SOIL MECHANICS

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Unit 8 - Compressibility

May 27th, 2025

Day	08:00-09:30	09:45-11:15	13:00-14:30	14:45-16:15
19/05/25	Introduction	Programming	Phase Rel.	Tutorial
20/05/25	Classification	Tutorial	LAB	LAB
21/05/25	Compaction	Tutorial		
22/05/25	Groundwater	Tutorial	LAB	LAB
23/05/25	Groundwater	Tutorial		
26/05/25	Effective Str.	Tutorial	Stress Incr.	Tutorial
27/05/25	Compressib.	Tutorial	LAB	LAB
28/05/25	Consolidation	Tutorial		
29/05/25	Shear Str.	Tutorial	Shear.Str.	Tutorial
30/05/25	Shear Str.	Review		

Any construction …

on, in, below the ground or built using soil …

must consider the geotechnics

The ground must be:

- safe - *strong enough to avoid collapse*
- serviceable - *incompressible enough to avoid excessive settlement*

This is the reason why this lecture is so important!

Safe & Serviceable

Contents

Compressibility … settlement (independent of time)

- How a soil responds to loading
- Can we measure it … in laboratory?
- Can we predict settlement?

- Exactly what kind of settlement behaviour is to be expected?
- Are there any limitations on our predictions?

Serviceability

When a soil is loaded, it deforms …

Pad footing

One dimensional compression:

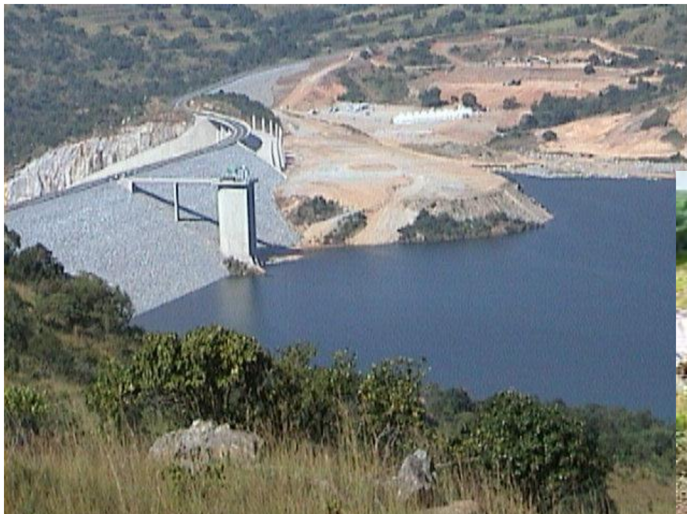
- vertical loading,
- vertical deformation,
- vertical drainage.

For example,

- under an embankment
- layer of fill.

… in one dimension ?

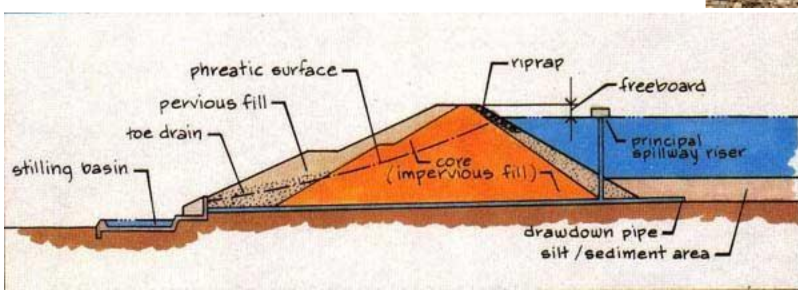
Embankments



Maguga, Swaziland

Argyll

Roadford, Devon



Settlement & phase relations

Since in one-dimension,

$$\otimes V = \Delta H \text{ x } A$$

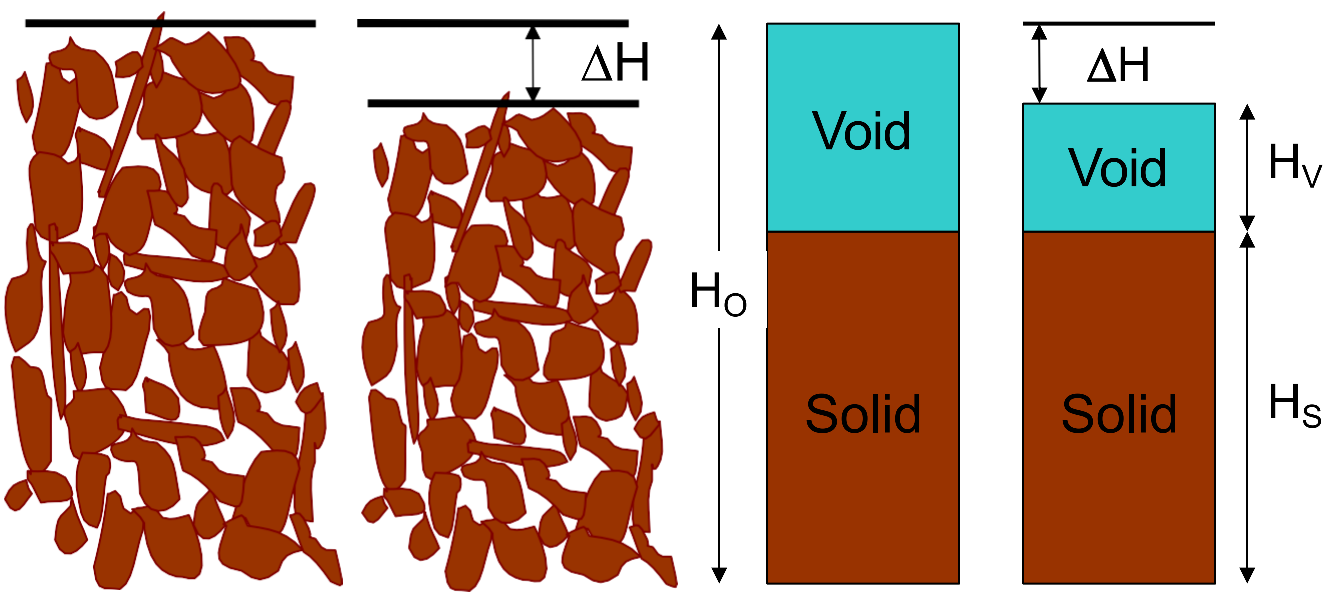
$$\varepsilon_V = \frac{\Delta V}{V_o} = \frac{A\Delta H}{AH_o} = \varepsilon_H$$

