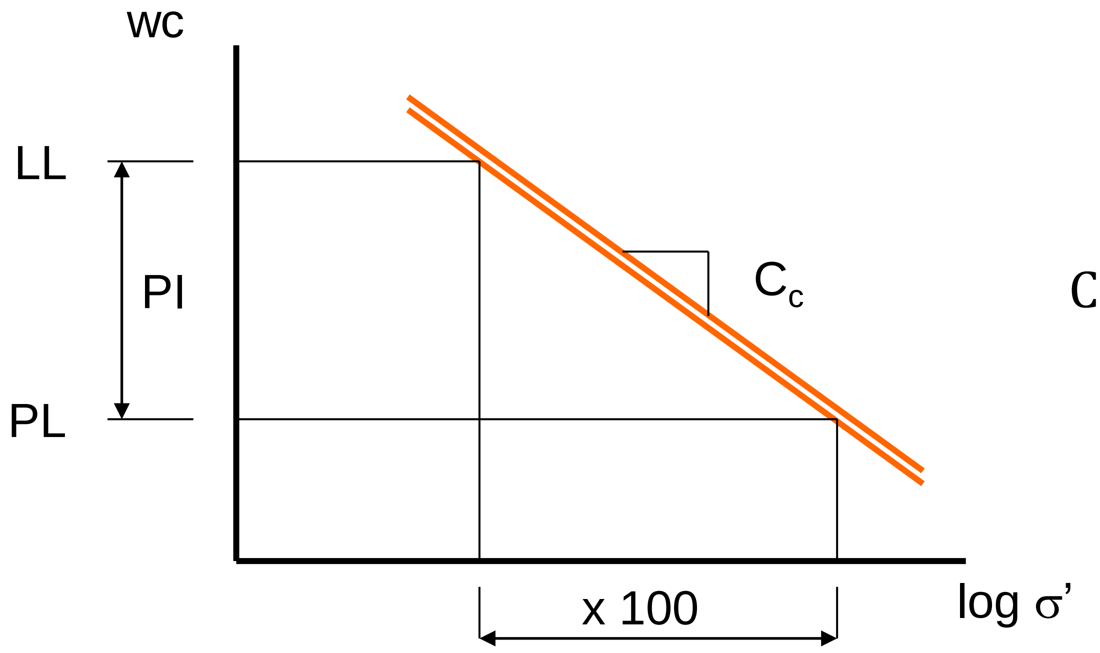
(Muir Wood 1990)

Rounded sand: 32°

Angular sand: 35°

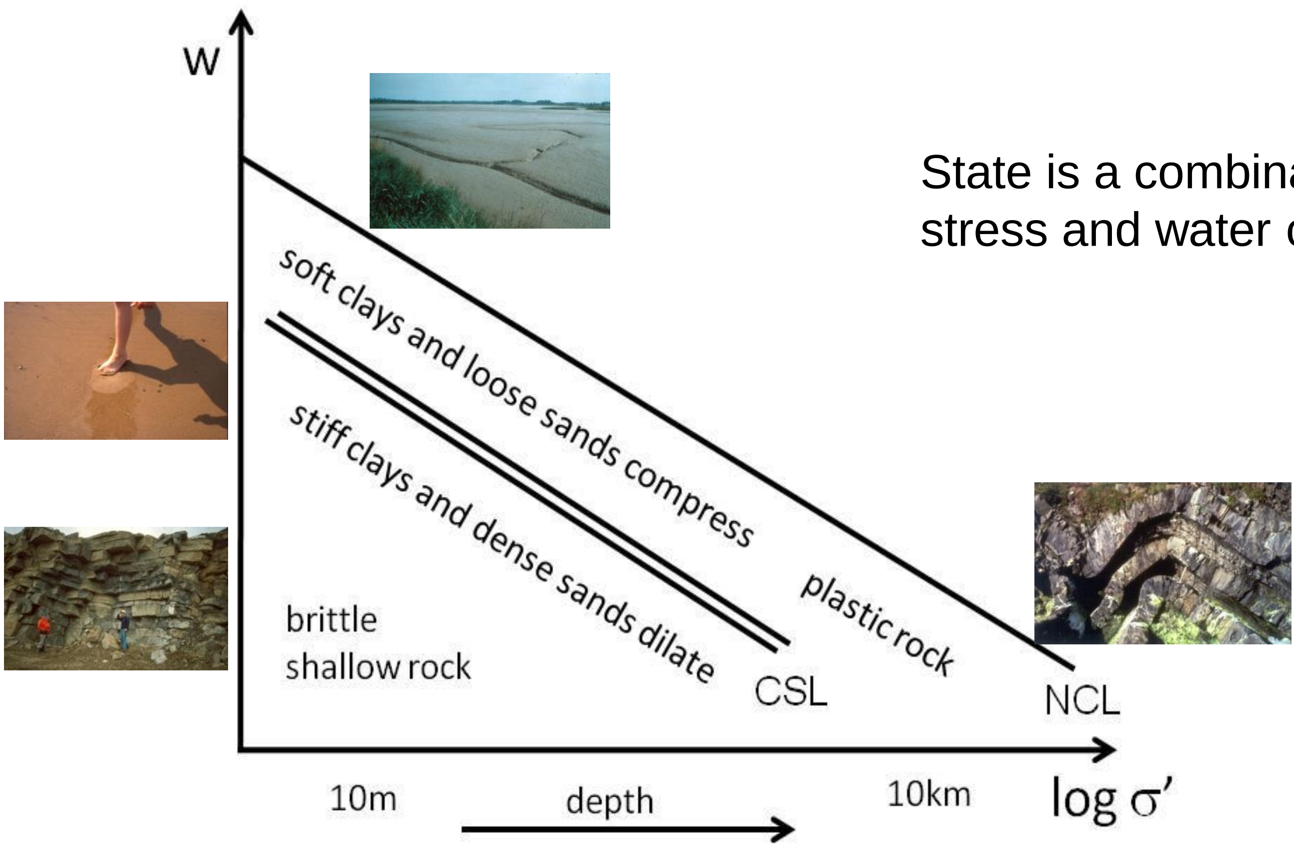
Carbonate sand: 40°

Compressibility C_c related to PI.



