Question 1: Given σ' and dial gauge reading (for each σ') and e_0 (or method to calculate e_0)

Example (processing of oedometer results)

Consider embankment scenario (p.35 notes).
Imagine that load from embankment $\Delta\sigma_v$ = 100 kPa (e.g. 5 x γ_s with γ_s = 20 kN/m^3) and that the average initial in-situ effective stress in clay layer σ_v' = 100 kPa and that clay layer is 5m thick.

Results from compression readings from an oedometer test on a specimen of the saturated clay layer for which G_s = 2.73 are given in the table below.

Pressure (kPa) σ'_v	Dial gauge reading (mm)	ΔH (mm)	Δe	e
0	5.000	-	-	0.890
54	4.747	0.253	0.025	0.865
107	4.493	0.507	0.050	0.840
214	4.108	0.892	0.089	0.802
429	3.449	1.551	0.154	0.736
853	2.608	2.392	0.238	0.652

Initial thickness of specimen was 19.0 mm and initial w = 32.6 %.

<u>Determine m_v for the stress increment of 100 - 200 kPa</u>

given: h_0, ΔH
find $e_0 = \frac{w G_s}{S_r}$
find $\Delta e = \frac{\Delta H}{H_0}(1+e_0)$

now we have $\underbrace{h_0, \Delta H; e_0, \Delta e}_{H \text{ and } E \text{ for every kPa}}$

↓

find m_v

(i) $e_0 = w_0 G_s$
$= 0.326 \times 2.73 = 0.890$

(ii) from phase diagram

$$\frac{\Delta e}{\Delta H} = \frac{1+e_0}{H_0} = \frac{1.890}{19.0} = 0.0995$$

(n.b. this ratio Δe / ΔH does not change as long as cumulative values used).

So $\Delta e = 0.0995\,\Delta H$ (tabulated above)

We can now plot e versus log σ_v' (on semi-log paper) or linearly interpolate

$$m_v = \frac{1}{1+e_{100}}\left(\frac{e_{100}-e_{200}}{200-100}\right)$$
$$= \frac{1}{1.843}\left(\frac{0.843-0.807}{200-100}\right)$$
$$= 1.95 \times 10^{-4}\ \text{m}^2/\text{kN}$$

these value can be obtained from plots of e / log σ_v' or linear interpolate!

We can now calculate the total long-term settlement from embankment construction (which is the same as the compression of the clay layer):

$\rho_\infty = m_v\,\Delta\sigma_v'\,H$

$= 1.95 \times 10^{-4} \times 100 \times 5 = 0.098$ m = 98 mm

☆ VERY IMPORTANT EXAMPLE

Example where average degree of consolidation U and time factor T_v used in conjunction with oedometer results

Consider the embankment scenario shown on p. 35 for which oedometer test data were used to determine the maximum long-term settlement from constructing the embankment (p. 35): $\rho_\infty = 98\text{ mm}$

Let's assume a $c_v = 0.5\text{ m}^2/\text{yr}$ value for the clay layer.

a.) How much settlement occurs after 1 year?

$$T_v = \frac{c_v t}{h^2} = \frac{0.5 \times 1}{2.5^2} = 0.08$$

n.b. $h = 2.5\text{ m}$ as we have 2-way drainage.
Knowing T_v we can determine U either directly from the graph on p. 46 or by interpolating values from the table.

$$\Rightarrow U \approx 34\% \qquad \therefore \rho_t = 0.34\,\rho_\infty = \underline{33\text{ mm}}$$

b.) How long will it take for 70% consolidation to take place?

If $U = 0.7$, $T_v = 0.403$ (from graph or table, p. 46)

$$\therefore t = \frac{T_v h^2}{c_v} = \frac{0.4 \times 2.5^2}{0.5} = \underline{5\text{ yrs}}.$$

We can also calculate the permeability of the clay for this stress increment using the oedometer test data

$$k = c_v m_v \gamma_w \qquad \text{(p. 43)}$$
$$= 0.5 \times 1.95 \times 10^{-4} \times 9.8$$
$$= 9.6 \times 10^{-4}\text{ m/yr}$$
$$= \underline{3.0 \times 10^{-11}\text{ m/sec}}.$$

If we took another c_v value, say $c_v = 5m^2/yr$

For (a.) $\rho_t = 87$ mm $(U = 0.89)$

(b.) $t = 0.5$ yrs

It is important to determine the correct value of c_v (ie. for the appropriate stress change).
c_v is also calculated from the oedometer test data.

