IMPERIAL COLLEGE LONDON

MEng EXAMINATION 2019

PART II

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

CI2 - 250: Soils and Engineering Geology

Thursday 23rd May 2019: 09:30 - 12:30hrs

Answer all FIVE questions.
All questions carry equal marks.

Use separate answer books, one for Part A and the other for Part B.

DO NOT OPEN THIS EXAMINATION PAPER UNTIL INSTRUCTED TO DO SO BY THE INVIGILATOR

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

PART A

Use a separate answer book for this part, answer all four questions.

1. A wide excavation, as shown in Figure Q1, is made in clay of permeability $k = 3 \times 10^{-10}$ m/sec and unit weight $\gamma = 18.5$ kN/m^3 in which steady ground water conditions have been established consistent with the water levels shown. The clay is saturated both above and below the water table. State any assumptions that you need to make in the following sections.

   a.) Determine the pore water pressure and vertical effective stress at points A and B:
      (i) before the excavation was made;
      (ii) immediately after excavation;
      (iii) in the long term after the excavation has been allowed to fill with water to the level of the original ground water table.

   (12 marks)

   b.) Is there any danger of uplift of the floor of the excavation at stage (ii) above?

   (3 marks)

   ~~yes. $U_{A_1} = -36.6$ kPa, $U_{B_1} = 137.2$ kPa big Δu upwards.~~

   uplift occurs if $u_B > \sigma_B$
   in stage (ii) $u_B = 137.2$ kPa, $\sigma_B = 148$ kPa.
   $u_B < \sigma_B$. no uplift but very close to uplift.

   c.) What is the rate of flow into the ~~exaction~~ excavation at stage (iii)? Note that any flow in from the sides should be neglected which means that that only one-dimensional vertical flow needs to be considered and a flow net is NOT expected. Give the answer in m^3/day per metre length if the excavation width is 50 m.

   (5 marks)

(a)(i)

$u = 0$ m

$\times A$, $u = \frac{\Delta u}{d_{OB}} \times d_{OA} = \frac{14}{11} \times 3 = 3.82$ m
$= 37.4$ kN/m^2

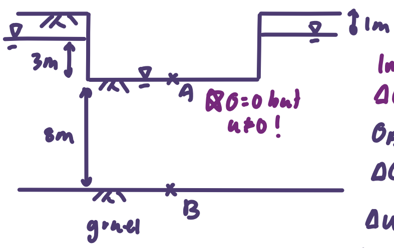
$\sigma = 4 \times 18.5k = 74$ kN/m^2

$\times B$, $u = 14$m $= 137.2$ kN/m^2
$\sigma = 222$ kN/m^2

$\sigma_A' = \sigma_A - u_A$
$= 74k - 37.44k$
$= 36.56$ kN/m^2

$\sigma_B' = \sigma_B - u_B$
$= 222k - 137.2k$
$= 84.8$ kN/m^2

(ii)



$\sigma = 0$ but $u \neq 0$!

Immediately after excavation
$\Delta\sigma = \Delta u$

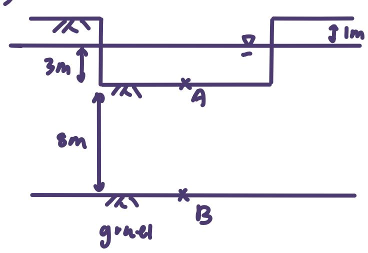
$\sigma_{A_1} = 0$
$\Delta\sigma = 0 - 74k = -74$ kN/m^2
$\Delta u = \Delta\sigma$
$u_{A_1} - u_{A_0} = -74k$
$u_{A_1} = 37.4k - 74k = -36.6k$

$\left.\right\}$ $\sigma_A' = \sigma_A - u$
$= 0 - (-36.6k)$
$= 36.6$ kN/m^2

$\sigma_{B_1} = 8 \times 18.5k = 148$ kN/m^2
$u_{B_1} = u_{B_0} = 137.2$ kN/m^2
$\left.\right\}$ $\sigma_B' = \sigma_B - u_B = 10.8$ kN/m^2

u fixed for entire question (piezometer reading)

(iii)