$$C_c = \frac{PI\,.\,G_s}{200}$$

State



State is a combination of stress and water content

State and behaviour at engineering stresses

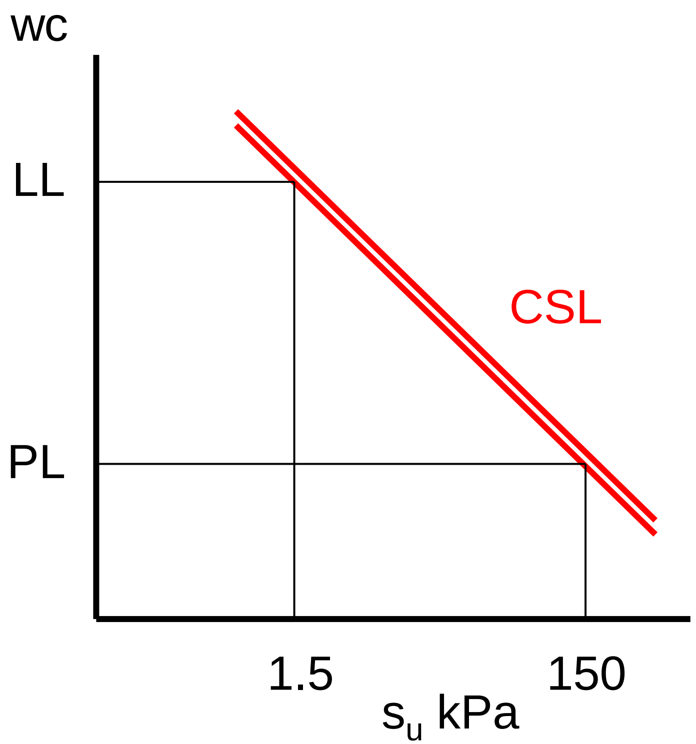
loose → dense

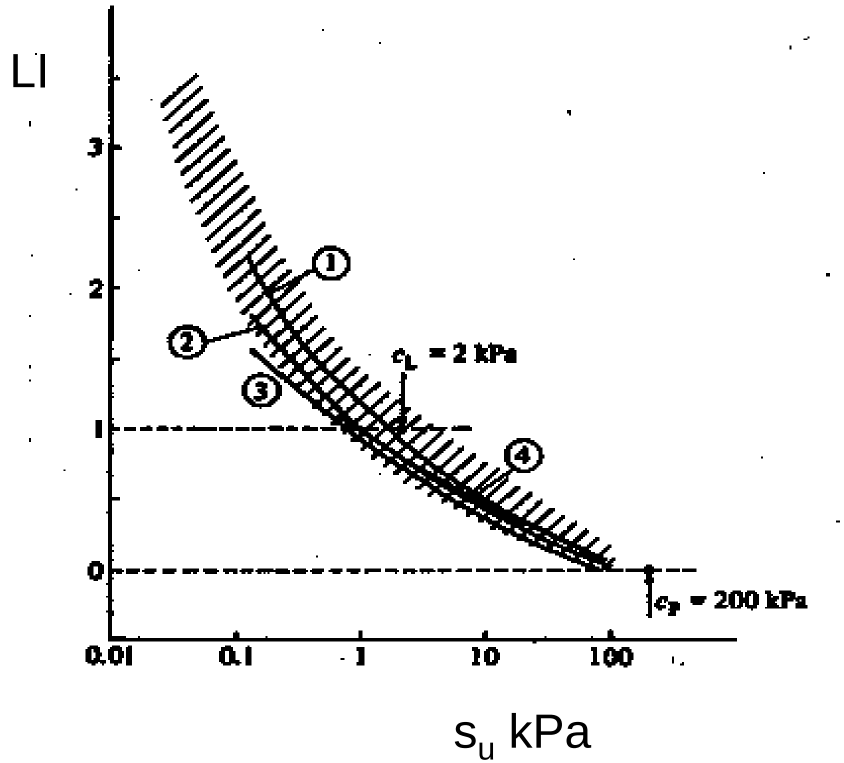
clays: LL → PL (LI)

sands: minimum density → maximum density (D_r)

