**IMPERIAL COLLEGE LONDON**

**MEng EXAMINATION 2024**

**PART II**

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

**CIVE 50007: Soils and Engineering Geology**

Friday 17th May 2024: 09:30 - 12:30 hrs (BST)

*Answer all FIVE questions.*
*All questions carry equal marks.*

Take the unit weight of water, $\gamma_w$, as 9.8 kN/m$^3$.

1) An impermeable concrete dam as shown in Figure Q1 has been constructed on a series of four strata as detailed in the table below. The upstream reservoir level is 15 m above the ground surface and the water table is at ground level on the downstream side of the dam. An 8-m deep cut-off wall has been installed close to the toe of the dam, as shown.

| Stratum | Description | Thickness (m) | Permeability (m/sec) |
|---|---|---|---|
| A | Dense sandy GRAVEL | 5.1 | $10^{-4}$ |
| B | Firm sandy SILT | 6.0 | $10^{-6}$ |
| C | Dense silty SAND | 3.9 | $10^{-5}$ |
| D | Very stiff CLAY | 20.0 | $10^{-12}$ |

In the following sections, explain and discuss any assumptions that are made.

a.) Draw a flow net beneath the dam, assuming in the first instance that the different granular strata were not identified in an early ground investigation and it was thought that strata A to C were one homogeneous layer with a permeability of $k = 10^{-5}$ m/sec. Clearly indicate the boundary conditions.

- assume that stratum D is impermeable.

(7 marks)

b.) Estimate the daily flow beneath the dam per metre run.

$q = kH\frac{N_f}{N_d}$ $N_f = 2$, $N_d = 9$ H (total head drop) = 15 m

(2 marks)

$= 10^{-5}\,ms^{-1} \times 15\,m \times \frac{2}{9} = 2.88\ m^2 day^{-1}$ can also be written as $2.88\ m^3 day^{-1}$ per unit width.

c.) Following a more detailed ground investigation, strata A to D were accurately defined along with their permeability values as given in the table above. Draw the flow net beneath the dam. Note that first you will need to determine the average horizontal and vertical permeability values for the layer system using the expressions given below.

$$k_x = \frac{1}{z}\left[z_1 k_1 + z_2 k_2 + \ldots + z_n k_n\right] \qquad k_z = \frac{z}{\left(\frac{z_1}{k_1} + \frac{z_2}{k_2} + \ldots + \frac{z_n}{k_n}\right)}$$

scaling x by $\sqrt{\frac{k_y}{k_x}} \approx 0.25$

where $z = z_1 + z_2 + \cdots + z_n$

$k_x = \frac{5.1\times10^{-4} + 6.0\times10^{-6} + 3.9\times10^{-5}}{5.1+6+3.9}$ $= 3.7\times10^{-5}$ m/sec

$k_z = \frac{5.1+6+3.9}{\frac{5.1}{10^{-4}} + \frac{6.0}{10^{-6}} + \frac{3.9}{10^{-5}}}$ $= 2.3\times10^{-6}$

(8 marks)

d.) Estimate the daily flow beneath the dam per metre run and comment on this value compared with that from part (b).

(3 marks)