$$\frac{\Delta H}{H_O} = \frac{\Delta V}{V_O} = \frac{V_{V0} - V_{V1}}{\left(V_{S0} + V_{V0}\right)}$$

$$\frac{\Delta H}{H_O} = \frac{V_{V0}/V_{S0} - V_{V1}/V_{S0}}{\left(V_{S0}/V_{S0} + V_{V0}/V_{S0}\right)}$$

$$\therefore \frac{\Delta H}{H_O} = \frac{e_0 - e_1}{\left(1 + e_0\right)}$$

Remember soil particles are incompressible



Assuming vertical strain is a simple (elastic) function of the vertical stress increment,

$$\frac{\Delta H}{H_0} = \frac{e_o - e_1}{1 + e_o} = m_v(\Delta\sigma_V)$$

Where m_v is an elastic stiffness parameter known as the coefficient of volume compressibility,

Using notation S for settlement, i.e. S=ΔH,

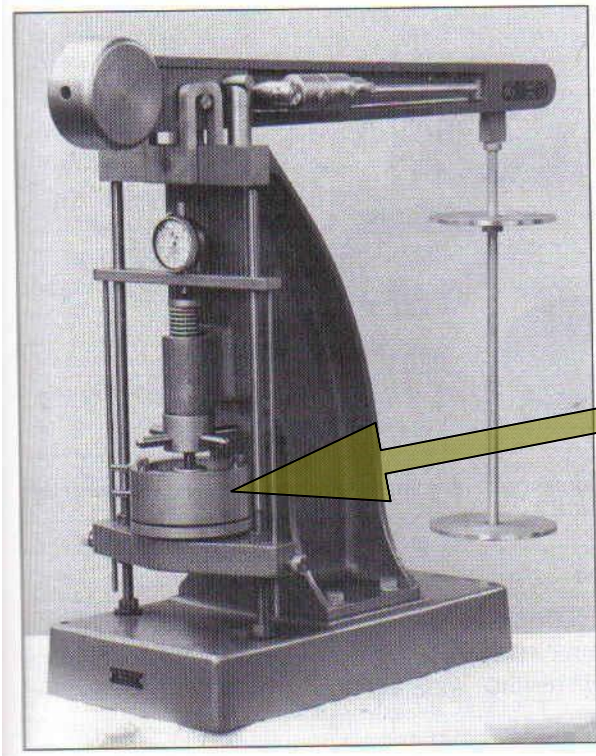
$$\boxed{S = m_v \Delta\sigma_v' H_0}$$

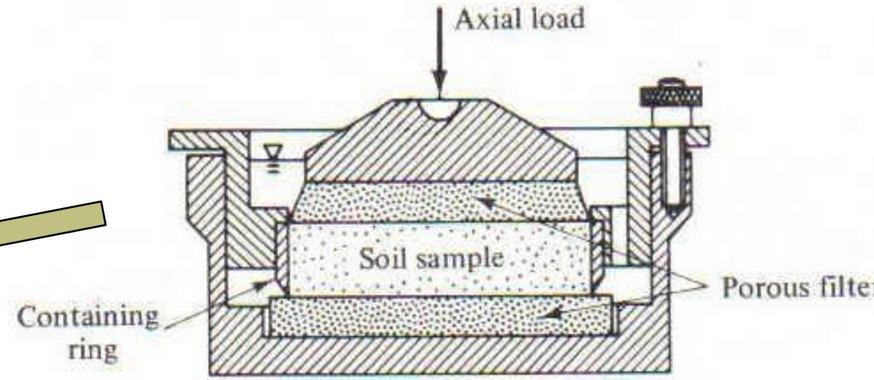
where

$$\boxed{m_v = \frac{e_0 - e_1}{(1 + e_0)(\sigma_1' - \sigma_0')}}$$

NB m_v depends on effective stress

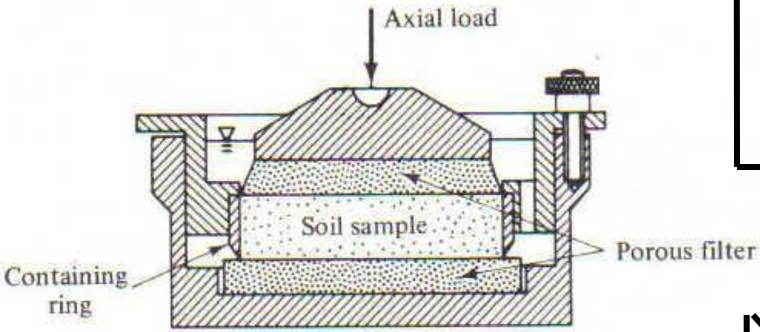
Coefficient of volume compressibility - m_v

