University of Sao Paulo – Polytechnic School

A Course of Lectures in Geotechnical Engineering

Professor John Atkinson

October 2016

1 Basic Soil Behaviour

Topics

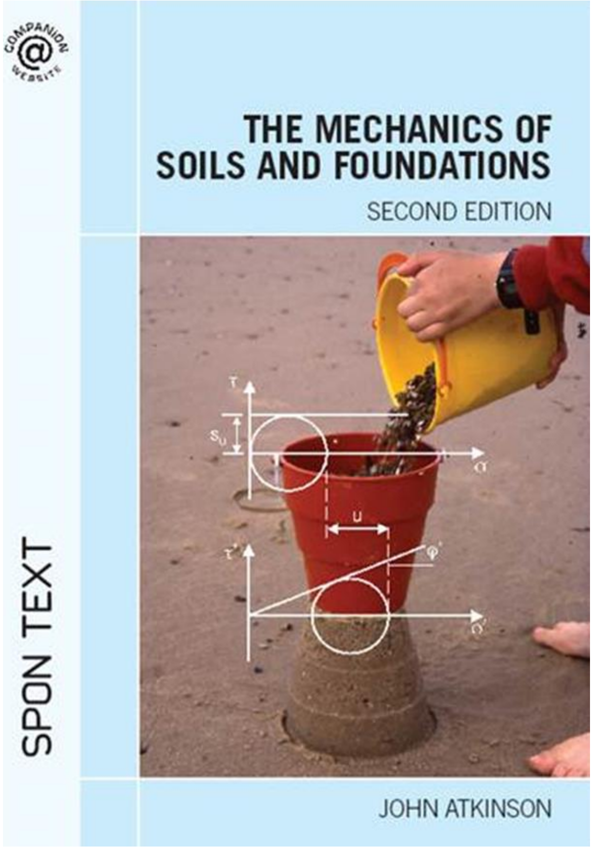
1 – Basic Soil Behaviour

2 – Geological Origins of Engineering Soils

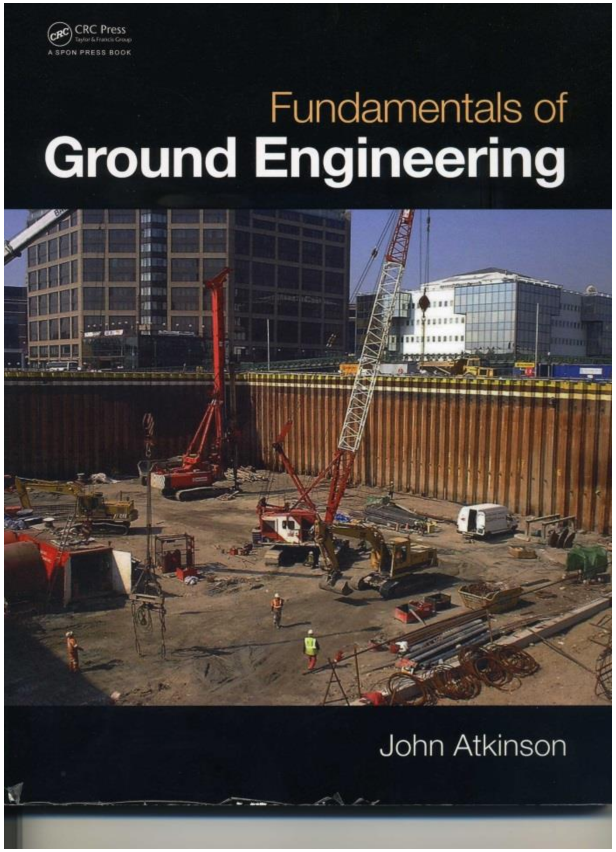
3 – Simple Analyses with Pencil and Paper

4 – Parameters for Design

Fundamental components of an undergraduate course



SPON TEXT
THE MECHANICS OF SOILS AND FOUNDATIONS
SECOND EDITION
JOHN ATKINSON



CRC Press
A SPON PRESS BOOK
Fundamentals of Ground Engineering
John Atkinson

2007

2014

Fundamental Principles

1 All soils and rocks were formed by natural geological processes.

2 Soils and rocks behave as they do irrespective of the language spoken by the engineer.

3 Engineers do calculations that show the works are safe serviceable and economic; these must apply in all circumstances but are approximate

It is all physics

What is the minimum that graduates should be able to do?

1st degree graduates:

with a geological map and memoir, some tubes of soil from the site, a pencil and paper produce safe and serviceable designs for simple foundations and slopes.