CIVE 50007 Tutorial Sheet 3 - The oedometer test and consolidation

Type I Question (given σ' and ΔH) and ways to determine e_0 → find m_v!
→ single fixed t, measure H for every σ'

Q1) A sample of soft natural clay has been taken from a depth of 8.7m below ground level. The strata consist of 3.35m of silt (γ_s = 18.5 kN/m^3), overlying clay (γ_s = 15.7 kN/m^3). Ground water level is 1.5m below G.L. (the silt, as a consequence of capillary rise, may be assumed to be almost saturated).

A consolidation test is carried out on the clay sample with the following results:

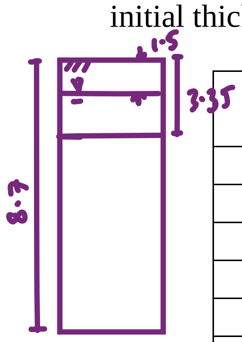
natural water content = 68.0%
specific gravity of grains = 2.70
initial thickness of specimen = 22.5mm.

$\Big\} e_0 = \frac{wG_s}{S_r} = \frac{0.68(2.7)}{1.0} = 1.836$

This ΔH is incremental same as Δe.

$\Delta e = \frac{\Delta H}{H_0}(1+e_0)$ $e_i = e_0 - \Delta e$

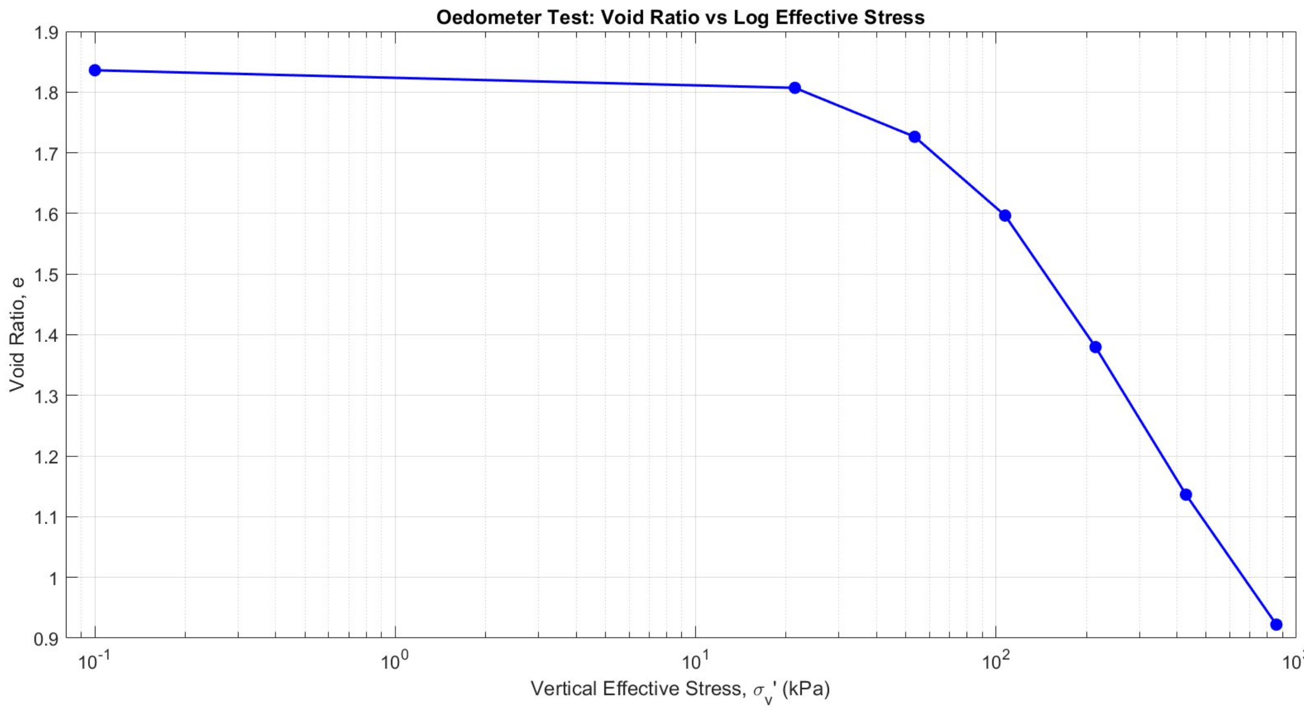
$\sigma' = \sigma - u$



$e_0 = 1.836$

Vertical stress (kPa)	Incremental* compression ΔH (mm)	Δe	e
Capillary pressure unknown	-		
21.4	0.23	0.0290	1.8070
53.6	0.64	0.0807	1.7263
107.2	1.03	0.1298	1.5965
214.4	1.72	0.2168	1.3797
428.8	1.93	0.2433	1.1365
857.6	1.70	0.2143	0.9222