soft and weak → stiff and strong

Undrained Strength and Water Content



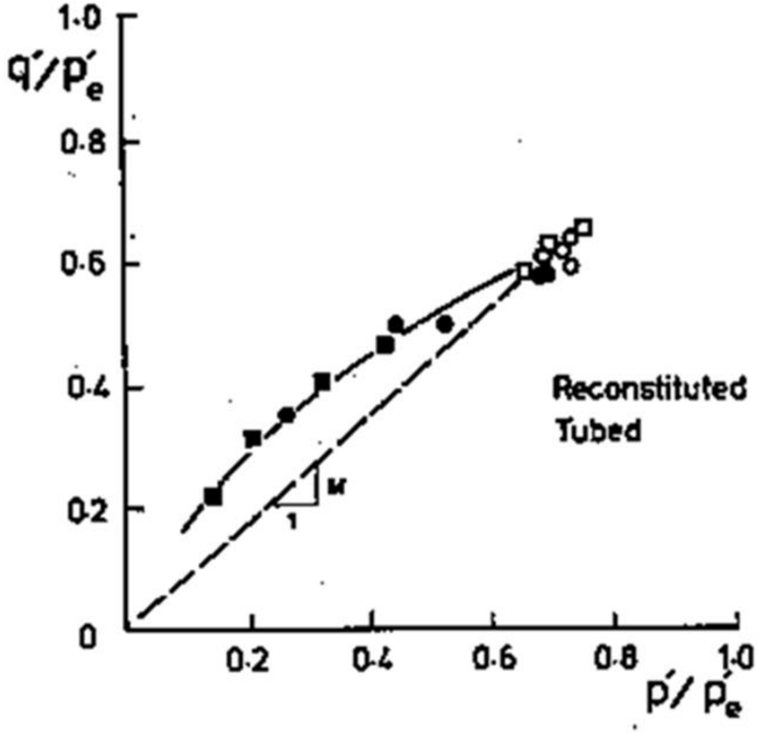


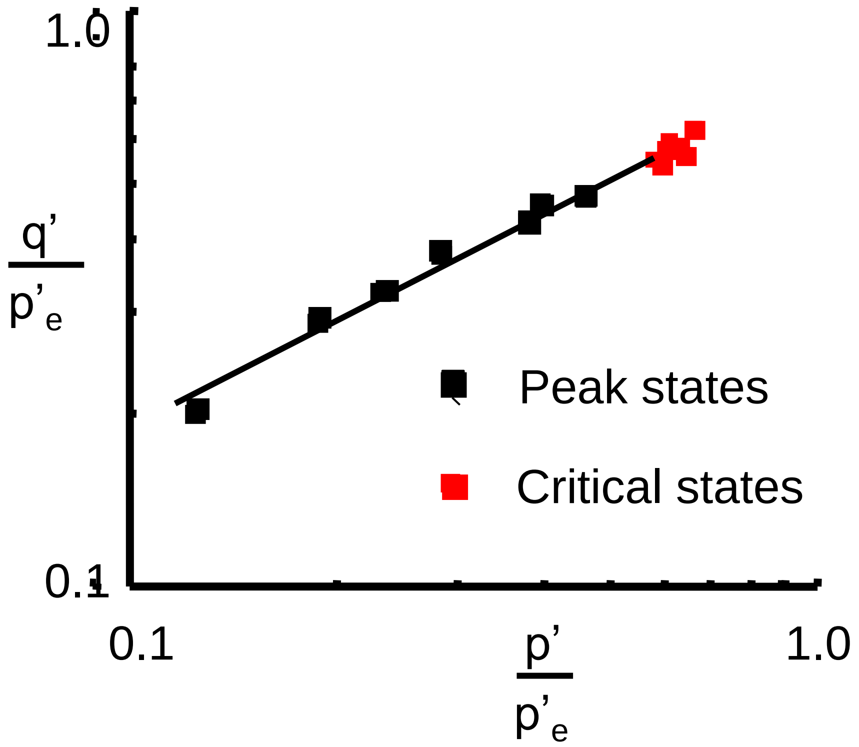
(Muir Wood, 1990)

Peak strength – curved envelope - normalised

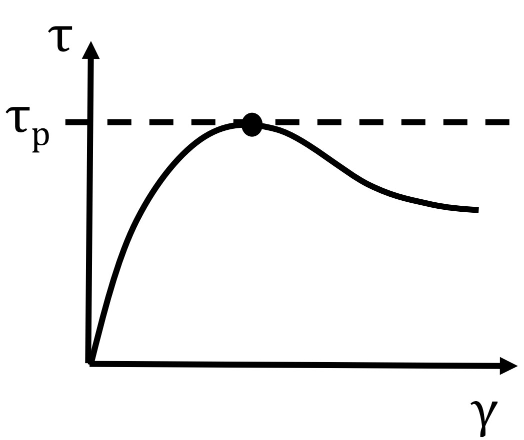
$$\frac{q'}{p'_e} = A\left(\frac{p'}{p'_e}\right)^b$$