And this can be tested

1 – Basic Soil Behaviour

Unconfined compression of sand and clay

Angle of repose in clay slope

Unconfined compression test on sand

Dilation and drainage in sand

Soils are the same

Behaviour is controlled by pore pressure and friction

1 – Basic Soil Behaviour

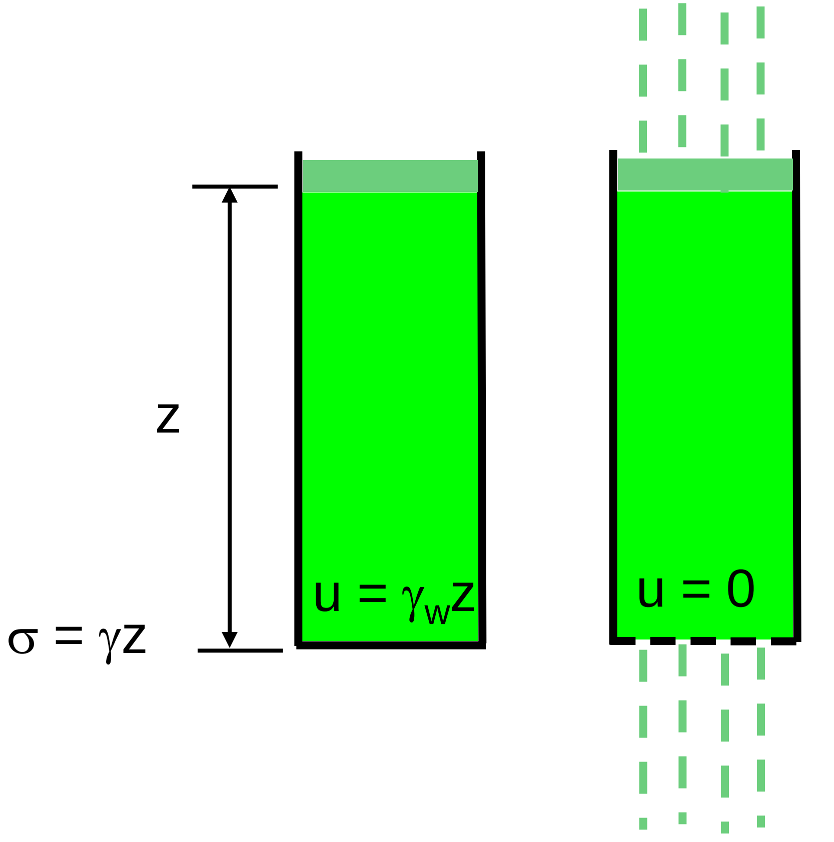
Effective stress

$\sigma' = \sigma \;-\; u$

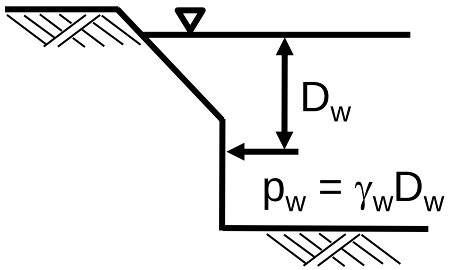
$(q + \gamma z)$

pore pressure

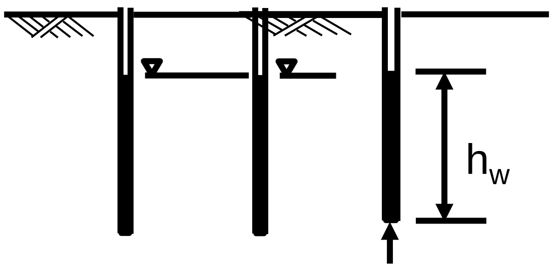
governs all soil behaviour



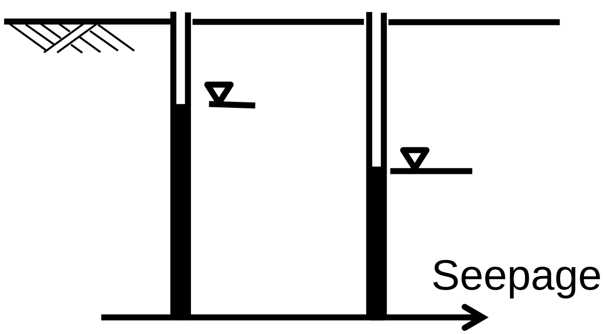
Water – pore pressure, drainage, loading



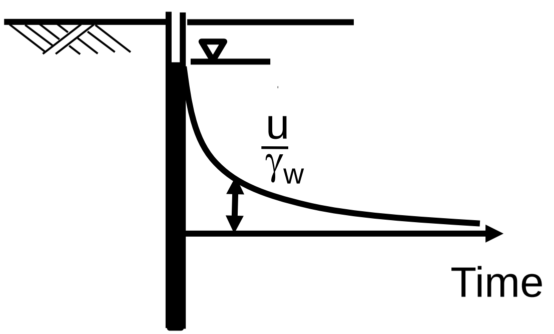
Free water



Hydrostatic $u = \gamma_w h_w$

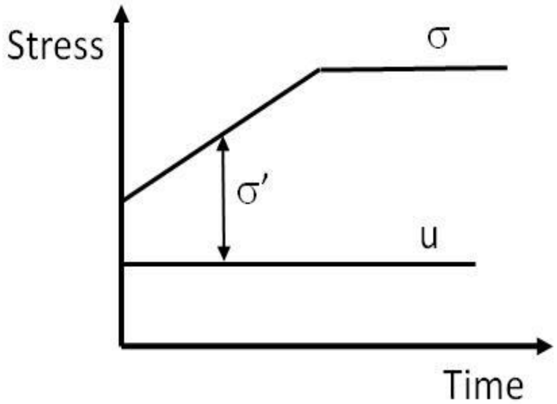


Steady state seepage: V = ki



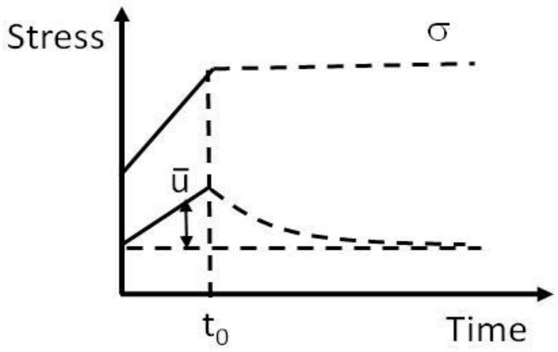
Consolidating

Drained - undrained



Drained = slow loading or fast drainage

pore pressure is constant or known
effective stress analyses



Undrained = fast loading or slow drainage

pore pressure is unknown
water content remains constant
total stress analyses

Followed by consolidation

Rates of loading and drainage.

Drained = slow loading or fast drainage

$\delta u = 0$

σ' known

effective stress analysis

$\tau = (\sigma - u)\tan\phi'$

Stiffness E' and ν'

Undrained = fast loading or slow drainage

$\delta\varepsilon_v = 0$

u not known

total stress analysis

$\tau = s_u$

Stiffness E_u and $\nu_u = ½$

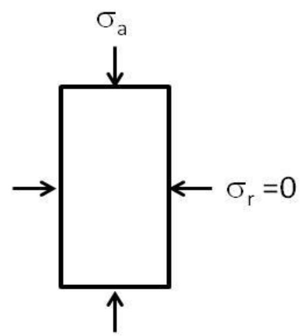
Rates of loading and drainage.