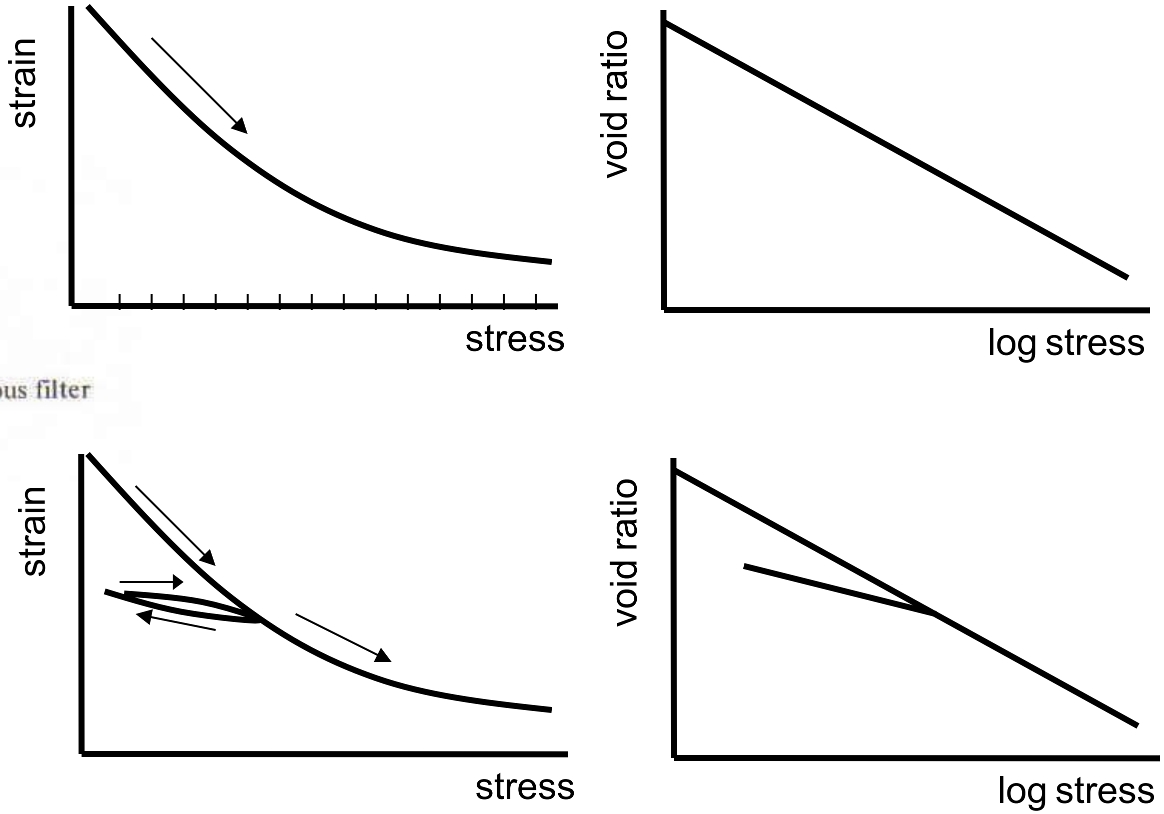




Oedometer: one dimensional compression in lab

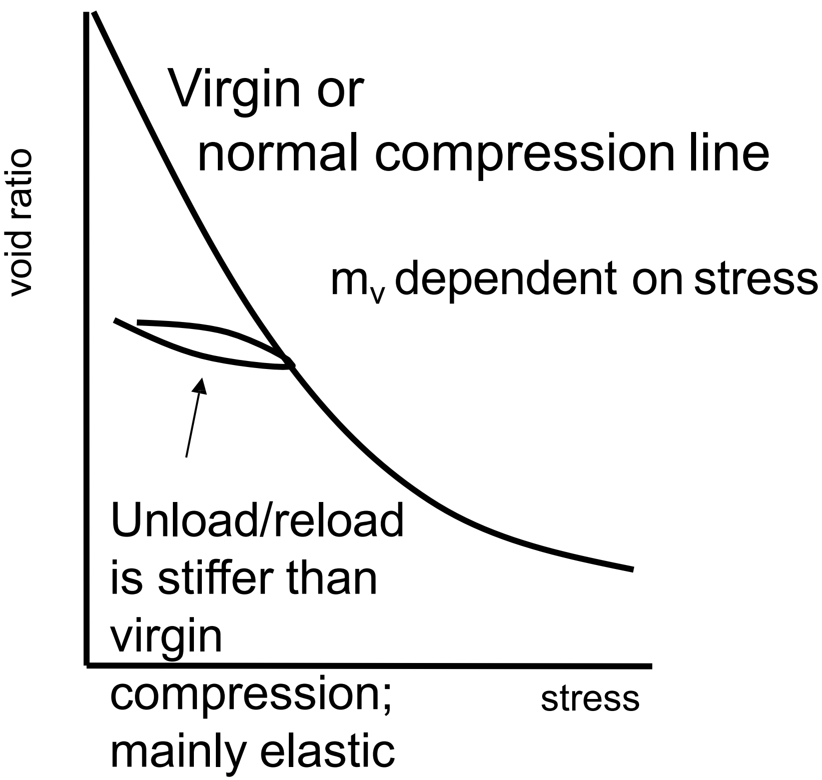
Oedometer – one dimensional compression





Compressibility – (a) magnitude

An oedometer test clearly shows fundamental soil response to a load-unload-reloading sequence.