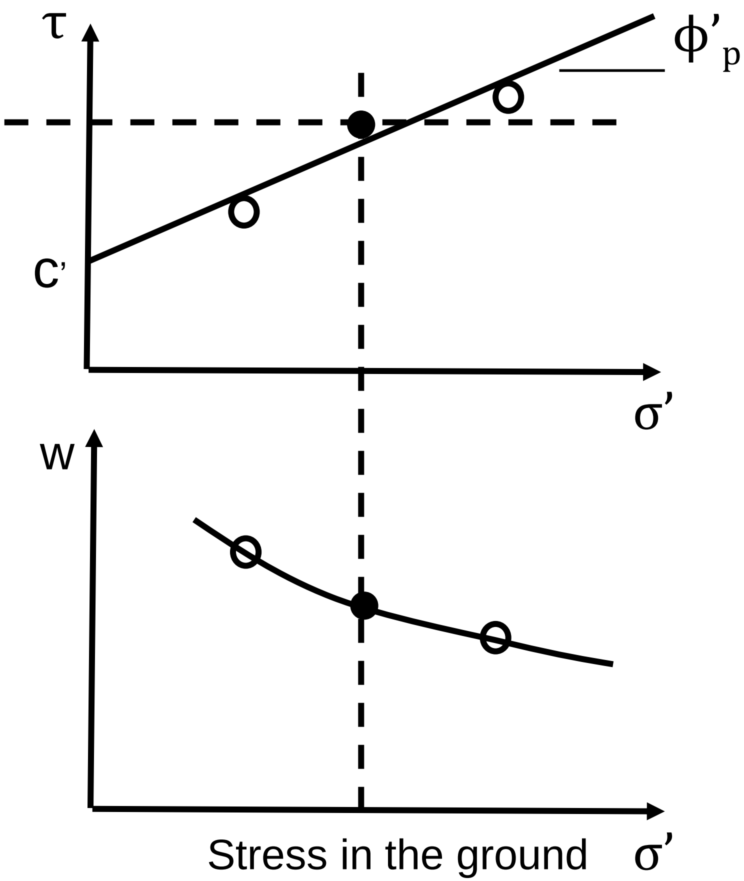
A and b are material parameters





Peak strength – linear envelope

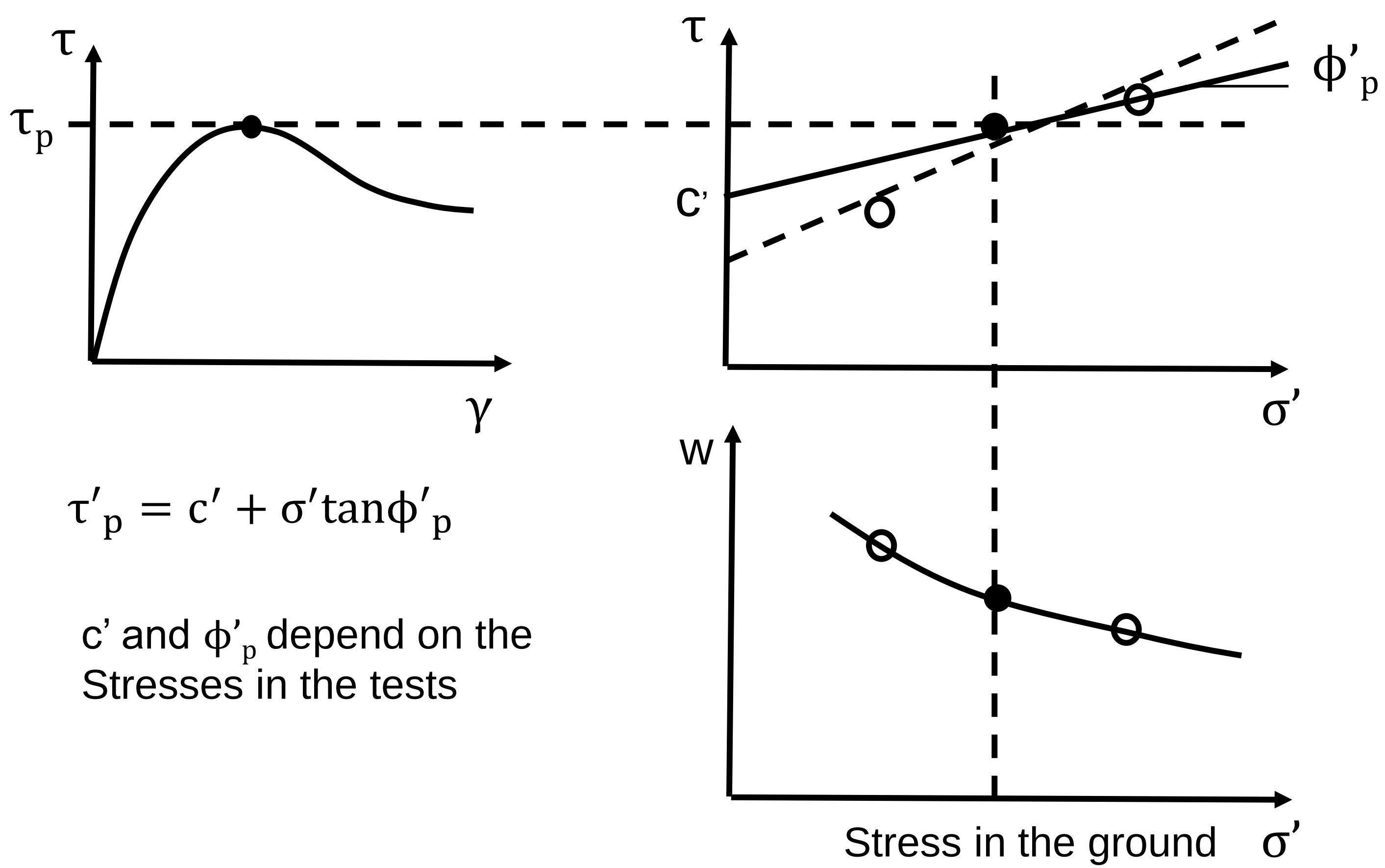




$$\tau'_p = c' + \sigma'\tan\phi'_p$$

c' and ϕ'_p depend on the
Stresses in the tests

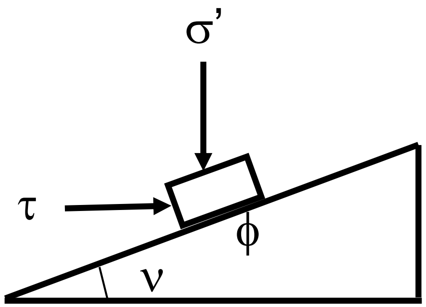
Peak strength – linear envelope



$$\tau'_p = c' + \sigma' \tan\phi'_p$$