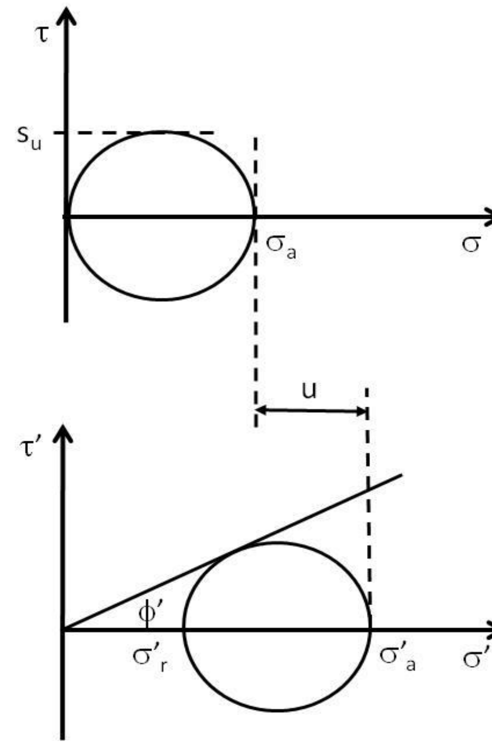
Construction	
Earthquake;	10 s
Small excavation;	3 hrs = 10^4 s
Small foundation;	10 days = 10^6 s
Embankment;	3 months = 10^7 s
Large building;	3 years = 10^8 s
Erosion;	30 years = 10^9 s

Drainage (time for 1m seepage)	
Gravel;	$<10^2$ s
Sand;	10^2 to 10^5 s
Silt;	10^5 to 10^8 s
Clay;	$>10^8$ s

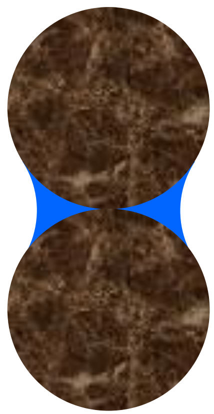
For typical construction times 3 hours to 3 years sands and gravels are drained and silts and clays are undrained

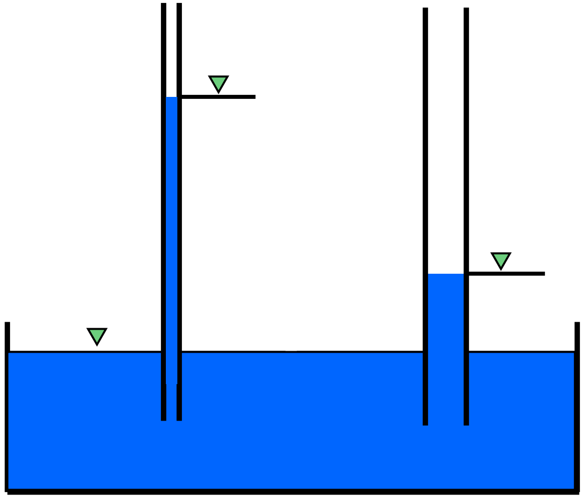
Unconfined strength = suction + friction





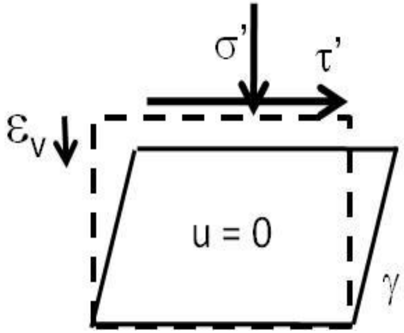
Pore water suction



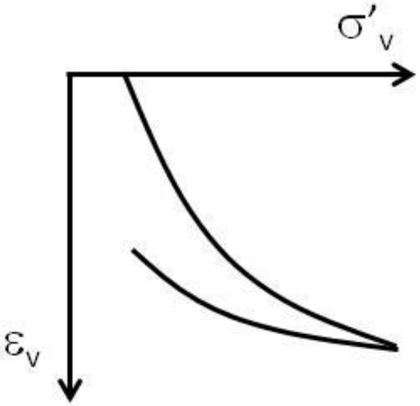


Soil	Grain size (mm)	Ht of sat (m)	Suction (kPa)
Clay	0.001	60	600
Silt	0.01	6	60
Sand	0.1	0.6	6