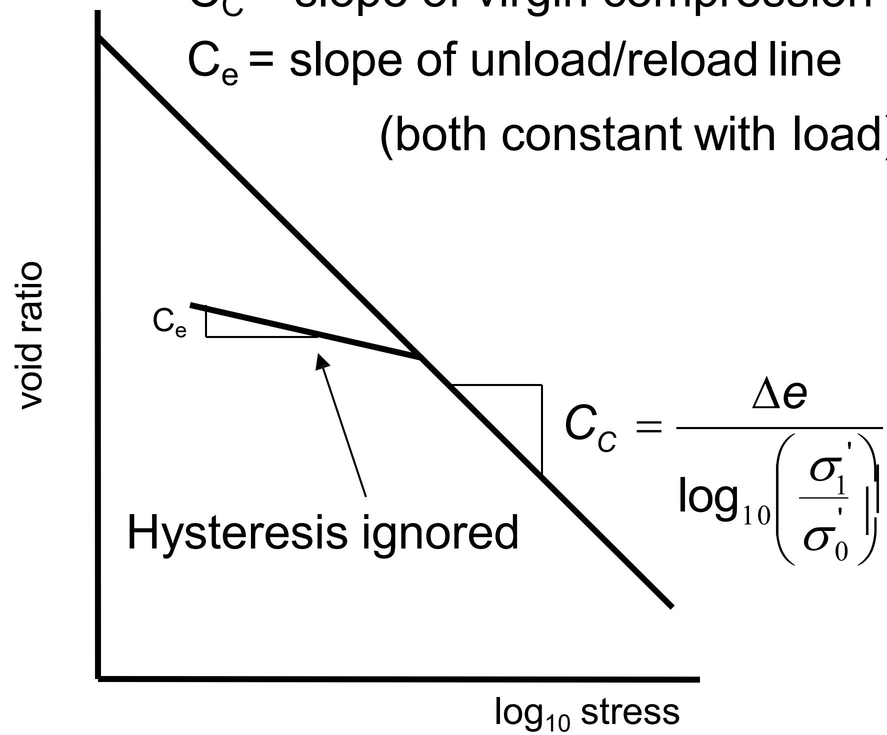


Compression indices

C_C = slope of virgin compression line

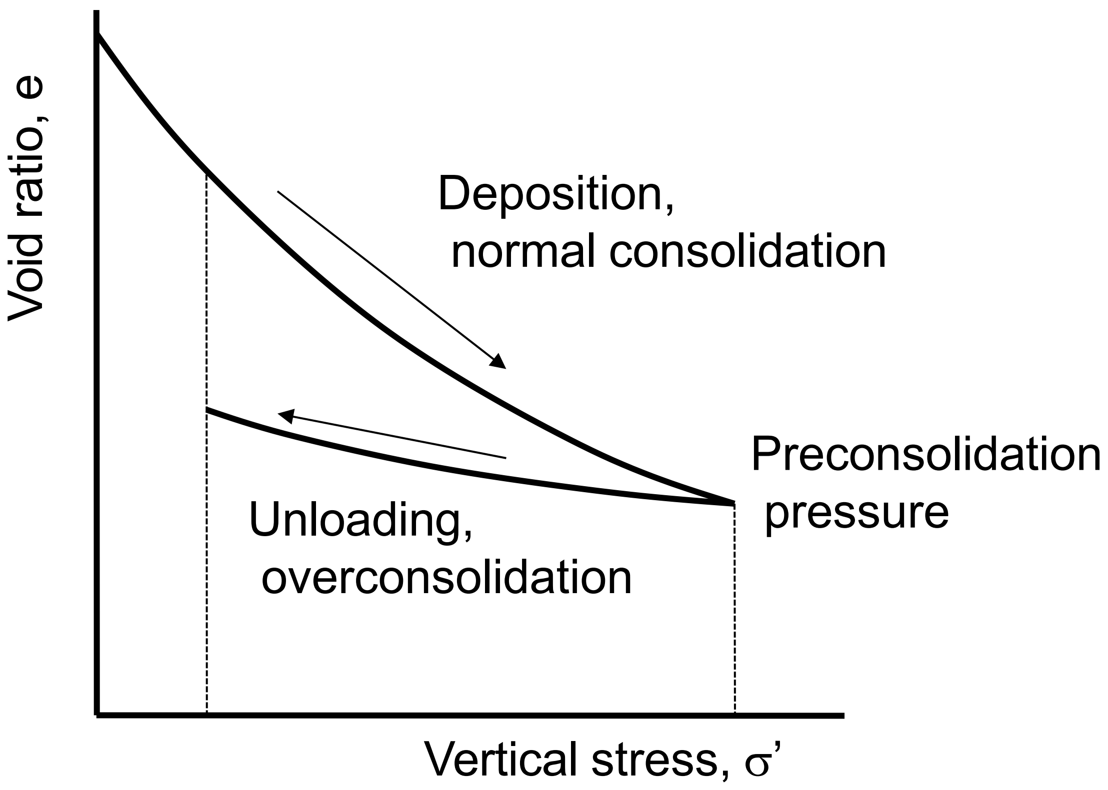
C_e = slope of unload/reload line

(both constant with load)



Interpretation of compressibility

… for a normally consolidated soil. But what if geological history has subjected soil to a much higher load than that presently experienced?