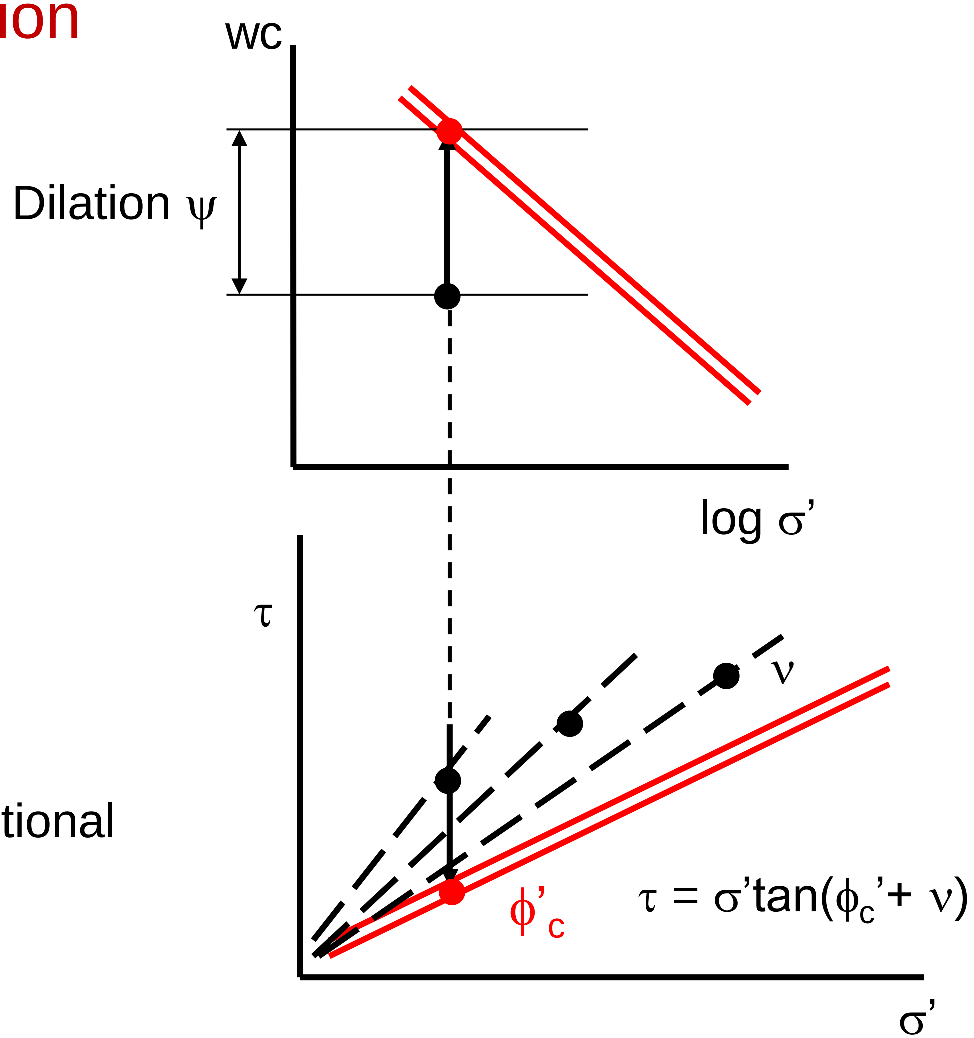
c' and ϕ'_p depend on the Stresses in the tests

Peak strength and dilation



$$\frac{\tau}{\sigma'} = \tan(\phi' + \nu)$$

Peak angle of dilation ν proportional to state parameter ψ



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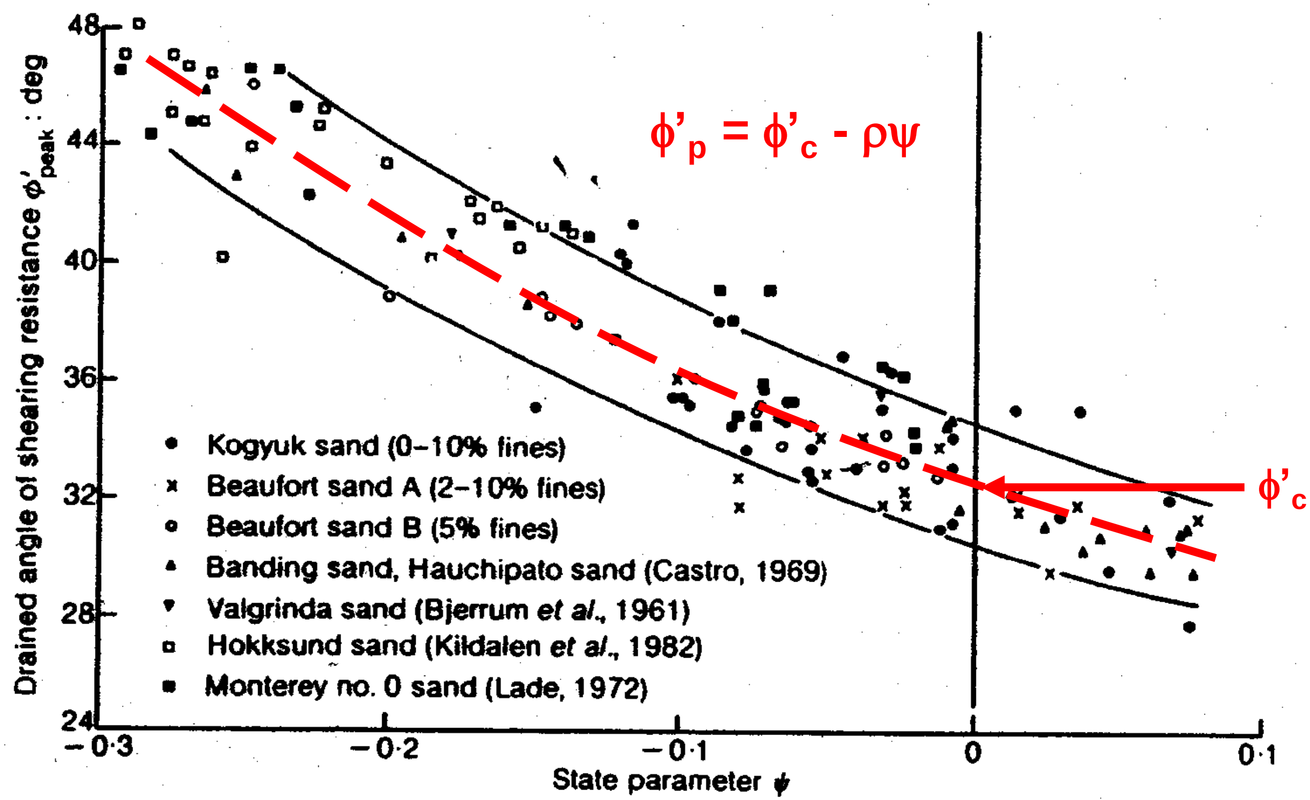
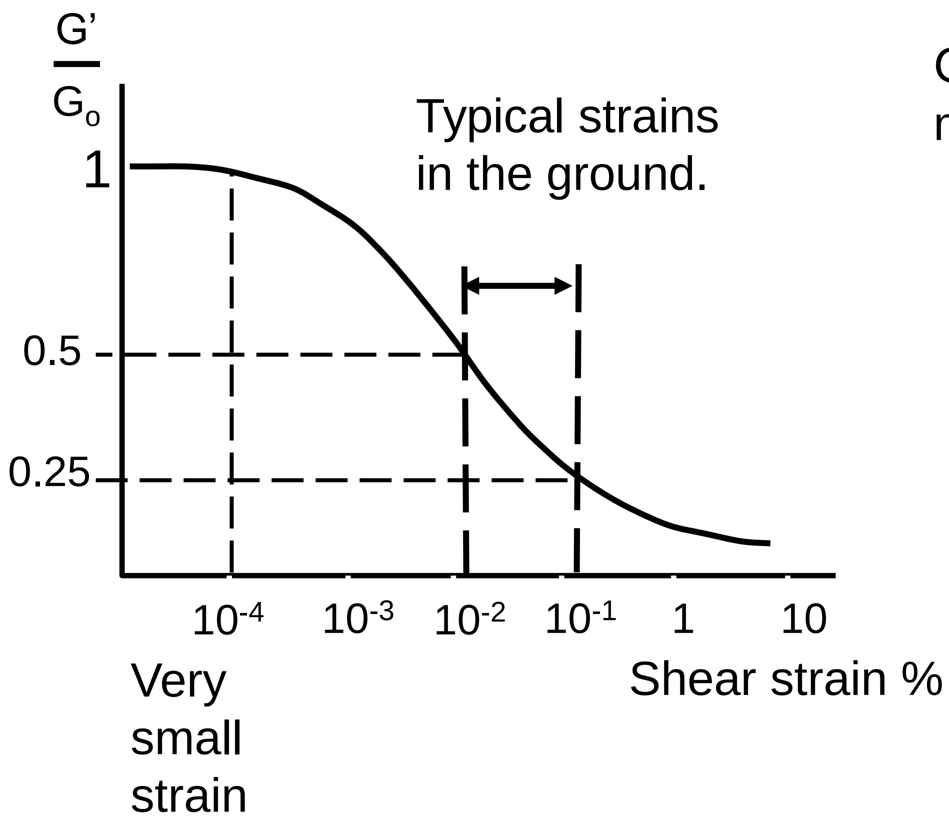
Peak Strength and Dilation