$\sigma_{A_2} = 3 \times 9.8k = 29.4$ kN/m^2
$u_{A_2} = 3 \times 9.8k = 29.4$ kN/m^2
$\left.\right\}$ $\sigma_{A_2}' = \sigma_A - u_A = 0$

$\sigma_{B_2} = 3 \times 9.8 + 8 \times 18.5 = 177.4$ kN/m^2
$u_{B_2} = u_{B_0} = 137.2$ kN/m^2
$\left.\right\}$ $\sigma_{B_2}' = 40.2$ kN/m^2

(c) $Q = Aki$, $i = \frac{\Delta h}{\Delta s}$

$h_A = z_A + \frac{u_A}{\gamma_w} = 8 + 3 = 11$m

$h_B = z_B + \frac{u_B}{\gamma_w} = 0 + 14 = 14$m

$\frac{Q}{w} = lki$

$i = \frac{h_A - h_B}{\Delta s} = \frac{11 - 14}{8} = \frac{-3}{8}$

$q = 50\text{m} \times 3 \times 10^{-10}\,\text{m s}^{-1} \left(\frac{3}{8}\right) \times (24 \times 60 \times 60)\,\text{s/day}$
$= 4.86 \times 10^{-4}$ m^3/day/m (upward)

2. A stratum of soft saturated clay of variable thickness is everywhere underlain by free-draining sand. The ground water conditions in both clay and sand are hydrostatic with respect to a water table at the surface of the clay.

a.) If the water content, w, of the clay varies with depth as given below, plot the corresponding relationship between void ratio and vertical effective stress and hence determine the coefficient of volume compressibility, m_v, of the clay for a stress range of 50 to 100 kPa. Make the simplifying assumption that $\gamma = 17$ kN/m^3 throughout the clay stratum and take $G_s = 2.70$.

(11 marks)

$\underbrace{\dfrac{\Delta H}{H_0} = \dfrac{\Delta e}{1+e_0}}$

usually we use this if compression, ΔH is given. or scales of height, H. depth, z IS NOT height, H!

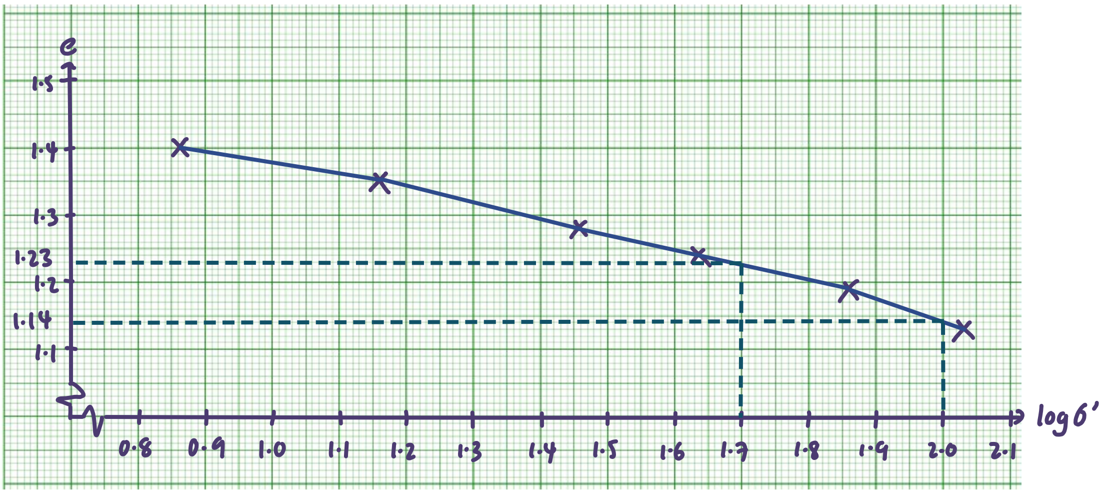
$e = \dfrac{wG_s}{S_r}$

taking $S_r = 1.0$:

$e = wG_s$

Depth (m)	1	2	4	6	10	15
w (%)	52	50	47.5	46	44	42
e	1.404	1.35	1.2825	1.242	1.188	1.134
$\sigma = \gamma_s z$ (kPa)	17	34	68	102	170	255
$u = \gamma_w z$ (kPa)	9.8	19.6	39.2	58.8	98	147
$\sigma' = \sigma - u$ (kPa)	7.2	17.4	28.8	43.2	72	108
$\log \sigma'$	0.857	1.158	1.459	1.635	1.857	2.033

for plotting, → cause we only plot $e - \log\sigma'$. But for finding m_v, $m_v = \dfrac{1}{1+e_1}\left(\dfrac{e_1 - e_2}{\sigma_2' - \sigma_1'}\right)$