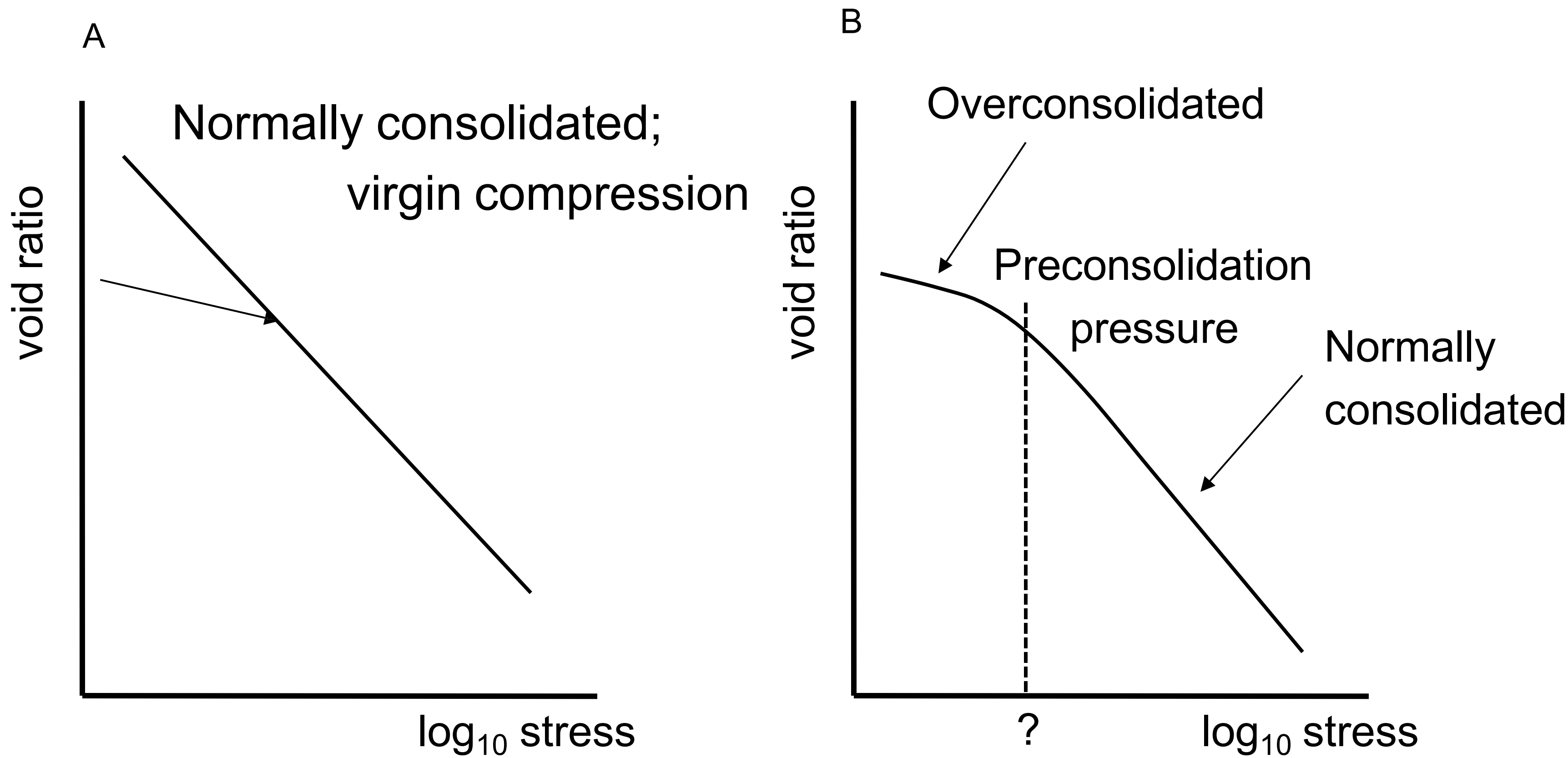


Often oedometer data reveals evidence of previous loading.

Soil has a memory!

Typical oedometer results

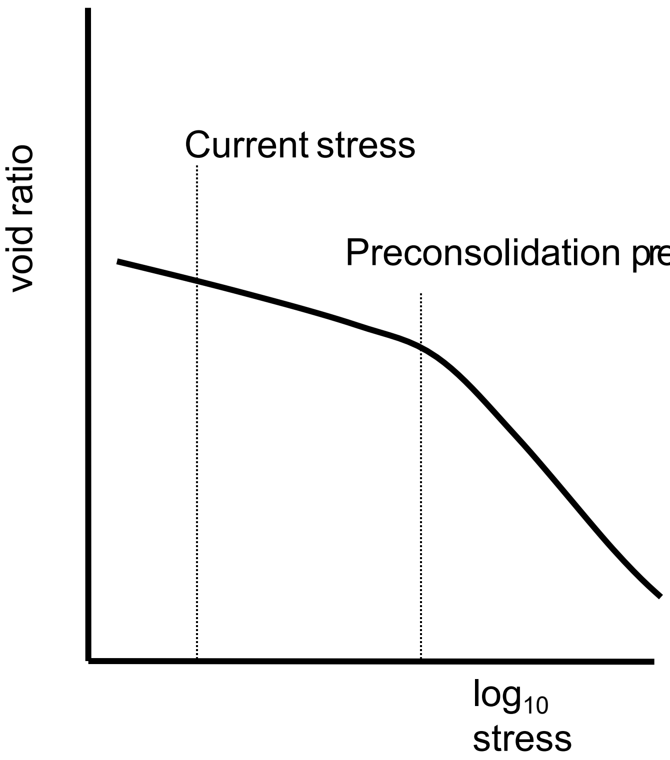
Normally consolidated or overconsolidated?



An unknown soil

In fact the preconsolidation pressure is a useful parameter; it enables us to define an overconsolidation ratio, which gives a valuable insight into soil behaviour.

Preconsolidation pressure is simply the maximum stress to which a soil has previously been loaded



Overconsolidation ratio (OCR) is the ratio of the preconsolidation pressure to the current stress state

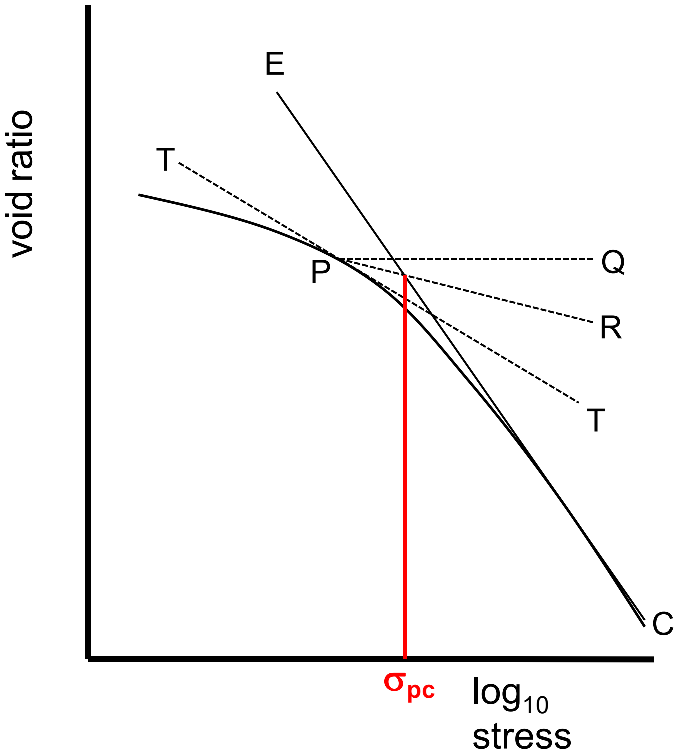
$$OCR = \frac{\text{Preconsolidation pressure}}{\text{current stress}}$$

Overconsolidation ratios can be as high as 20+

What kind of soil has an OCR = 1.0 ?