Drained angle of friction as a function of ψ for several sands

(Been and Jefferies, 1986)

Stiffness related to movements



G'_o for very small strain measured in dynamic tests

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Experimental Process – Who does what?

Observe gauges.

↓ Calibrations and corrections – by the laboratory

Graphs of stress and strain

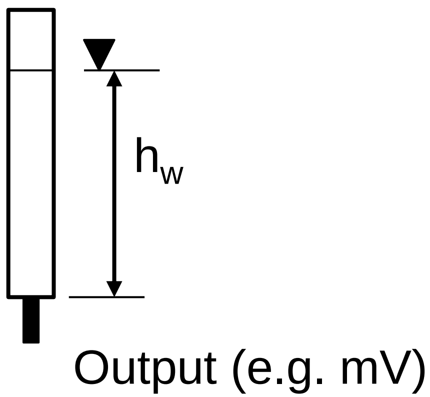
↓ Definitions and mechanics – who does this?

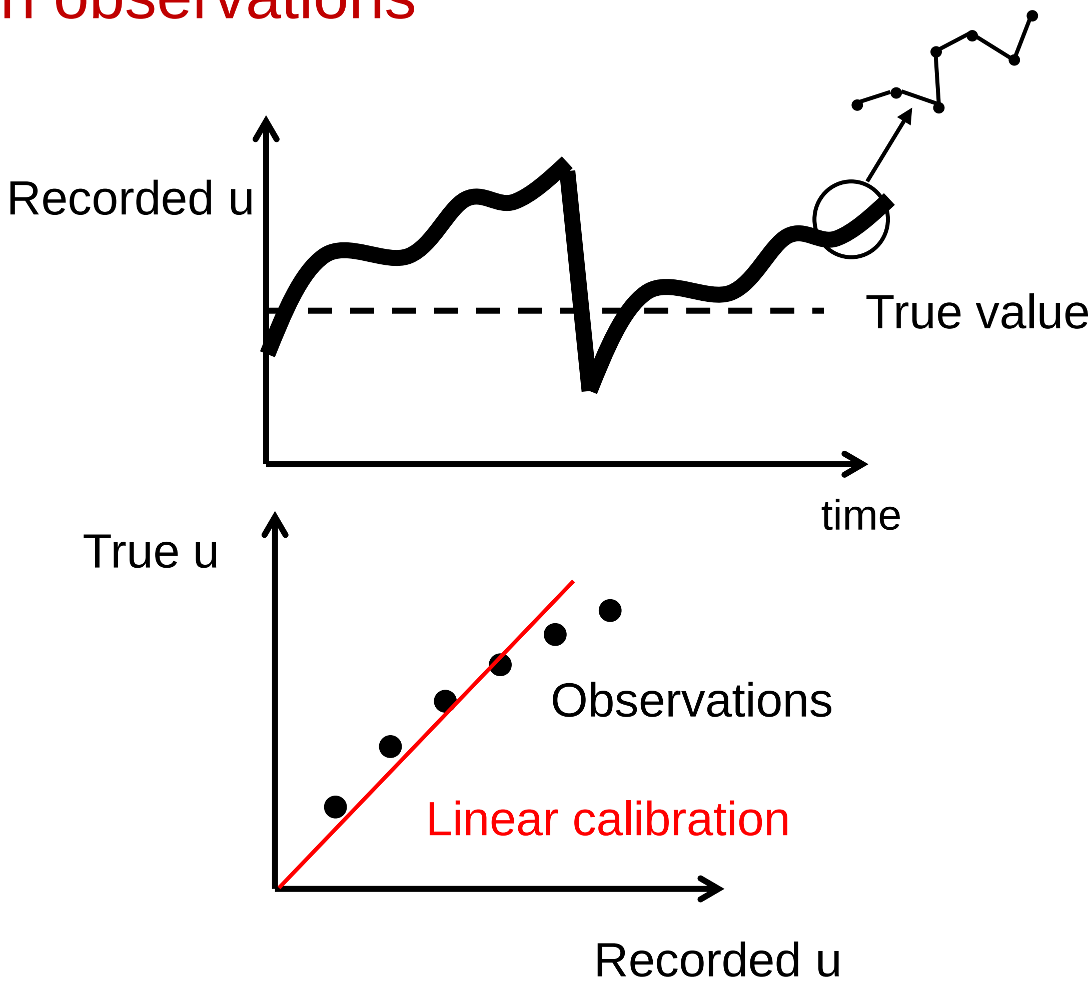
Derive parameters for strength and stiffness