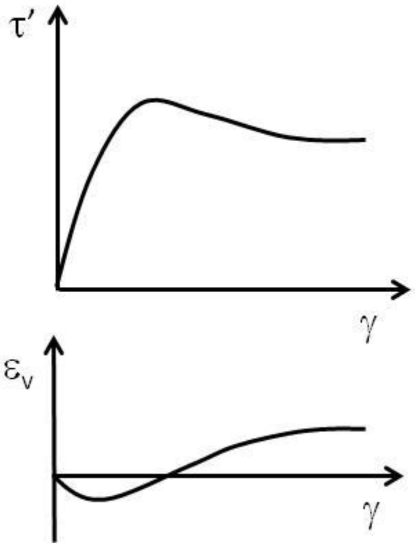
Shear and compression



Compression = change of size



Shearing = distortion = change of shape



Shearing also causes change of size = coupling

State and Behaviour

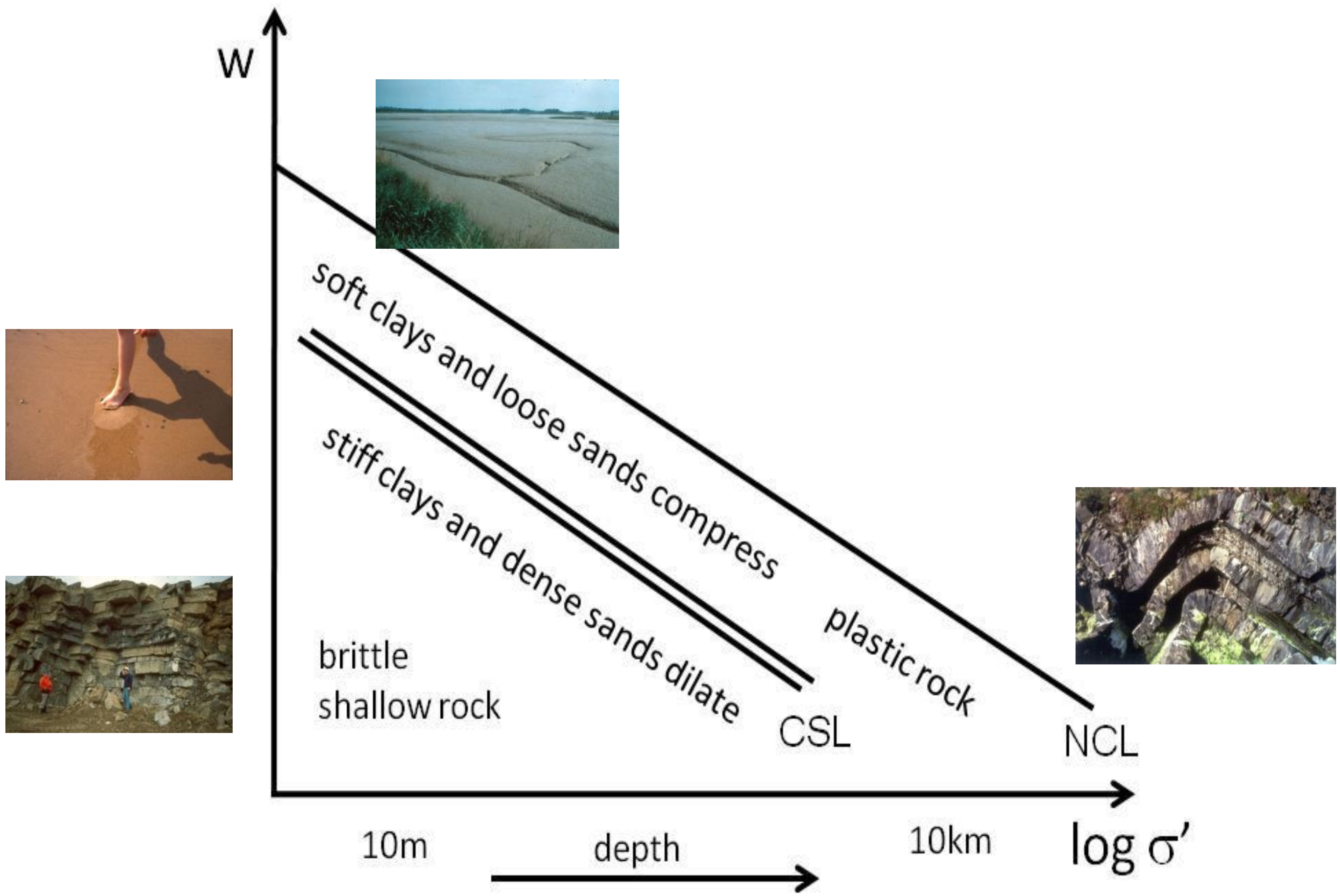
loose dense

clays	LL	(LI)	PL
sands	minimum density	(D_r)	maximum density

soft and weak

stiff and strong