Overconsolidation

Casagrande's method



1.Locate point of maximum curvature and draw tangent to oedometer curve at that point (TT)

2.Draw horizontal line through point of contact (PQ)

3. Bisect angle QPT (PR)

4. Produce back straight line part of virgin compression curve (CE)

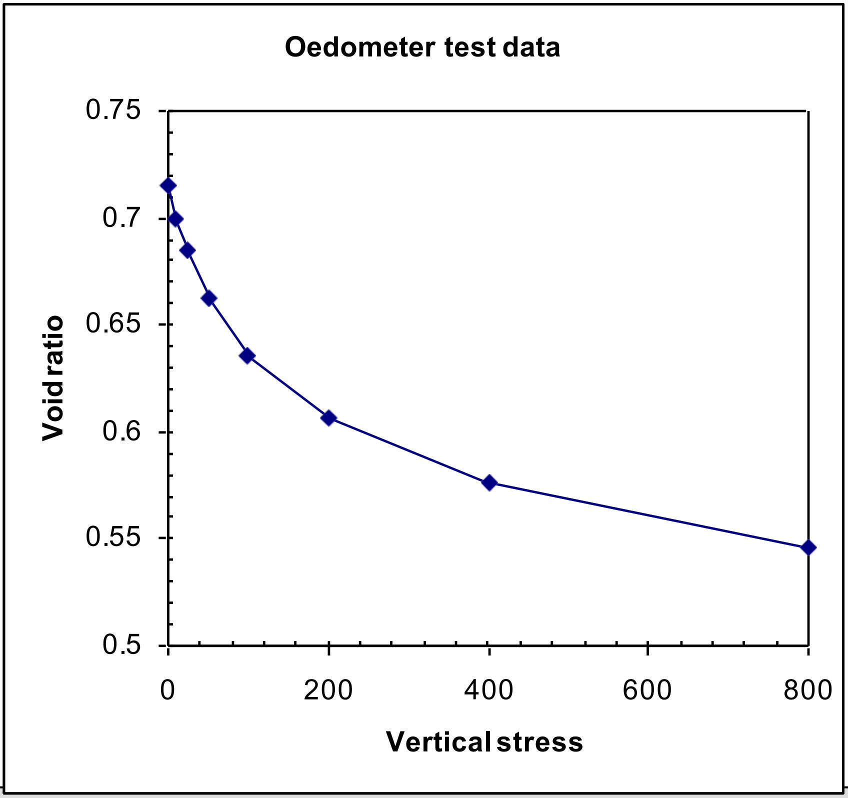
The intersection between (CE) & (PR) gives an estimate of the preconsolidation pressure, σ_{pc}.

Graphical determination of preconsolidation

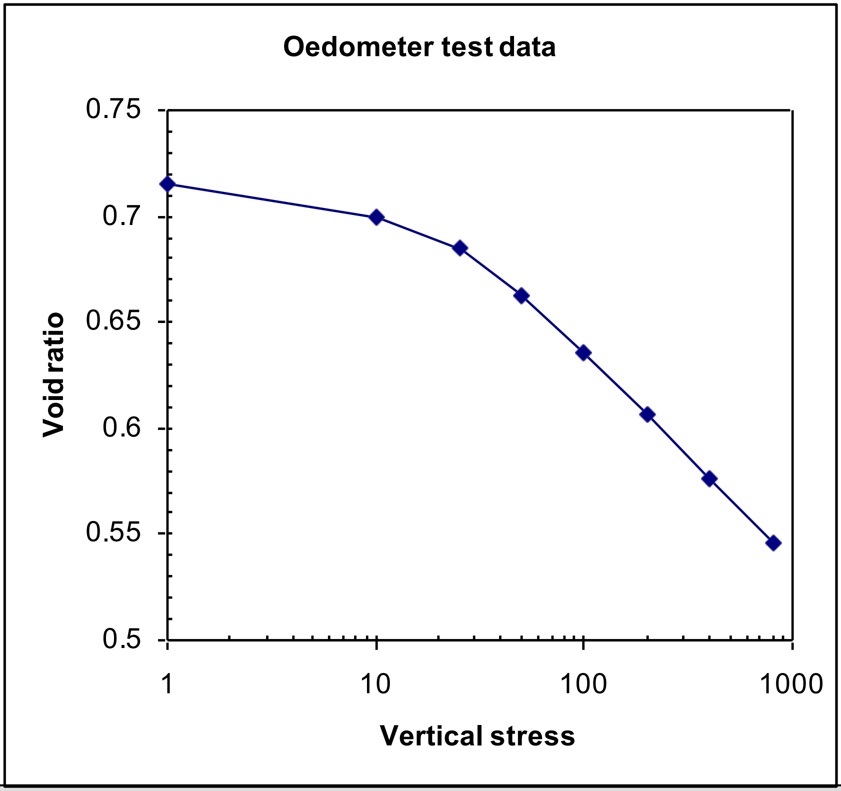
An informed interpretation … overconsolidation?

The question addresses the issue of overconsolidation and its influence on compressibility. A log stress graph will be helpful.   In this case, the low preconsolidation pressure (40 - 50 kPa) suggests only light overconsolidation, possibly a normally consolidated soil.

