IMPERIAL COLLEGE LONDON

MEng EXAMINATION 2020

PART II

This paper is also taken for the relevant examination for the Associateship

CIVE 95010: Soils and Engineering Geology

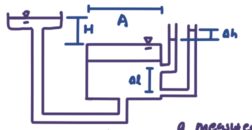
Thursday 21st May 2020: 12:00 to 15:00 hrs (BST)

An extra 30 minutes will be added on to the times shown above in order for you to scan and upload your answers.

Answer all FIVE questions.
All questions carry equal marks.

Take the unit weight of water, γ_w, as 9.8 kN/m^3.

(a)



$q = Ak\frac{\Delta h}{\Delta l}$

q measured from overflow [$m^3 s^{-1}$]
A, Δh, Δl all shown in diagram.

1. Understanding how water flows through an earth embankment dam forms a crucial component to assessing its stability and safeguarding it from erosion. Determining permeability is a vital part of the necessary seepage analysis.

a.) Explain, using a sketch, how you would determine the permeability of a sand using a permeameter apparatus similar to that demonstrated in lectures and your laboratory class.

(7 marks)

b.) For a given sand what causes the permeability to vary and how would you investigate the potential range of permeability using the apparatus described in part (a)? answer : k depends on ρ

compact the sand and measure k for different level of compact.

(2 marks)

b.) A section through a model experiment designed to investigate flow through an earth dam, similar to that used in your laboratory class, is shown in Figure Q1.
(i) Draw on your answer sheet the outline of the dam, filter and water levels using the scaled dimensions given in the figure. (Hint: start by drawing base.)
(ii) Construct a flow net on your drawing and explain how you would calculate the flow. State any assumptions that you need to make.
(iii) If the dimensions given in Figure Q1 represent a given scale (e.g. 1:10), what additional information would you need to calculate the flow?

$q = kH\frac{N_f}{N_d}$, assume the soil is isotropic

(8 marks)

d.) The flow measured during the model dam experiment is greater than the flow calculated using the flow net. List potential reasons for this.

(3 marks)

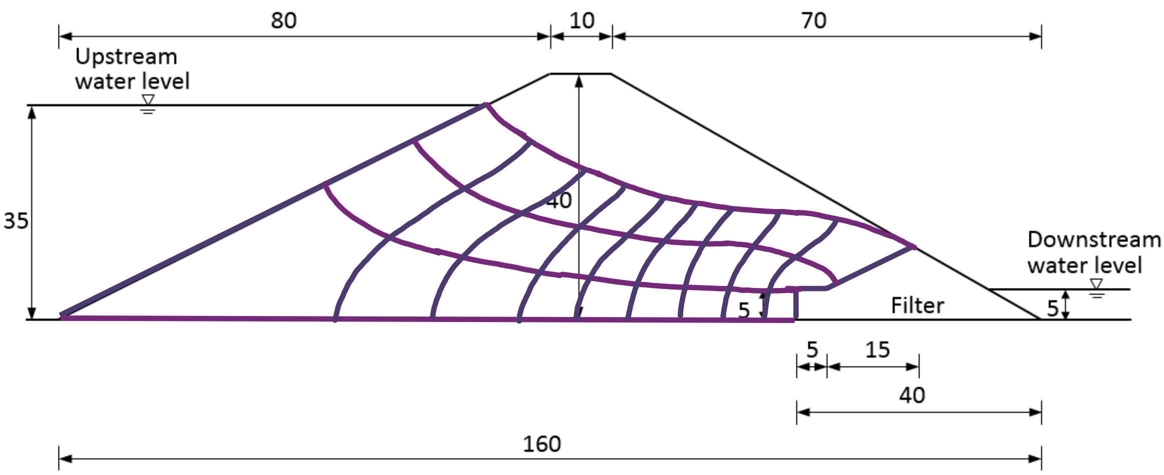


Figure Q1 (all dimensions in mm)

2. A consolidation test was performed on a sample of soft clay in a conventional oedometer (two drainage boundaries). The initial thickness of the specimen was 20 mm, and at the beginning of the test, before any load application, the compression dial gauge read zero. For the vertical stress increment from 160 kPa to 320 kPa the change in thickness with time was as follows.