↓ Judgement and factors – by the engineer

Determine characteristic or design values

Sources of error in observations





Noise

Drift

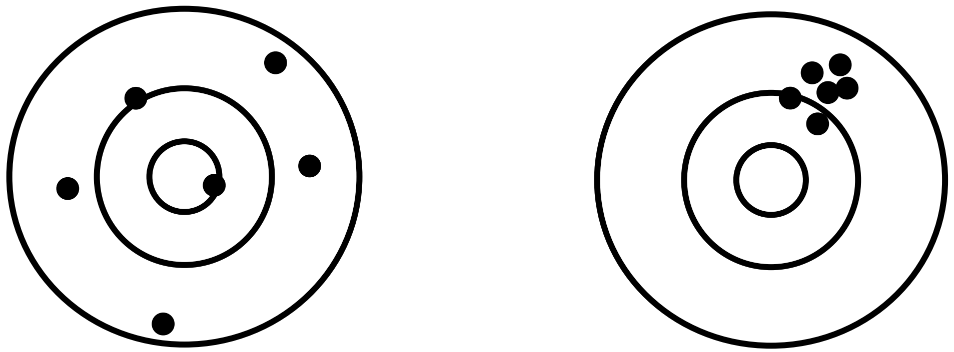
Fault

Calibration

Repeatability – do you believe it?

Accuracy: difference between recorded value and true value: but what is the true value.

Accuracy



What do you believe if you don't know the target?

Resolution = precision: size of bullet hole; how many significant figures?

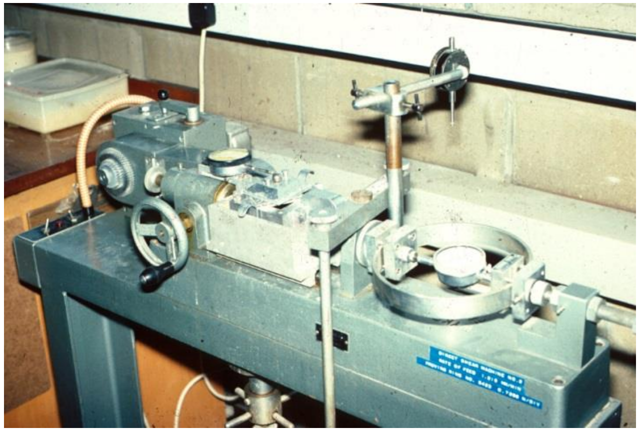
Scatter – can the data be averaged?

Accuracy: difference between recorded value and true value (not as a %)

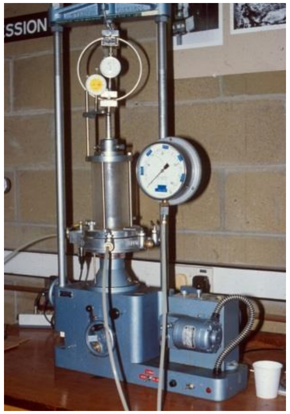
Can the laboratory quote the accuracies of all the values of stress and strain?

Standard laboratory strength and stiffness tests

Oedometer



Direct shear



Triaxial

Triaxial stress path

Standard in situ tests

SPT

N blows

Shear vane

Torque
Shear strength

CPT

Cone and
sleeve
stresses

Shear wave

Travel time
Velocity

Experimental Process – Who does what?

Observe gauges.

↓ Calibrations and corrections – by the laboratory

Graphs of stress and strain

↓ Definitions and mechanics – who does this?

Derive parameters for strength and stiffness

↓ Judgement and factors – by the engineer

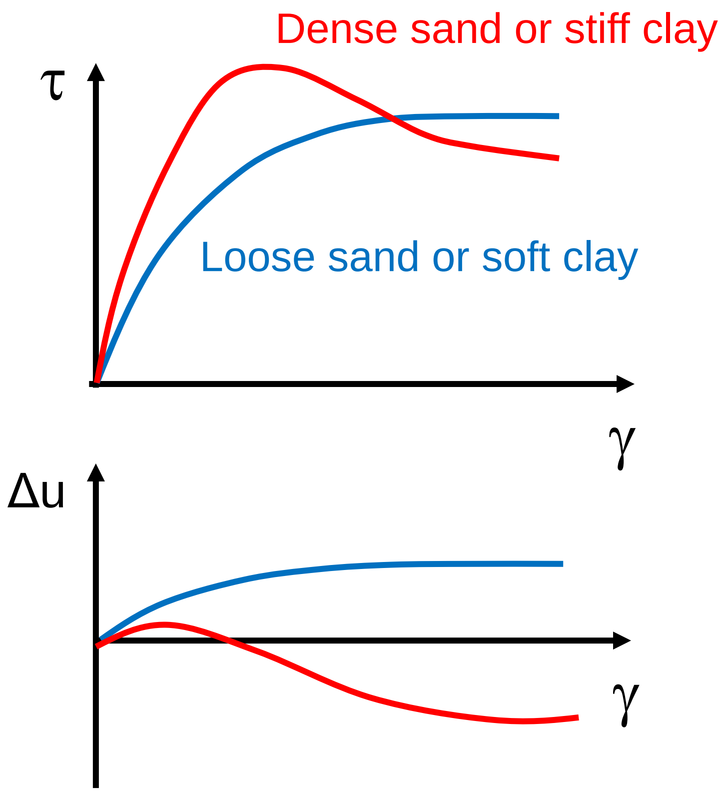
Determine characteristic or design values