State of soil and rock



1 – Basic Soil Behaviour

1.1 How do soils behave?

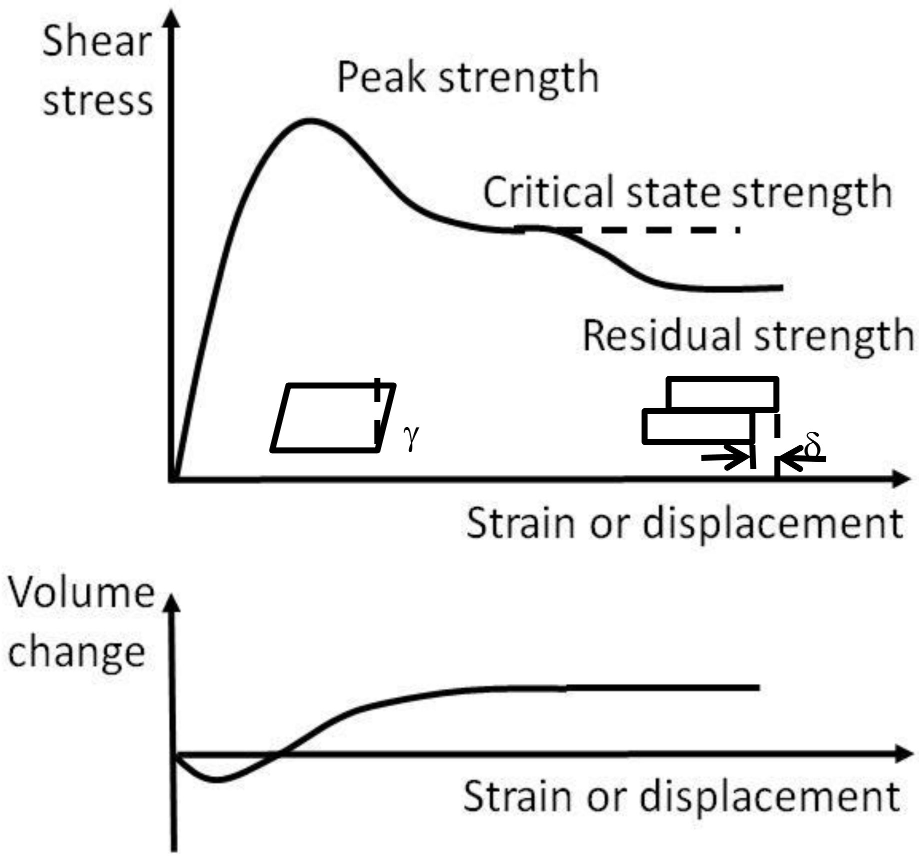
1.2 Effective stress and drainage

1.3 Strength

1.4 Stiffness and compression

1.5 Consolidation

Soil has several strengths



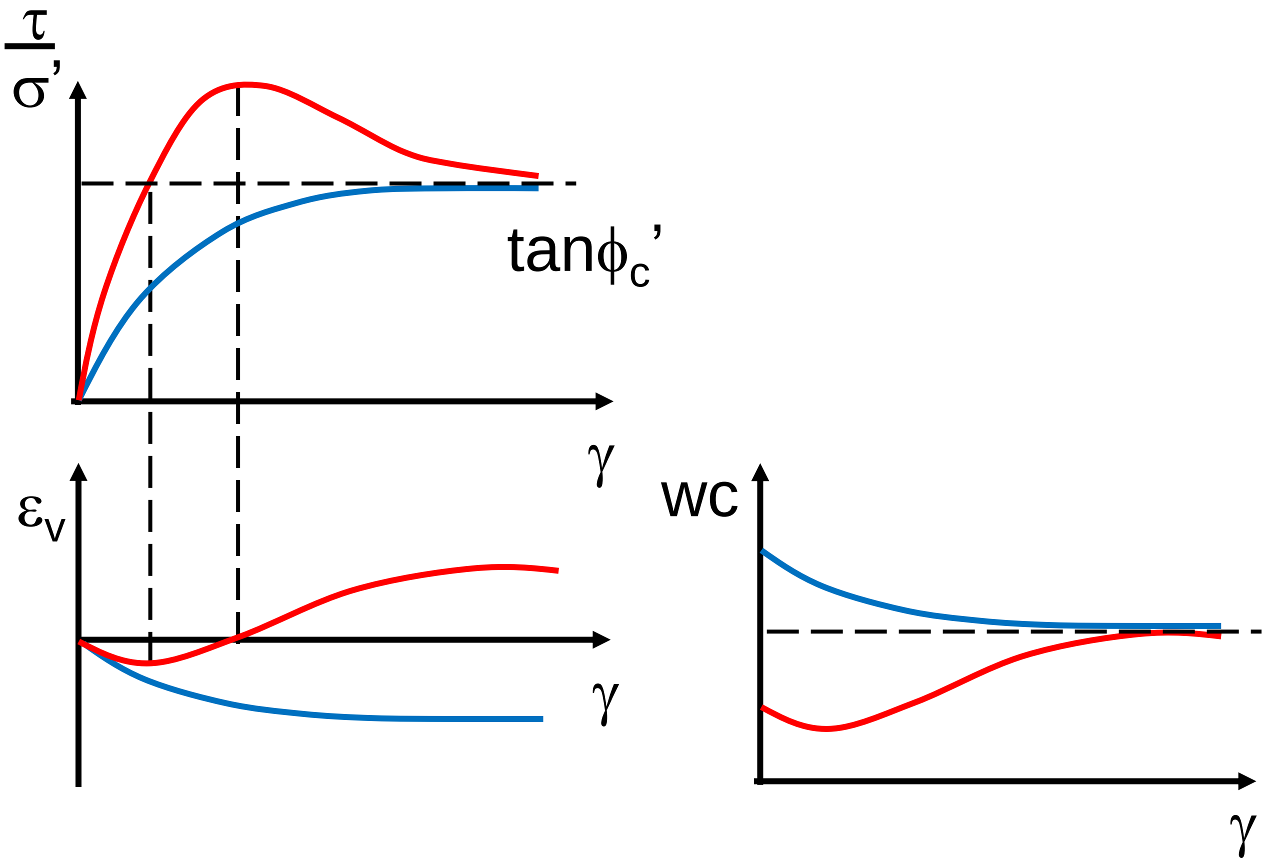
Peak and critical state strength
    turbulent flow
    continuum