this is type 2 question where we are given $h(t)$ and we can find c_v which allow us, if want to find $T_v = \frac{c_v t}{H^2}$ (find t)

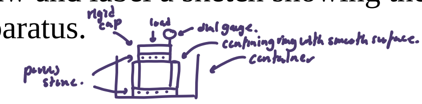
Time (minutes)	Dial gauge reading (mm)
0	1.39
0.25	1.52
1.0	1.64
4	1.87
9	2.08
16	2.20
25	2.29
64	2.42
121	2.46
225	2.50
1444	2.61

before time = 0, $\sigma = 160$ kPa
this is $\sigma = 320$ kPa!

$H_0 = 20 - 1.39$ not $H_0 = 20$!

so H_0 should take $H_0 = 20\text{mm} - 1.39\text{ mm} = 18.61\text{mm}$
NOT $H_0 = 20\text{mm}$!
this is $\sigma = 0$ kPa!

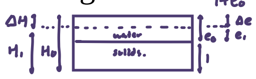
a.) Draw and label a sketch showing the essential components of the oedometer apparatus.



(4 marks)

b.) Write down the expression for the coefficient of compressibility, m_v in terms of void ratio and show how it can be expressed in terms of sample compression Δh using a phase diagram. $m_v = \frac{1}{1+e_0}\left(\frac{\Delta e}{\Delta \sigma'}\right) = \frac{1}{H_0}\left(\frac{H_0 - H_1}{\sigma_1' - \sigma_0'}\right)$ $\frac{\Delta H}{\delta \sigma'}$

memorise this phase diagram!

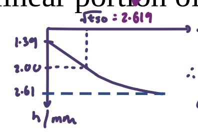


c.) Assuming that compression is solely due to primary consolidation, determine the coefficient of compressibility, m_v and the coefficient of consolidation c_v for the 160 kPa to 320 kPa stress range. Recall that the linear portion of the relation between U and T_v has the equation $U = \sqrt{(4T_v/\pi)}$.

(kinda unique to find m_v with $h(t)$ graph)
find m_v:
$H_0 - H_1$ is how much H change when σ from 160→320!
$m_v = \frac{1}{H_0}\left(\frac{H_0 - H_1}{\underbrace{\sigma_1' - \sigma_0'}_{160\text{kPa}}}\right) = \frac{1}{18.61}\left(\frac{2.61 - 1.39}{160}\right) = 4.097 \times 10^{-4}\ \text{m}^2/\text{kN}$
$H_0 = H_0(160 \to 320) = 20\text{mm} - 1.39\text{mm} = 18.61\text{mm}$

find c_v (typical) find c_v with $h(t)$ graph)

to get $\sqrt{t_{50}}$ can use linear interpolate.
we know $h = 2$mm is between $t = 4$ and $t = 9$
must interpolate h against $\sqrt{t}$ (not t!)
$\frac{\sqrt{9} - \sqrt{4}}{2.08 - 1.87} = \frac{\sqrt{t_{50}} - \sqrt{4}}{\underbrace{2.00}_{h(t_{50})} - 1.87}$
$\sqrt{t_{50}} = 2.619$



$\therefore t_{50} = 6.86$

(8 marks)

(not t_{50}!)
d uses H at t_0!
$H(t = t_0) = 20\text{mm} - 1.39\text{mm} = 18.61\text{mm}$

$c_v = \frac{2d^2}{16 t_{50}} = \frac{2\left(\frac{18.61}{2}\text{ mm}\right)^2}{16 \times 6.86\text{ mm}} = 1.30\ \text{m}^2/\text{year}$

remember we this unit in exam! (convert)

d) What would be the settlement ultimately (i.e. in the long term) and after 4 years, of a 8 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.

one way draining.