Natural scale

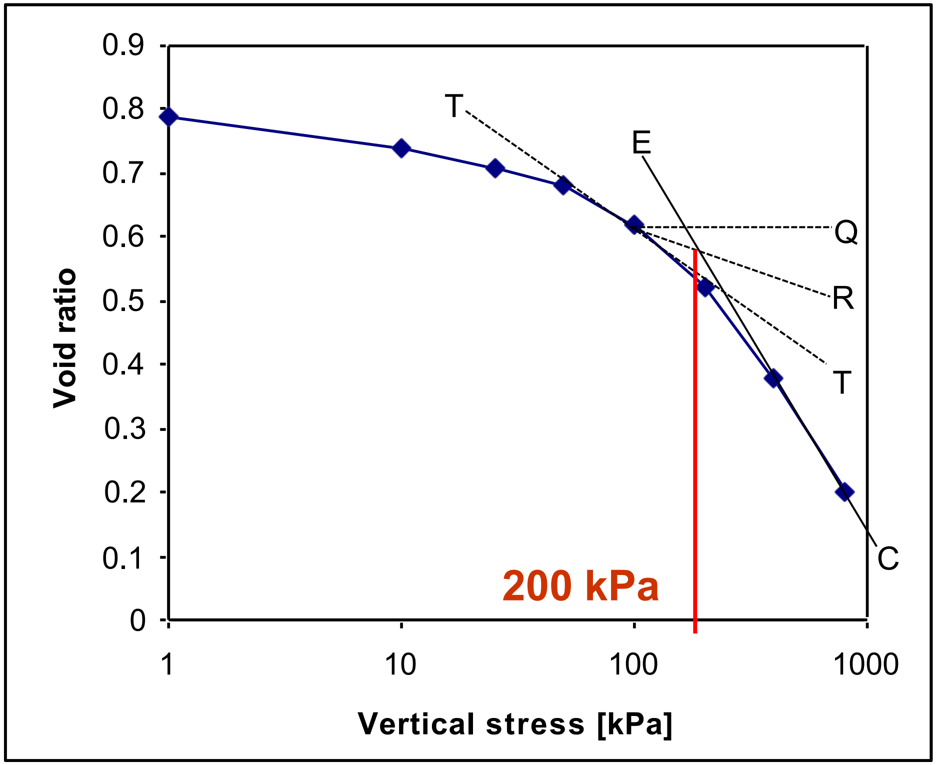


Logarithmic scale



A greater degree of overconsolidation.

In this next case Casagrande's construction is useful.



If the soil on the left is taken from shallow depth, e.g. 2m, then in-situ stress condition ($\sigma_v = \sigma'_v = 40$ kPa) is less than the preconsolidation pressure and the soil is ***overconsolidated*** (OCR ≈ 5)

If soil is taken from a depth of around 12m with water level about 3m below G.L, ($\sigma'_v \approx 12\text{x}20\text{-}9\text{x}9.81 = 150$ kPa) then OCR = 1.3 and we conclude that soil is ***normally consolidated***.

Pre-consolidation pressure - example

Be careful when selecting compression parameters …

- Values obtained from laboratory tests performed under loading conditions that correspond to those in-situ.

- A knowledge of the soil history and preconsolidation pressure is important in understanding the impact of loading. If final vertical stress is less than the preconsolidation pressure then settlements are likely to be relatively small.

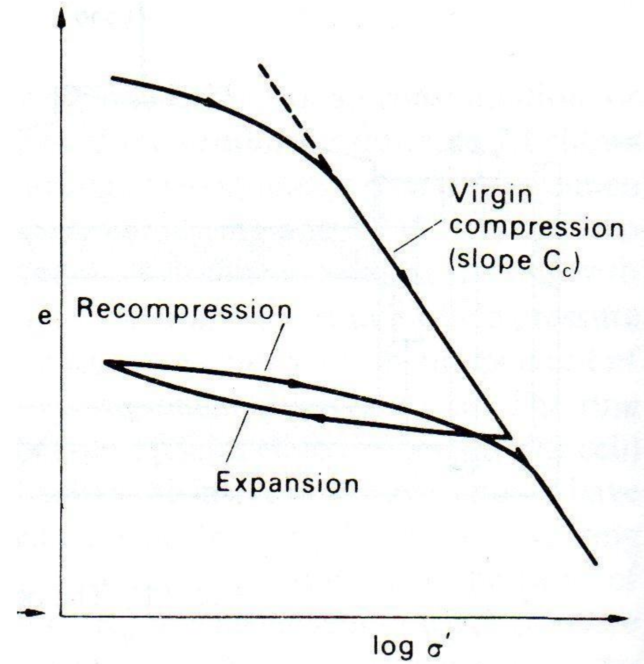
- Sampling effects. Some disturbance in the preparation of the laboratory has the effect of reducing slightly the slope of the measured virgin compression line, as compared to the in-situ slope. For a well kept and prepared sample, the difference will not be large.