a) From these results plot a graph relating void ratio and vertical effective stress, using a logarithmic scale for pressure (i.e. the laboratory consolidation curve).



b) From these data calculate the coefficient of one-dimensional compressibility, m_v, for a stress increment relating to an increase of 100 kPa above the initial in-situ stress at the depth in question (8.7m).

find in-situ (or initial) σ_v'

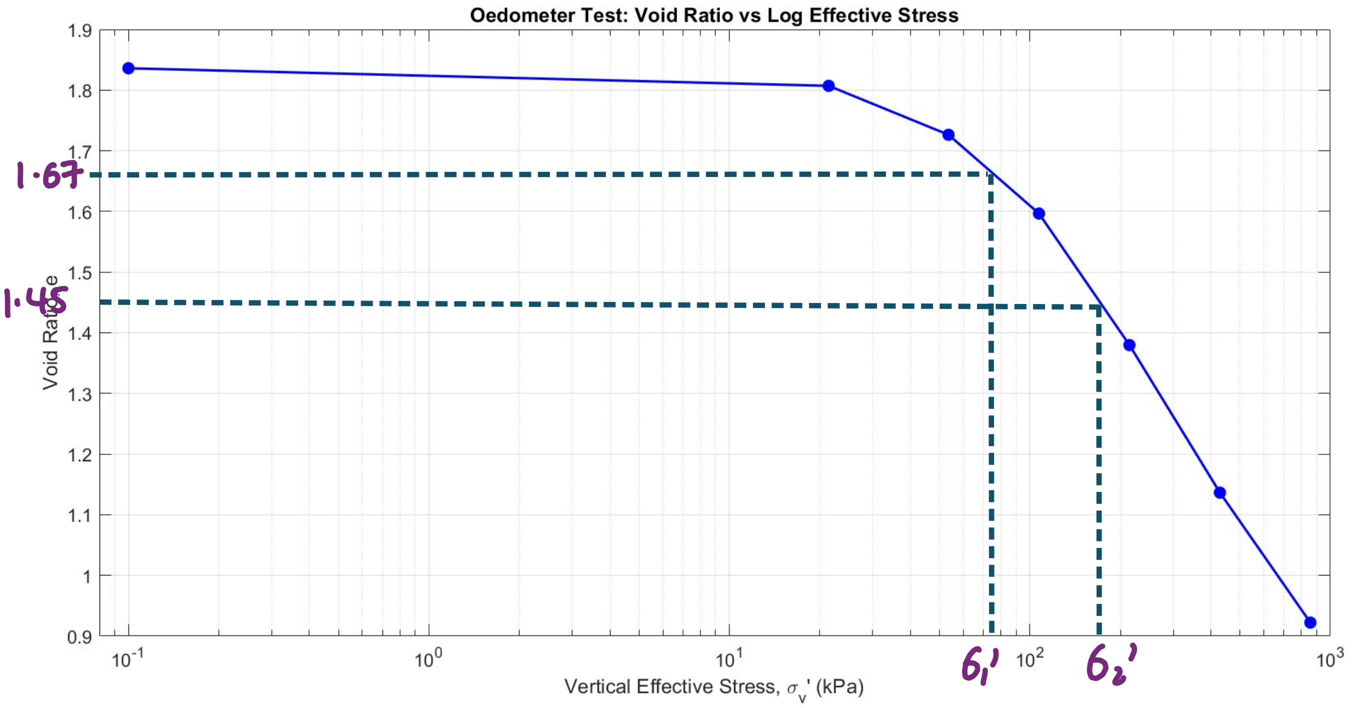
$\sigma_v' = \sigma - u$
$= 3.35 \times 18.5 + (8.7 - 3.35) \times 15.7 - \gamma_w (8.7 - 1.5)$
$= 75.338$ kPa

so we want to find m_v for $\sigma_1' = 75.338$ kPa to $\sigma_2' = 175.338$ kPa

we know $m_v = \frac{1}{1+e_0}\left(\frac{\Delta e}{\Delta \sigma'}\right)$

we need to find e_1 and e_2 (for σ_1' and σ_2')

100 kPa



$\therefore m_v = \frac{1}{1+1.836}\left(\frac{1.67-1.45}{100}\right) = 7.76 \times 10^{-4}$ m²/kN

c) If the increment of σ_v' represents the average change in vertical effective stress within a layer 5m thick, what would the resulting final settlement of the ground surface. Assume any other layers are incompressible for this exercise.