(5 marks)

$\rho_\infty = m_v \cdot \Delta\sigma_v' \cdot H$
$= 4.097 \times 10^{-4}\ \cancel{\text{m}^2/\text{kN}} \times 160\ \cancel{\text{kN}/\text{m}^2} \times 8\text{m}$
$= 0.5244$ m

$\rho_t = U \rho_\infty$
find U when $t = 4$ years.
→ can use c_v

$T_v = \frac{c_v t}{H^2}$, $U = 2\sqrt{\frac{T_v}{\pi}}$ $U = 2\sqrt{\frac{0.08125}{\pi}} = 0.3216$

$T_v = \frac{1.30\text{m}^2/\text{year} \times 4\text{year}}{(8\text{m})^2}$
$= 0.08125$

$\therefore \rho = 0.3216 \times 0.5244\text{m} = 0.1687$ m

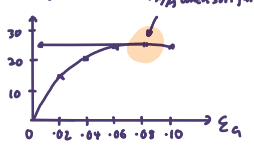
3. The results from the undrained shearing stage (in compression) of a triaxial test on a saturated normally consolidated clay are given in the table below. The sample had an initial effective stress of 30 kPa (prior to loading ram and load cell being brought into contact with sample). In the following questions, state and if necessary discuss, any assumptions that you make.

a.) If the sample had an initial length of 76 mm and diameter of 40 mm, plot the deviator stress versus axial strain curve and determine the deviator stress acting on the sample at failure.

$A = \frac{A_0}{1-\varepsilon_a}$; $A_0 = \frac{\pi}{4}D^2 = \frac{\pi}{4}(40^2) = 1256.6 mm^2$

(9 marks)

Axial load (N)	Axial compression (mm)	$\varepsilon_a = \frac{x}{l=76}$	A [mm²]	Pore water pressure (kPa)	deviator stress = Fx/A [kN/m²]
0	0	0	1256.6	0	0
18.0	1.52	0.02	1282.2	6.5	14.04
27.0	3.04	0.04	1309.0	10.0	20.63
31.5	4.56	0.06	1336.8	11.5	23.22
34.0	6.08	0.08	1365.9	12.5	24.89
33.5	7.60	0.10	1396.2	13.0	23.99



[n.b. assume that the area at each stage of shearing can be calculated using the following expression:

$$A = \frac{A_0}{1 - \varepsilon_a}$$

where A = sample area, A_0 = sample area at start of shearing, ε_a = axial strain.]

one of the hardest question I've seen.

b.) Draw the Mohr's circles for the failure conditions in the sample in both total and effective stresses (both on the same diagram). (Hint: the cell pressure can be deduced from the initial effective stress and pore water pressure.)

(6 marks)

c) Determine the corresponding strength parameters. At which angle to the horizontal would you expect the plane of failure to form?

(5 marks)

(b)

$A = \frac{A_0}{1-\varepsilon_a}$; $A_0 = \frac{\pi}{4}D^2 = \frac{\pi}{4}(40^2) = 1256.6 mm^2$

(9 marks)

Axial load (N)	Axial compression (mm)	$\varepsilon_a = \frac{x}{l=76}$	A [mm²]	Pore water pressure (kPa)	deviator stress = Fx/A [kN/m²]
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18.0	1.52	0.02	1282.2	6.5	14.04
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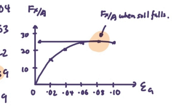
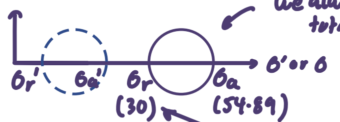


when drawing Mohr's Circle... ①



we always get to know total stress first... why?

② Initially, given $\sigma'_0 = 30 kPa$ we know $u_0 = 0$ hence $\underbrace{\sigma = \sigma' + u = 30 kPa}$

this is σcell and will not be changing the entire experiment! only Fx/A will be changing which causes u to change.