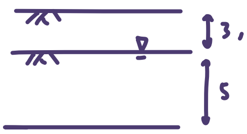


$m_v = \dfrac{1}{1+1.23}\left(\dfrac{1.23-1.14}{100-50}\right) = 8.072\times10^{-4}$ m²/kN

$\log 50 = 1.699$, $\log 100 = 2$

b.) If a wide embankment 3 m high, composed of free-draining fill, of bulk unit weight 19 kN/m^3, is now constructed over the soft clay at a location where the clay is 5 m thick, determine how much the clay stratum will compress. Assume that the water table remains at the top of the clay in the long term.

(3 marks)



$\Delta\sigma = 3(19) = 57\ kPa$ $\underline{\underline{\Delta\sigma' = \Delta\sigma}}$ (long term)

$\rho_\infty = m_v H \Delta\sigma'$

$= 8.072 \times 10^{-4} \times 5 \times 57 \times 10^3$

$= 230.052\ mm$ ⟵ why mm? m_v [m²/kN], H [m], $\Delta\sigma'$ [10³ N/m²] } [m/k] [mm]

c.) An oedometer test on a representative sample of this clay, subjected to a stress increase corresponding to that applied by the embankment, took 90 minutes to reach a degree of consolidation, U, of 90%. If the sample was initially 25 mm thick, and double drainage was allowed in the oedometer, calculate the time required for 90% of the embankment settlement to occur. $H/2$

$t_{90} = 90$

(6 marks)

$$T_v = \frac{c_v t}{H^2}$$

to find c_v usually we need to have $H(t)$ and then plot then use $c_v = \frac{3d^2}{16 t_{50}}$ or $c_v = \frac{0.848 d^2}{t_{90}}$

but since we already had m_v last question we can convert:

$$c_v = \frac{k}{\gamma_w m_v}$$

but no! we are missing k!

so we have to either of the top 2 eqn.

since given t_{90}, use second eqn.

$$c_v = \frac{0.848 \times (25mm/2)^2}{(90 \times 60s)} = 2.453 \times 10^{-8}\ m^2 s^{-1}$$

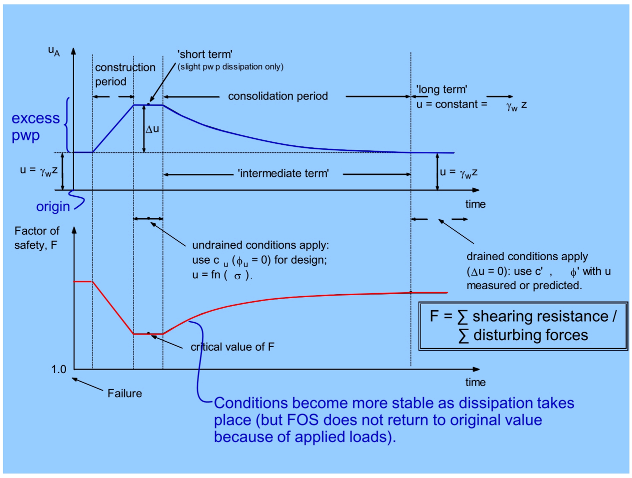
U	T_v
0.1	0.008
0.2	0.031
0.3	0.071
0.4	0.126
0.5	0.197
0.6	0.287
0.7	0.403
0.8	0.567
0.9	0.848
1.0	∞

$$t = \frac{T_v H^2}{c_v} = \frac{0.848 \left(\frac{5}{2}\right)^2}{2.453 \times 10^{-8}} \approx 6.85\ years.$$

3. Shear strength parameters can relate to either 'short-term' or 'long-term' conditions.

a.) Discuss, with the aid of diagrams relating pore water pressure and Factor of Safety to time, what are meant by 'short term' and 'long term' conditions for cases involving (i) a foundation loading and (ii) a cutting. Explain whether short- or long-term conditions are critical in each case.