(Answers: b) 75.4 kPa; c) 8.65 x 10^{-4} m²/kN; d) 0.43m).

$\rho_\infty = \overbrace{m_v}^{7.76\times10^{-4}} \underbrace{H}_{5m} \underbrace{\Delta\sigma_v'}_{100 kPa} = 7.76 \times 10^{-4} \times 5 \times 100 = \underline{\underline{0.39 m}}$

Type 2 Question: Given t and h find cv (rate/speed of consolidation)
→ single fixed σ_v', measure h for every t

Q2 During the stress increment 107.2 to 214.4 kPa in the previous consolidation test, the following results were obtained:

This Δh is cummulative from time, t=0!

Time, *t* (mins)	Reduction in sample thickness, h (mm) Δh
0	0
0.5	0.08
1.0	0.16
2.25	0.24
4.0	0.33
6.25	0.41
9.0	0.50
12.25	0.58
16.0	0.67
20.25	0.74
25.0	0.82
36	0.97
49	1.08
64	1.19
81	1.27
100	1.33
121	1.37
144	1.42
169	1.46
225	1.54
324	1.59
1444	1.72

at here, h = 20.6mm! not 22.5mm!

EXTREMELY IMPORTANT → find d for cv!

Initial thickness of sample (no load) = 22.5mm.

thickness when "σ' = 107.2 kPa" experiment is done

$= 22.5\text{mm} - (0.23+0.64+1.03)$
$= 20.6\text{mm}$

use H at t_0 for d! not at t_{50}! and not H_0! (22.5)

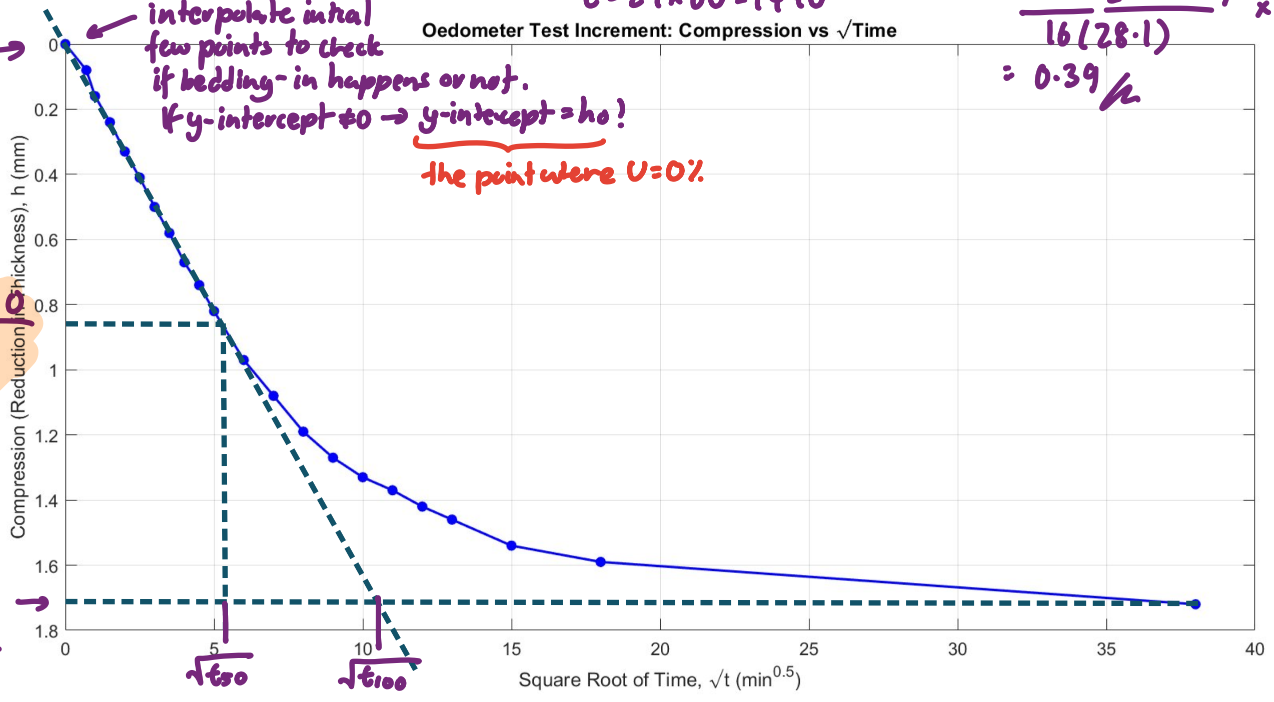
Plot the compression against √*t* and calculate the coefficient of consolidation, c_v, assuming all consolidation to be complete after 24 hours.