③ so $\sigma_r = \sigma_{cell}$
$= 30 kPa$

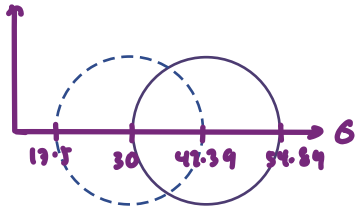
and $\sigma_a = \sigma_r + Fx/A$
$= 30k + 24.89k$
$= 54.89 kPa$

④ at Fx/A = 24.89 (failure state),
σr is still 30kPa but u is now increased to 12.5 kPa } so $\sigma'_r = \sigma_r - u$ (σcell)
$= 30 - 12.5$
$= 17.5 kPa$
; $\sigma'_a = \sigma_a - u$
$= 54.89 - 12.5$
$= 42.39 kPa$

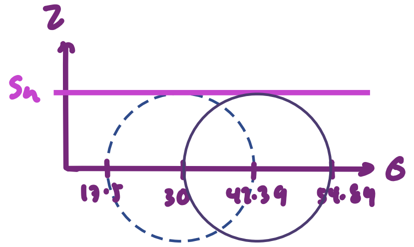
remember everything drawn on Mohr Circle is at failure state (It's only σr never change so σr = σinitial) but everything else especially σr' and σa' depends on failing state!

(σa depends too on Fx/A which is failing state)

2 so final graph should look:

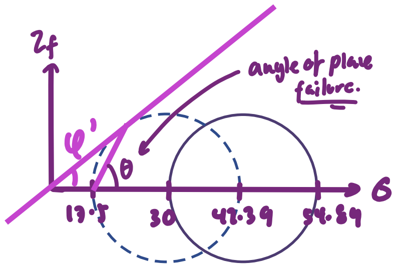


(c)



S_u = radius of Mohr's Circle
$= 24.89/2$
$= 12.445$ kPa

having the effective Mohr's Circle (since we measured u)
we can find Mohr Columb's Failure too



normal consolidate
means $c' = 0$!
(If we don't have this info we
need to get another sets of σ'
Mohr circle!)

4. The design of a planned railway line needs to assess the stability of excavated slopes in a clay soil. A site investigation indicates that the clay is saturated and homogeneous to a considerable depth, with a bulk unit weight, γ_{sat} = 20 kN/m^3. The site investigation did not provide a reliable value of the clay's undrained strength, S_u. However, during earlier temporary slope excavations at a site nearby in the same clay, a failure of a slope was recorded, the geometry of which is depicted in Figure Q4.

The slope in Figure Q4 was excavated with a 1.0 m wide horizontal bench in the middle of the slope height and with the gradient in both parts of 2.5:1 (vertical to horizontal). The excavated soil was deposited behind the crest of the slope, forming a surcharge, q, of 15kPa, which contributed to the slope failure.

Using the Limit Equilibrium method of analysis and clay properties given above, analyse the failure in Figure Q4 to determine the clay's undrained strength, S_u. Assume that the failure happened in an undrained manner, with the Tresca failure criterion active along the indicated planar failure surface, inclined at an angle θ to the horizontal.

a.) Identify all external and internal forces acting in the slope and mark their positions in the sketch of the slope.

(5 marks)

b.) Using two force equilibrium equations, resolving the forces in directions parallel and perpendicular to the failure surface, calculate the critical value of the angle θ and the magnitude of S_u of the clay.

(11 marks)

c.) Calculate the magnitudes of all forces identified in (a).

(4 marks)