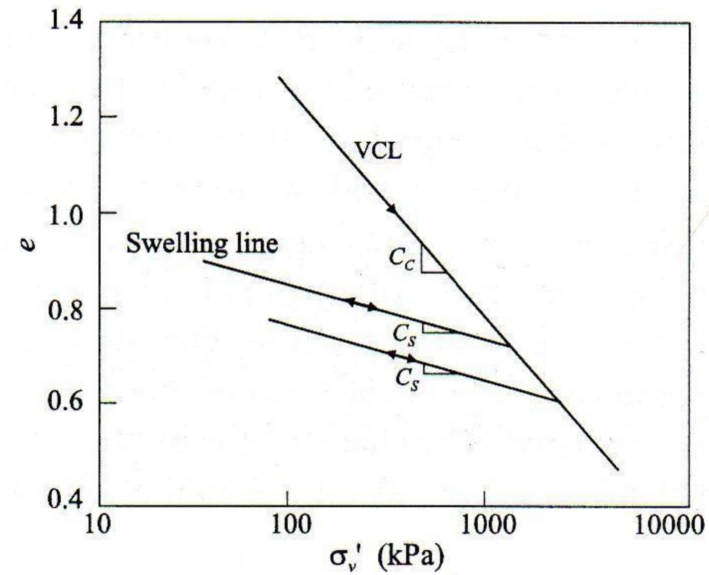
Parameter selection

Compression behaviour – in summary

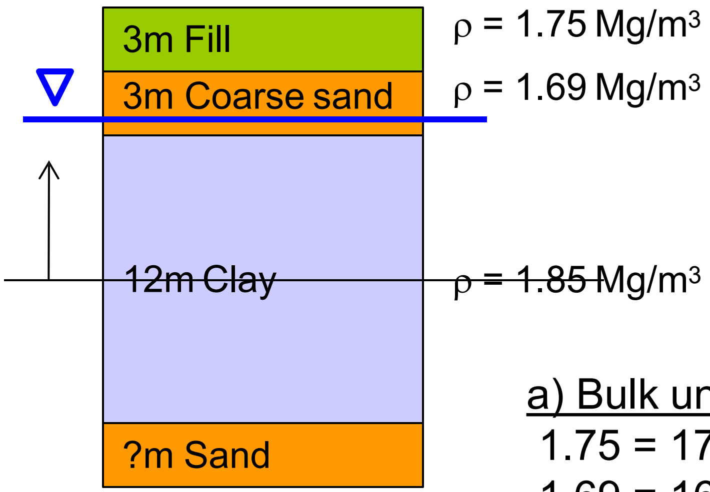
Typical soil behaviour under compression, which can be seen in all soils:

- Compression is highly non-linear.
- Unloading from some stress state on VCL, reveals irreversible deformation.
- Unloading and reloading may be treated as a linear elastic (reversible) phenomenon.
- During unloading and reloading, soil is much stiffer than the virgin response (flatter slope of unload/reload loop).
- When virgin curve is regained (at preconsolidation pressure), compressive stiffness rapidly reduces to that of the virgin soil.





Estimate the magnitude of settlement in clay layer:



To solve, determine:

a) Bulk unit weights
b) Initial vertical effective stress at centre of clay layer
c) Final vertical effective stress at centre of clay layer

a) Bulk unit weights are:

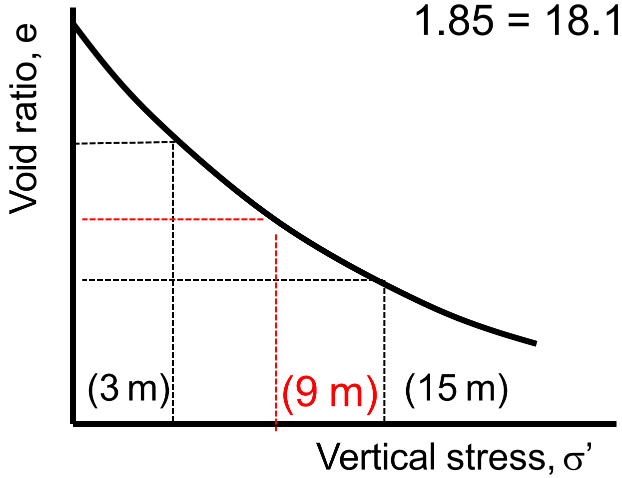
1.75 = 17.2 kN/m³
1.69 = 16.6 kN/m³
1.85 = 18.1 kN/m³

b) Initial vertical effective stress,

3 x 16.6 = 49.8
6 x 18.1 = 108.6
158.4
7 x 9.81 = -68.7
89.7 kPa

c) Final vertical effective stress

3 x 17.2 = 51.6
initial + 89.7
141.3 kPa



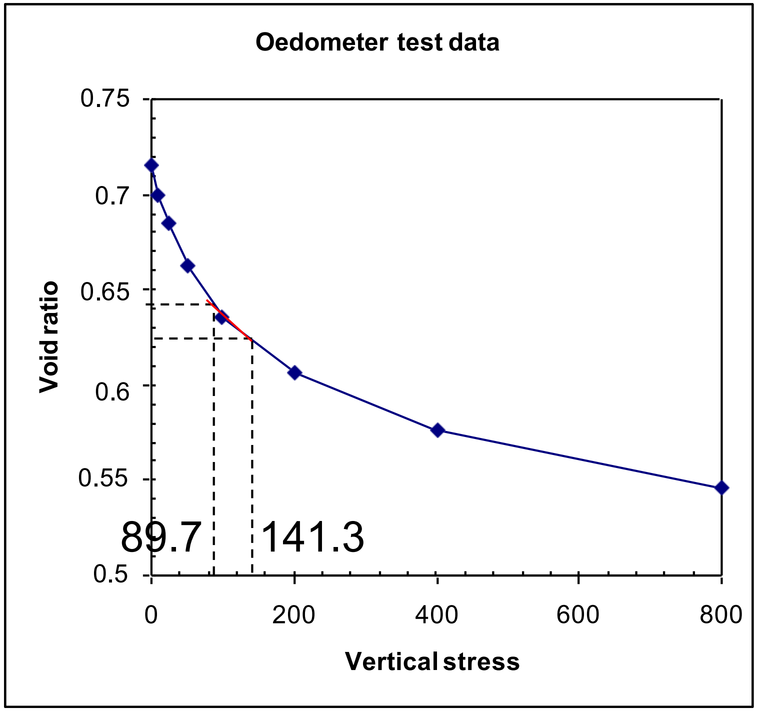
Worked example – 1

Oedometer test data:

d) Estimate average m_v over appropriate stress range:

Vertical stress [kPa]	Void ratio
1	0.715
10	0.700
25	0.685
50	0.662
100	0.636
200	0.606
400	0.576
800	0.546

<u>Graphically:</u>



89.7 – 141.3 kPa $m_V = \frac{e_0 - e_1}{(1+e_0)\Delta\sigma_v'} = \frac{0.640 - 0.622}{1.640 \times 51.6} = 0.213 \times 10^{-3} \frac{m^2}{kN}$

Settlement = $m_V \Delta\sigma_v' H_0$ = 0.21x10^{-3}x51x12 = **0.129m**

Worked example – 1