no creep! can straightaway use the formula: $c_v = \frac{3d^2}{16 t_{50}}$ (since two way drainage, $d = H/2$)

(Answer: c_v = 0.40 m^2/year). → and it also means U=100% at $t = 24 \times 60 = 1440$

$$= \frac{3\left(\frac{20.6}{2} \times 10^{-3}\right)^2}{16(28.1)} \times 365 \times 24 \times 60$$

$= 0.39$ //



U=0% → $h_0 = 0$

interpolate initial few points to check if bedding-in happens or not. if y-intercept ≠ 0 → y-intercept = h_0! the point where U=0%

$h_{50} = \frac{1.72 - 0}{2} = 0.86$

$\sqrt{t_{50}} \approx 5.3$
$t_{50} = 28.1$

U=100% → $h_{100} = 1.72$

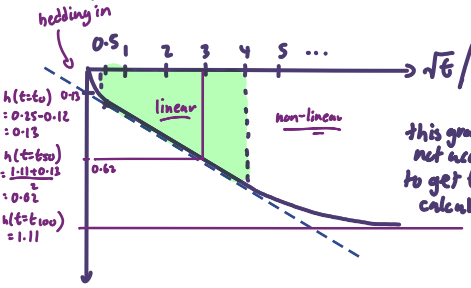
$\sqrt{t_{50}}$ $\sqrt{t_{100}}$

c) During the course of an oedometer test the sample was observed to compress as shown in the table below, following an increase in vertical effective stress from 100 to 200 kPa. Only one drainage boundary was provided in the test apparatus. After making an appropriate allowance for bedding-in errors, calculate the value of the coefficient of consolidation, c_v, assuming that only primary consolidation occurred and that this was complete within 24 hours.

The thickness of the sample at the end of the previous stage was 18.5 mm. Note that the linear portion of the relation between U and T_v has the equation $U = (4T_v/\pi)$.

(8 marks)

step 1. Find where t_0 is.



this graph is not accurate! to get t_{50} do calculation!

Time (minutes)	$\sqrt{t}$	Total compression (mm)
0.25	0.5	0.19
1.0	1.0	0.25
4	2.0	0.37
9	3.0	0.49
16	4.0	0.61
64	8.0	0.88
196	14.0	1.02
400		1.07
676		1.08
1444		1.11

0.06, 0.12, 0.12, 0.12 — linear.

0.27 — no longer linear

0.62 is between here

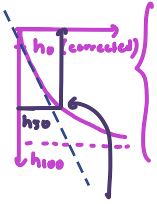
to find t_{50}, knowing that $h(t=t_{50}) = 0.62$:

linear interpolate:

$$\frac{\sqrt{64}-\sqrt{16}}{0.88-0.61} = \frac{\sqrt{t_{50}}-\sqrt{16}}{0.62-0.61}$$

$$\sqrt{t_{50}} = 4.148$$

$$t_{50} = 17.21$$



interpolate on the curve, not the linear line!

d uses H at t0 (uncorrected)

$$c_v = \frac{\pi d^2}{16\, t_{50}} = \frac{\pi\left(18.50\right)^2}{16 \times 17.21} = 2.0523 \text{ m}^2/\text{year}.$$

d) What would be the primary consolidation settlement ultimately (i.e. in the long term) and after 3 years, of a 10 m thick layer of this saturated clay subjected to a similar stress increase (as in part c)? Assume that the clay rests on impermeable rock and that there is a free-draining sand layer above it. [Hint: you will need to use the relationship between T_v and U as given in table/graph in your notes.]

(4 marks)