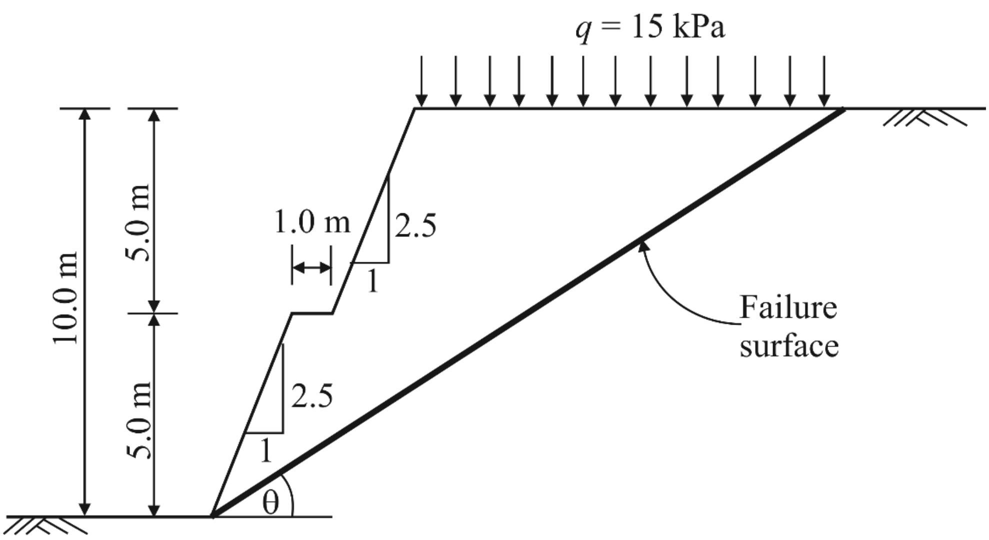


Figure Q4

5. A length of road cutting running north-south is causing concern. It is suspected that there may be a risk of cliff collapse.

The cutting is 10 m deep and both sides have been trimmed back to 75°. The rock mass has one set of persistent fractures, which have a friction angle of 35°. Figure Q5 shows a sketch of the cutting and two stereonet projections plotted with the poles of the fractures (black diamonds, which are the same in Stereonets 1 and 2). Stereonet 1 relates to the west side of the cutting and Stereonet 2 relates to the east side of the cutting. No other fracture sets are visible. The cliff section is dry.

a.) Provide a full explanation of what is shown in Stereonet 1 and Stereonet 2.

(7 marks)

c.) Match the terms given below with the correct letters on Stereonets 1 and 2 (A - F) in Figure Q5.

- Great circle
- Lateral limits
- Primitive circle
- Daylight envelope for toppling failure
- Daylight envelope for planar failure
- Friction Cone

(6 marks)

d.) What engineering protection measures would you apply to each slope to stabilise it against the failures identified in part (a.). Your answer should be specific to the geometry and failure mechanism identified.

(7 marks)

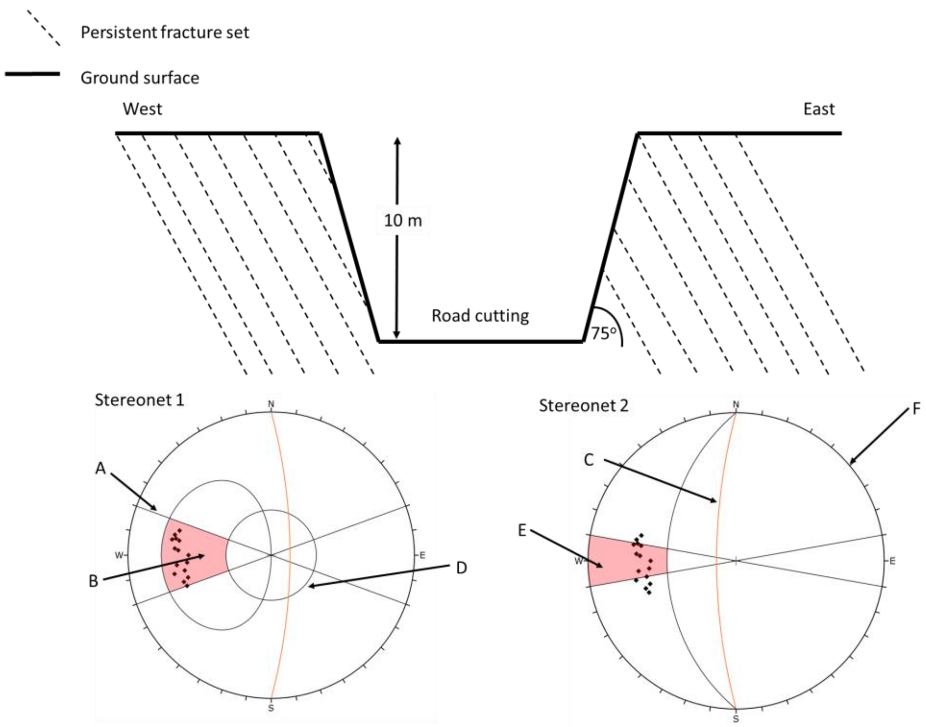


Figure Q5