Peak strength – dilation

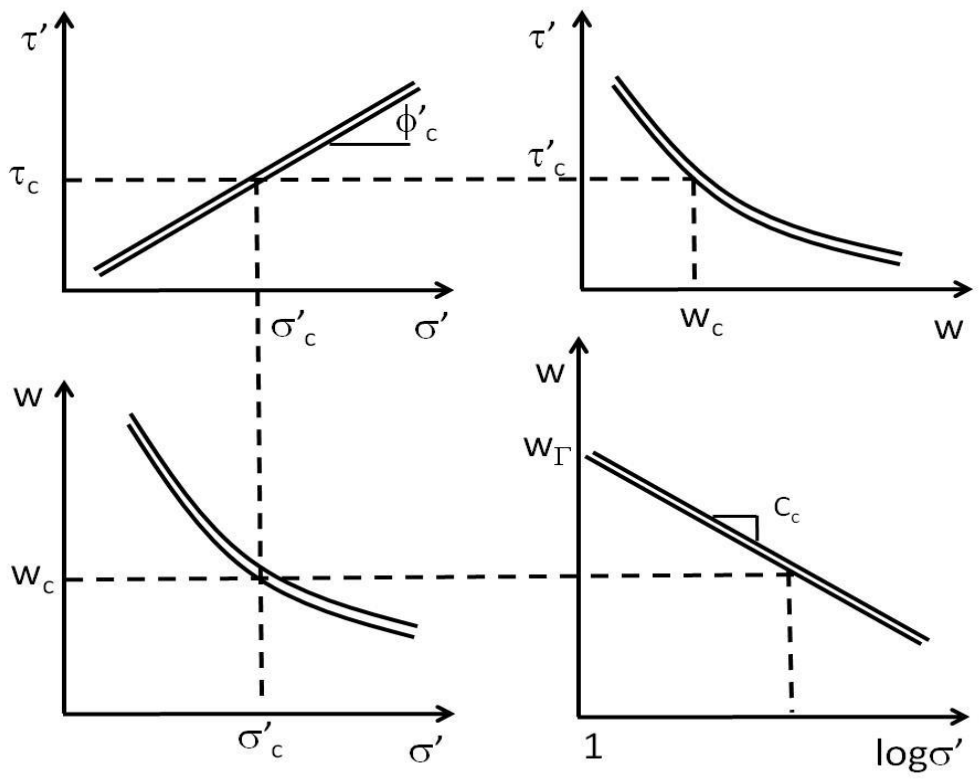
CS strength – constant volume

Residual strength
    laminar flow

Behaviour of soil – drained shearing



How strength and volume are related



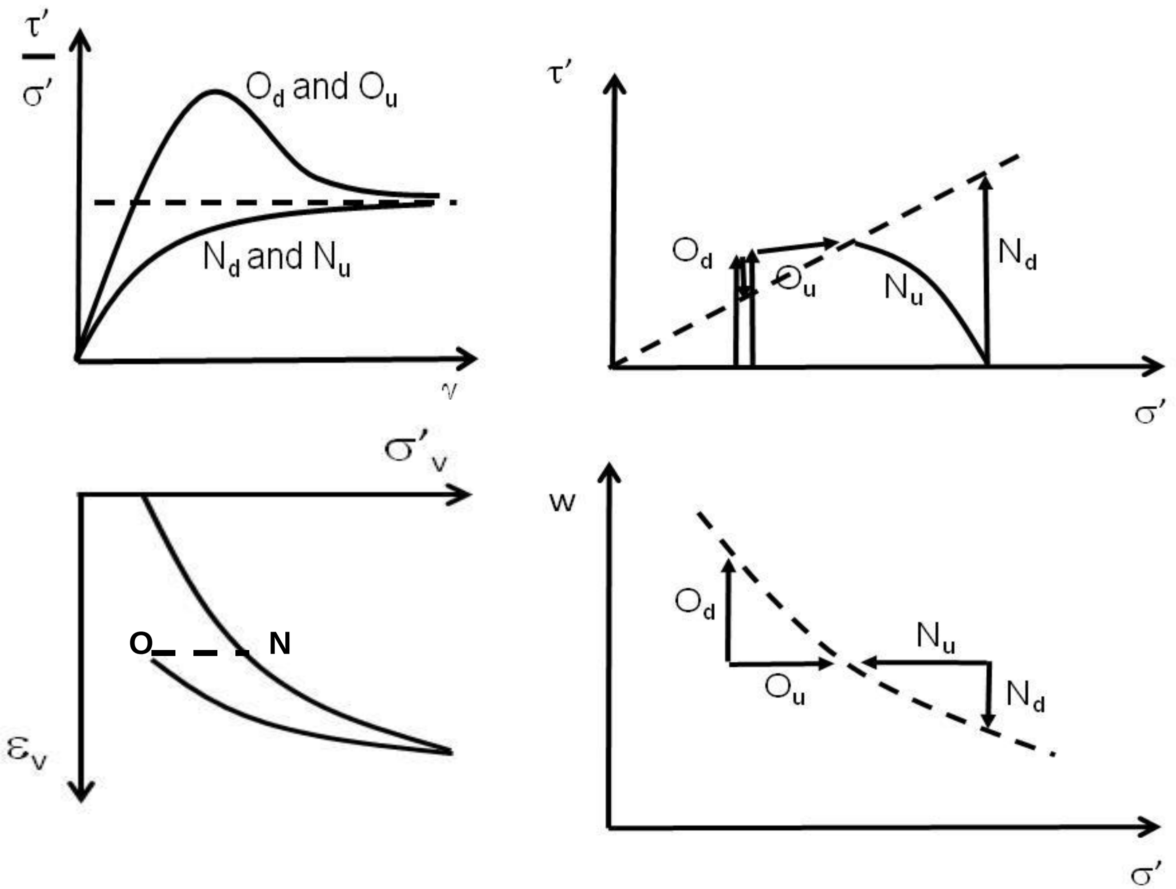
Definition

At constant volume shearing soil distorts at constant effective stress and at constant volume

Principle

There is a unique relationship between shear stress, effective normal stress and water content

Shear and compression of soil



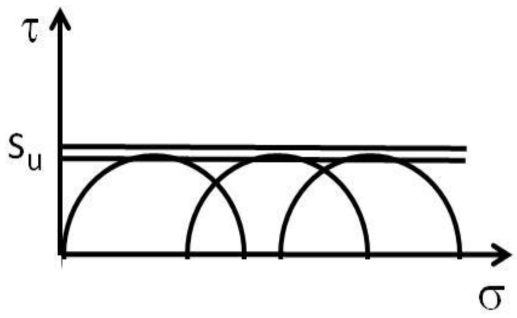
O = overconsolidated

N = normally consolidated

d = drained

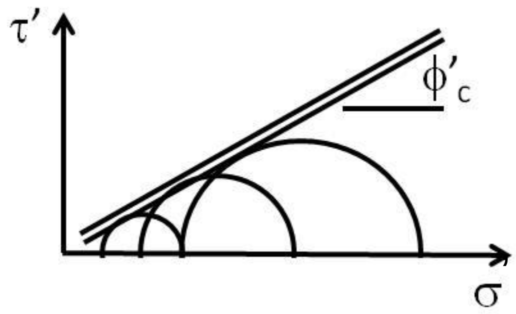
u = undrained

General Strength Equations



Undrained strength

$$\tau = s_u$$

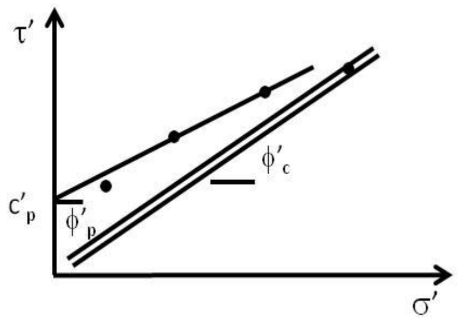


Effective stress strength

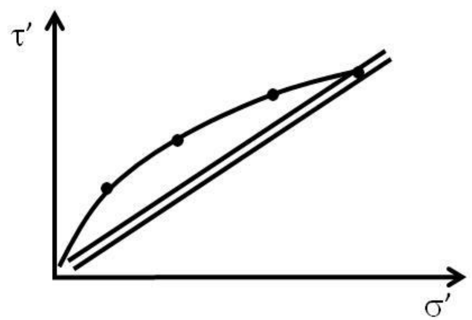
$$\tau' = c' + \sigma' \tan \phi'$$

but be careful with c'

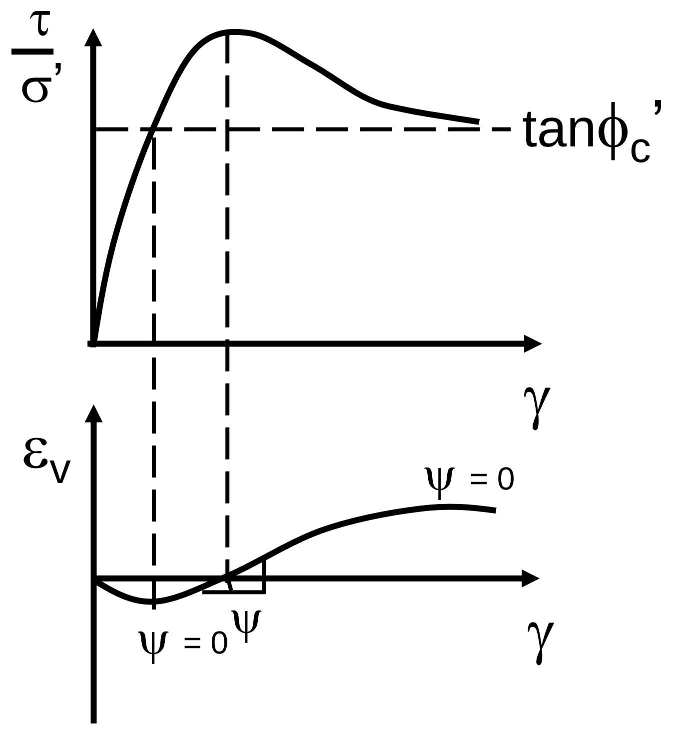
Peak Strength



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



Hoek-Brown $\tau' = A\,\sigma'^b$



Stress-Dilatancy $\tau' = \sigma' \tan(\phi'_c + \psi)$

Does soil have cohesion?
(Strength at zero effective stress)

Submerge in water and wait until pore pressures equalise.

Is c' due to bonding or to grain attractions?

Will bonding survive the strains imposed by the works?