From graphs to parameters

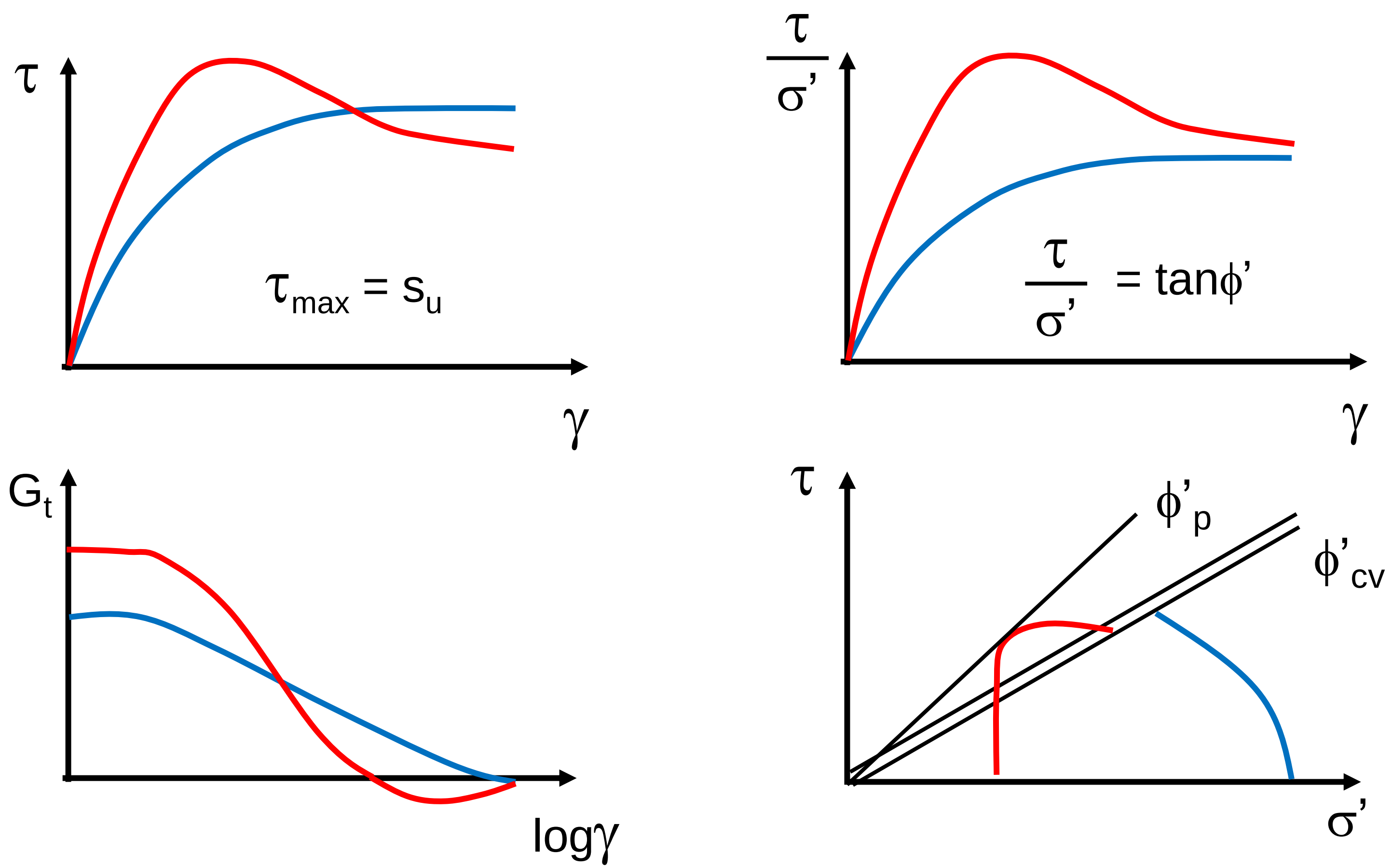
Typical data from undrained tests on saturated remoulded samples with same water content.

Determine values for strength and stiffness.

Who should so this? The laboratory or the engineer?



Interpretation of undrained test data.



Interpretation of test data.

Drained ϕ' or undrained s_u: does the structure get safer with time?

Peak strength or cv strength?

To prevent collapse cv strength with FoS $\leq$ 1

To limit deformations peak strength with load factor 0.3 (FoS = 3)

Strange observations

Unusual soil?
Errors?

Can you state the reliability and accuracies of the parameters you are using?

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Parameters and Factors

Structure	Critical Condition	Analysis	Parameter	Factor
Slope	Drained stability	Limit equilibrium	ϕ'_c u	$F_s = 1$
Foundation on clay	Drained settlement	Limit equilibrium	s_u (peak)	LF = 3
Foundation on sand	Drained settlement	Limit equilibrium	peak strength	LF = 3
Foundation	Drained settlement	Elastic	E' or M'	Relate to strain

4 - Summary

Parameters obtained from laboratory or in situ tests should be compatible with the basic soil description.

Design parameters depend on the structure and the design criteria – drained or undrained, prevent collapse or limit deformation.

There is much that can, and does, go wrong with laboratory and in situ testing – do you believe the data you are given?

It follows that the designer must determine the design parameters from the stress – strain test results.

Where have we been?

1 Basic soil behaviour

2 Geology

3 Simple analyses

4 Design Parameters

What else should a geotechnical engineer be able to do?