(10 marks)



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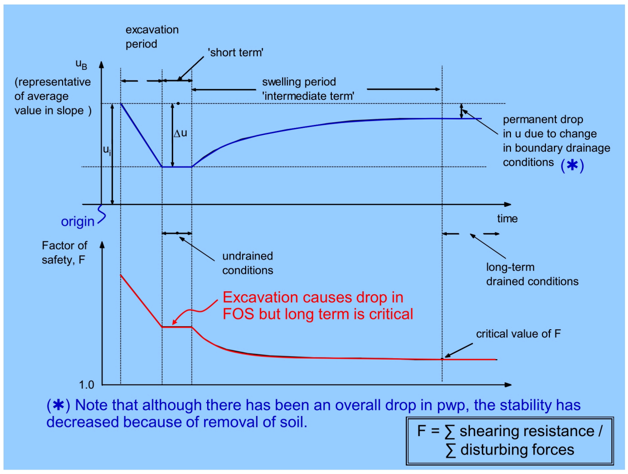

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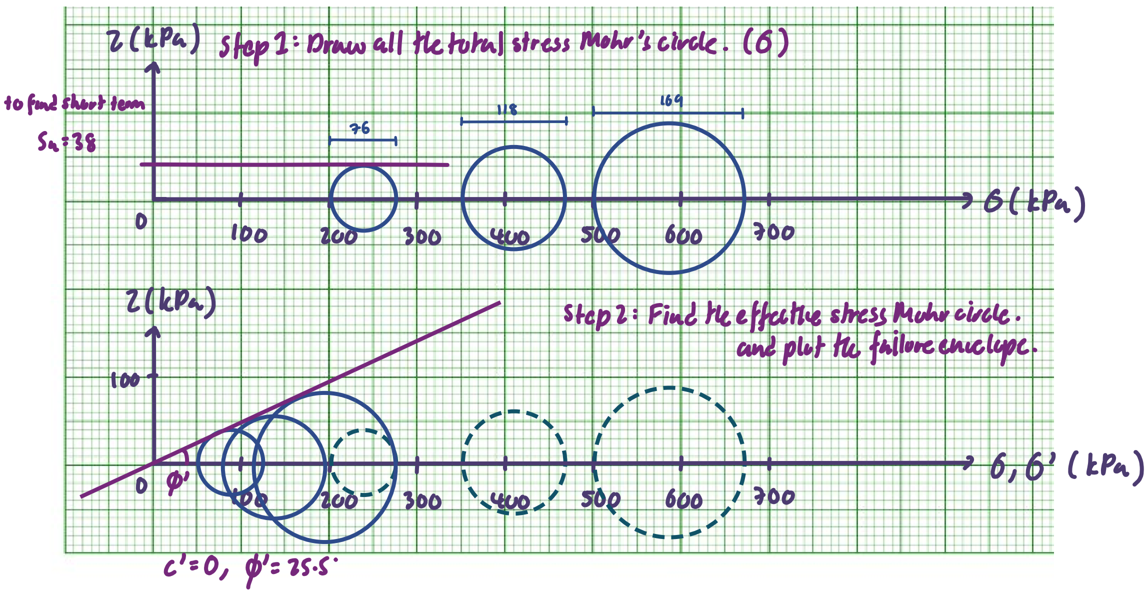
b.) Which shear strength parameters would you use for the short- and long-term cases and which type of triaxial test would you use to obtain them?

long term: $\tau_f = c' + \sigma_n' \tan\phi$ (Mohr Columb) short term: $\tau_f = S_u$ (tresca)
use consolidated-undrained unconsolidated-undrained

(4 marks)

c) Three triaxial tests were performed where isotropic consolidation was carried out to bring sample 1 to the same stresses as those in situ and samples 2 and 3 to higher stress levels prior to undrained shearing. The results given below relate to values at failure. Determine the short- and long-term shear strength parameters for sample 1.