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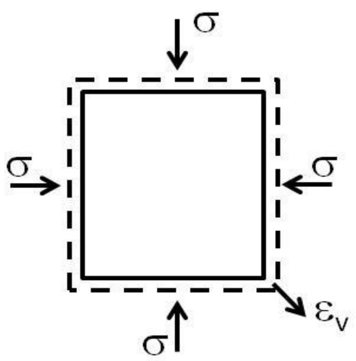
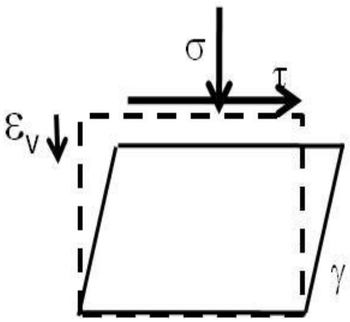
Stiffness: Shear and Compression



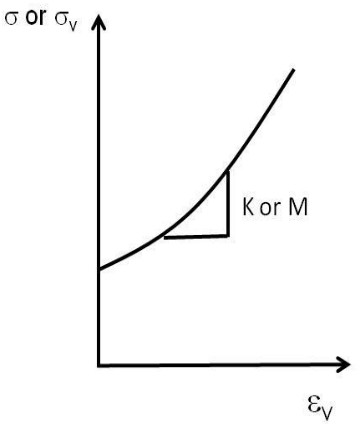
Compression:

change of size



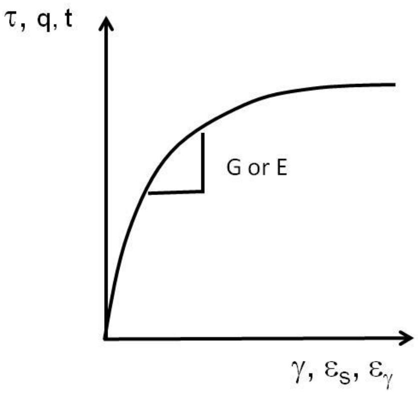
Distortion:

change of shape



Bulk modulus K'

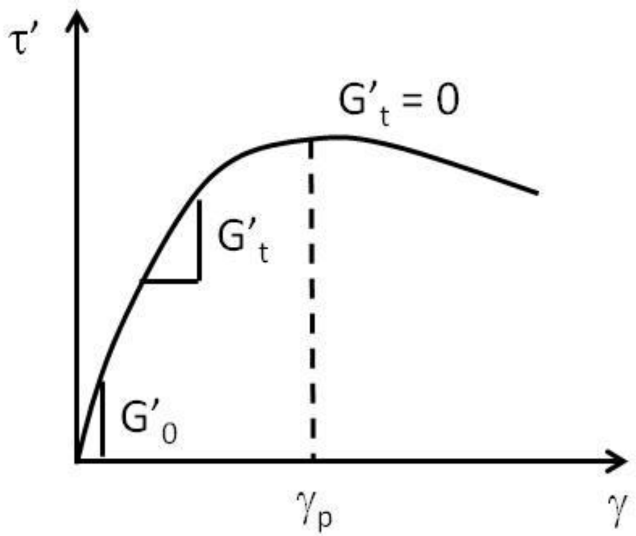
1D modulus M

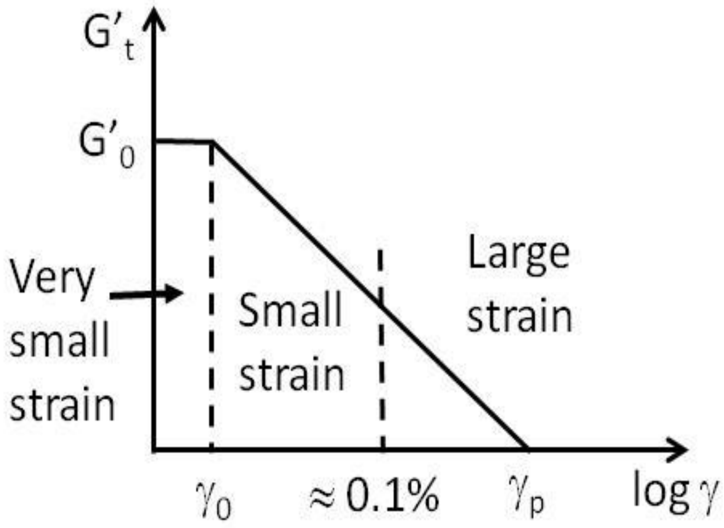


Shear modulus G'

Youngs modulus E'

Non-linear stiffness

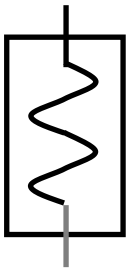




Measure G'_0 from shear wave velocity or from state and wc

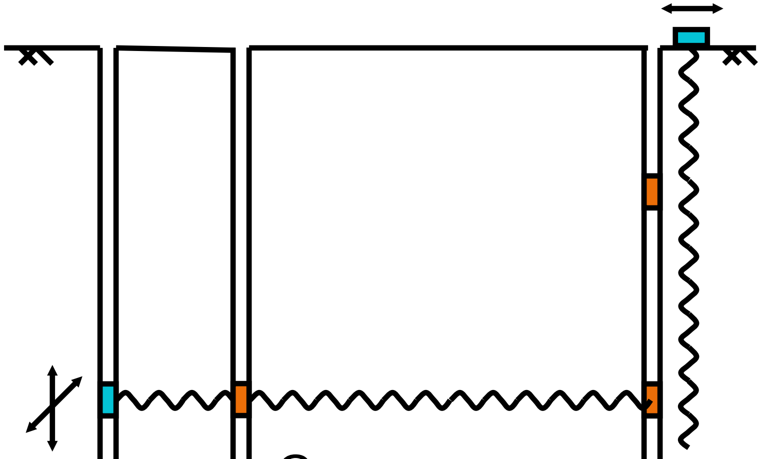
Typical design for strains of 0.1%; design $G' = G_u$ = about $G'_0/3$

Measurement of G_o from Shear Wave Velocity



Bender elements in triaxial or oedometer samples

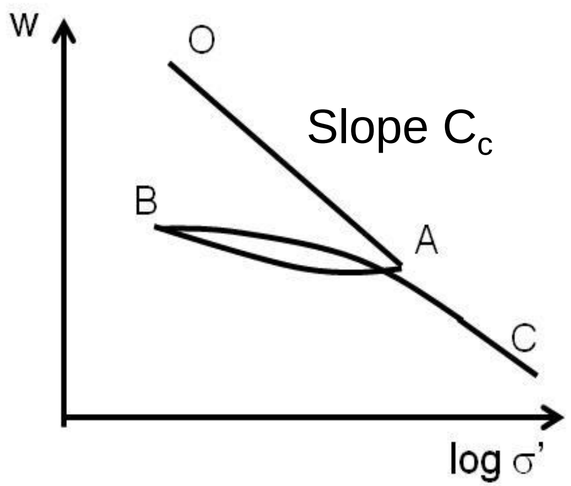
$$G_o = \frac{\gamma V^2}{g}$$

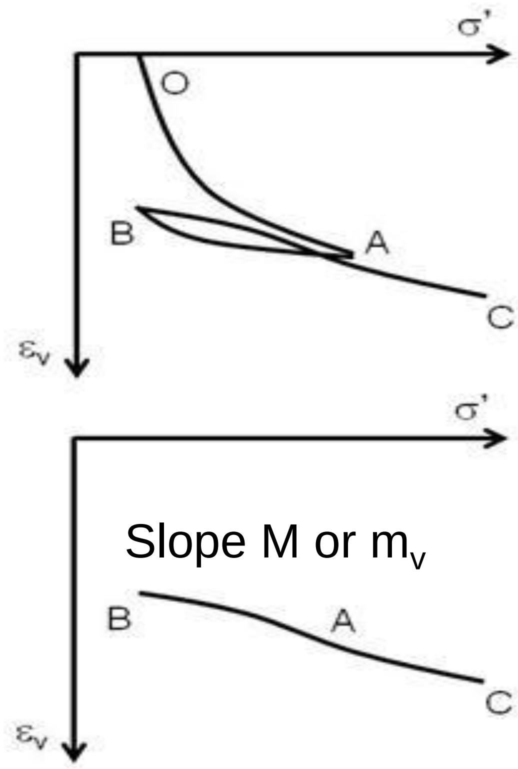


Cross hole

Down hole

1D Stiffness and Compressibility





For NC soils C_c constant

For OC soils M or m_v aprox constant

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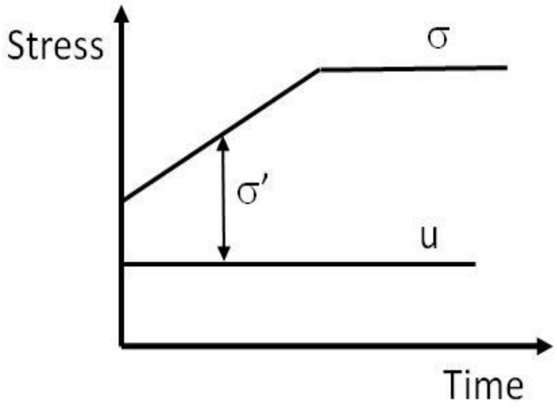
Consolidation



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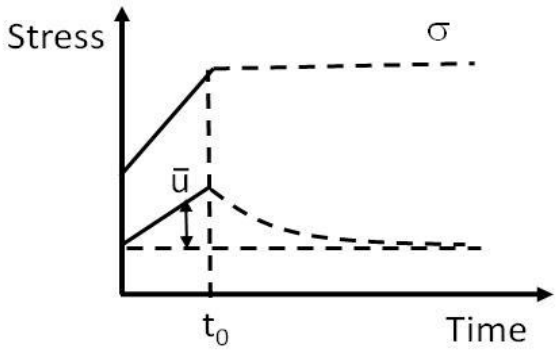
pore pressure is constant or known
effective stress analyses

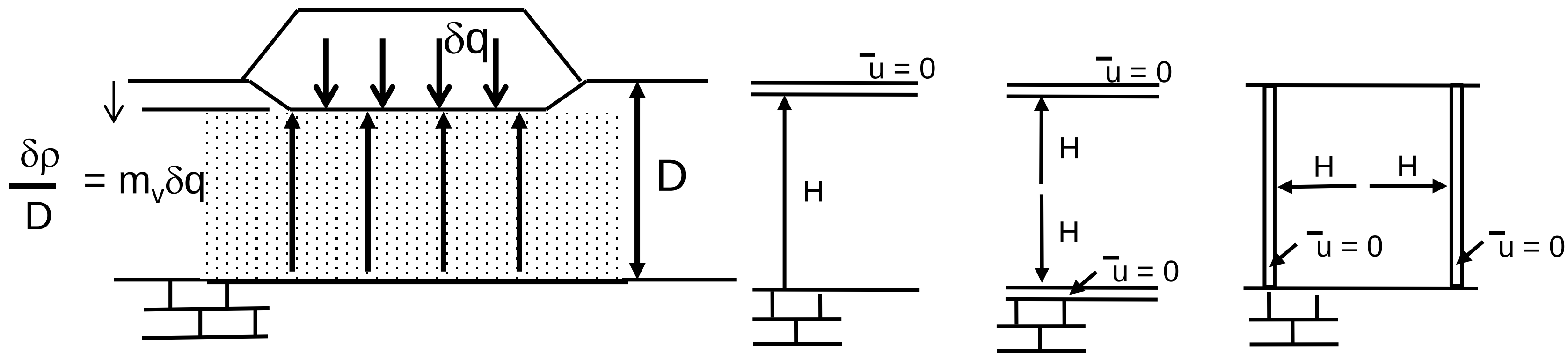


Undrained = fast loading or slow drainage

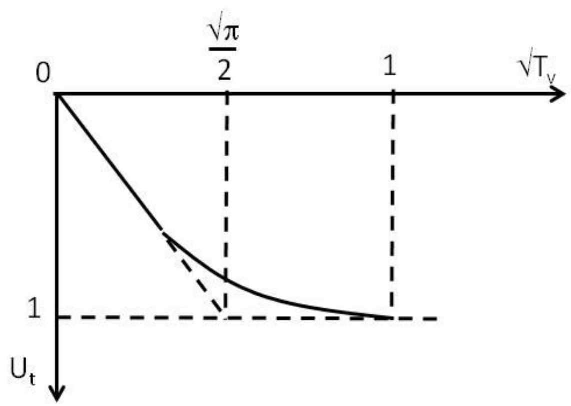
pore pressure is unknown
water content remains constant
total stress analyses

Followed by consolidation

Consolidation



H = drainage path length



$\delta\rho_{ct} = U_t \delta\rho_{c\infty}$

When consolidation is finished
$U_t = 1$ and $T_v \approx 1$

and time for consolidation
$t_c = H^2/c_v$

1 – Basic Soil Behaviour