Specimen no.	Cell pressure (kPa)	Deviator stress (kPa)	Pore water pressure (kPa)	σ_3'
1	200	76	148	200-148=52
2	350	118	269	350-269=81
3	500	169	385	500-385=115



(6 marks)

to find Mohr Columb Failure.
c', φ'
(long term)

4. The design of earthworks for a new development requires large temporary excavations, 10 m deep and with 1:1 (vertical to horizontal) slope inclinations in a homogeneous stiff clay, as shown in Figure Q4. To save on transportation costs, the excavated soil will be temporarily deposited as surcharge, q, on top of the slope, so that it is readily available for subsequent backfilling. As the site is busy, the piling up of the excavated material is limited to a 5.0 m wide area behind the slope, as depicted in Figure Q4. As a consequence, a tension crack may develop along the side of the surcharge area to about 1.5 m depth.

a.) Assuming the worst case scenario of the tension crack filling up with water and the failure surface of the slope being as depicted in Figure Q4, identify all external and internal forces acting in the slope and mark their positions and directions in a sketch of the slope similar to that in Figure Q4. The Mohr-Coulomb failure criterion applies along the failure surface.

(5 marks)

b.) Determine the magnitudes of all forces for the soil properties given in Figure Q4.

(10 marks)

c.) Using the Limit Equilibrium method of analysis calculate how much of the excavated soil (i.e. the magnitude of the surcharge, q) can be placed on top of the slope before it fails (i.e. when the factor of safety, F_s, equals to 1.0).

(5 marks)

You are reminded that the factor of safety, F_S, is calculated as a ratio of stabilising and disturbing forces acting along the failure surface:

$$F_s = \frac{c' \cdot l + \tan\phi' \cdot N'}{S}$$

where l is the length of the failure surface, c' is the cohesion, ϕ' is the angle of internal shearing resistance, N' is a resultant of the normal stresses and S is a resultant of the shear stresses acting along the failure surface.

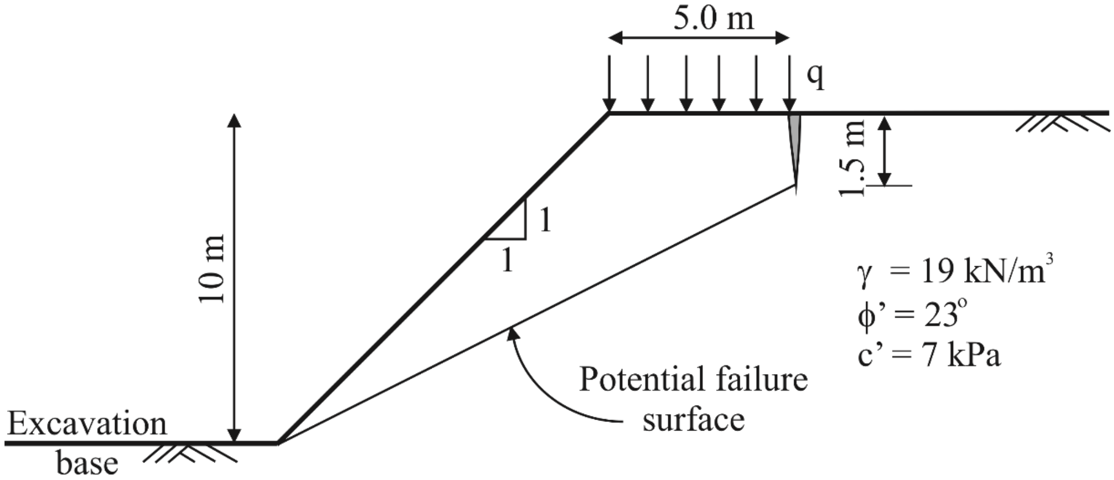


Figure Q4

PART B

Use a separate answer book for this part - make sure your annotated sheet is well attached.

5. NOTE: you are provided with a high-quality print and faint copy for your answer to part (a). DO NOT DRAW on the high-quality colour print; marks will not be awarded if you do.

   a) From your recollection of your site visit and using the high quality colour print as a guide, on the FAINT COPY highlight the main geological features and engineering issues that you can identify. Divide and outline the image into units of similar materials and/or hazards (for example, the sky might be one unit). Highlight any isolated or key features. Annotate fully; marks will not be awarded for outlines or features that are not clearly labelled.

   (12 marks)

   b) Recalling your field tests and observations as evidence and with the use of diagrams, what are the most like types of cliff failures? What processes are leading to cliff failure and what mitigation measures could be used to protect them?

   (8 marks)

CID:_________________________ You should annotate this figure