$q = kH\frac{N_f}{N_d}$, $k = \sqrt{k_x k_y} = 9.2\times10^{-6}$

$= 9.2\times10^{-6} \times 15 \times \frac{3}{8}$

$= 5.175\times10^{-5}\ m^3/s/m$

$= 4.4712\ m^3/day/m$

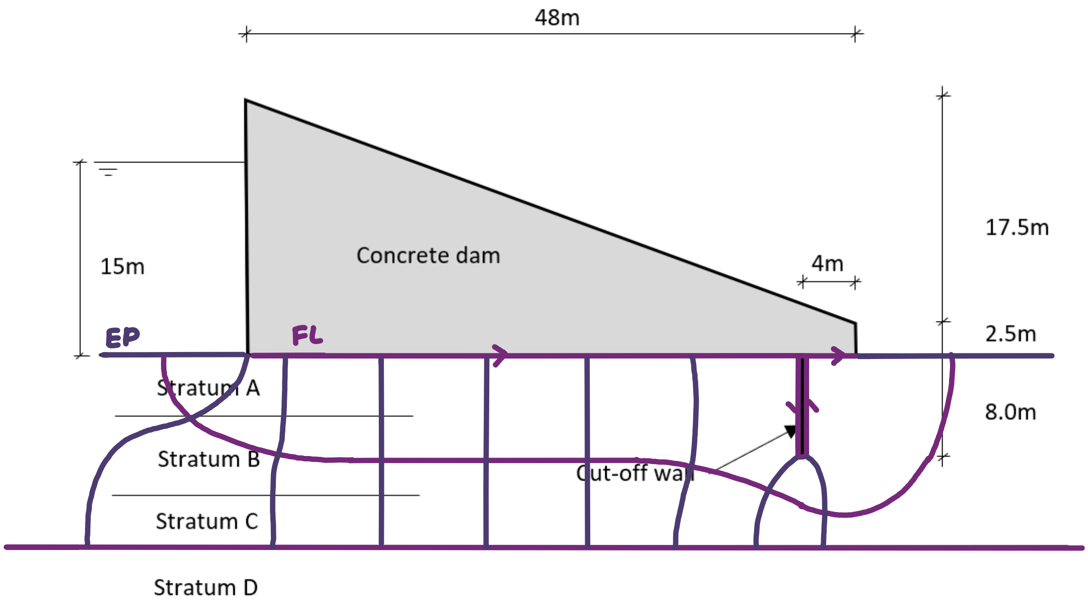
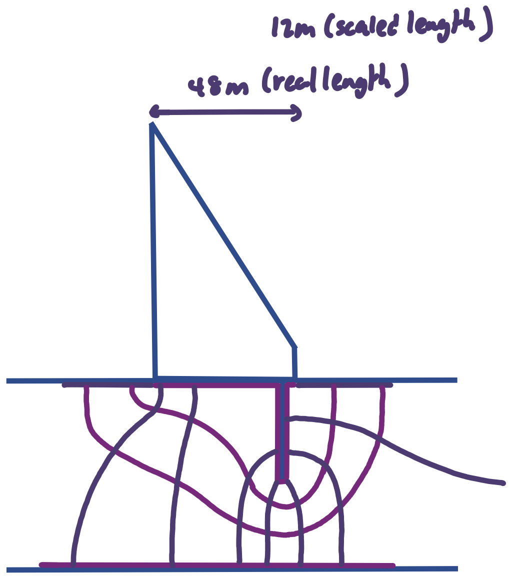

48m
17.5m
15m
Concrete dam
4m
EP
FL
2.5m
Stratum A
8.0m
Stratum B
Cut-off wall
Stratum C
Stratum D

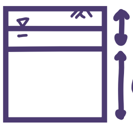
Figure Q1


12m (scaled length)
48m (real length)

2. A uniformly distributed load of 85 kN/m$^2$ is placed rapidly over a wide area. The ground conditions consist of 2 m of sand over 6 m of soft clay over an impervious and incompressible bedrock. The water table is at a depth of 1 m in the sand. From oedometer tests it has been determined that for the sand the compressibility may be regarded as zero, and that for the clay the coefficient of volume compressibility, $m_v$, is 0.0001 m$^2$/kN, and the coefficient of permeability is 5 x 10$^{-10}$ m/sec.

Note that for the sand $\gamma$ = 19.0 kN/m$^3$ (both above and below the water table) and for the clay $\gamma$ = 18.0 kN/m$^3$.

a.) What do you expect the initial (immediately after placing the load) and final (after complete consolidation) vertical total and effective stresses and pore water pressure to be at the mid-depth of the clay? Discuss any assumptions made.




(6 marks)

$\Delta\sigma = 85\ kN/m^2$

$\sigma_0 = 19(2)+3(18) = 92\ kN/m^2$ $\quad u_0 = 9.81(4) = 39.24\ kN/m^2$ $\quad \sigma_0' = \sigma_0 - u_0 = 92 - 39.24 = 52.76\ kN/m^2$

after adding load...

$\Delta\sigma = 85\ kN/m^2$

$\sigma_1 = 92+85 = 177$

initially all $\Delta\sigma = \Delta u$ ($\Delta\sigma' = 0$ hence $\sigma_1'$ still 52.76)

$u_1 = 39.24+85 = 124.24\ kN/m^2$

after consolidation complete.

u drop back to 39.24

$\Delta\sigma = \Delta\sigma' = 85$

$\therefore \sigma' = 52.76+85 = 137.76\ kN/m^2$

b.) Draw a sketch to show the essential details of the oedometer apparatus. Explain how the test is used to obtain $m_v$, the coefficient of compressibility.

(4 marks)

c.) What settlement over the loaded area do you expect to occur in the long term?

(2 marks)

$\rho_\infty = m_v H \Delta\sigma' = 0.001 \times 6 \times 85 = 0.051\ m$

only need to calculate region where consolidation happens.

d.) Given the relationship between $U$ and $T_v$ given in the table below, calculate the time (in years) within which you would expect 90 % of this settlement to occur.

(6 marks)

this is not type 1 or type 2 question
(find $m_v$, $C_c$ from H($\sigma'$)) (find $C_v$ from H(t))

this is just a simple application of cv question

find t for U=90%. (remember U and $T_v$ very related)

$\boxed{T_v = \frac{C_v t}{H^2}}$

$U = 90\% \rightarrow T_v = 0.848.$

need $C_v$...

$C_v = \frac{k}{\gamma_w m_v} = \frac{5\times10^{-10}}{10\times0.0001} = 5\times10^{-7}$

$t = \frac{H^2 T_v}{C_v} = \frac{6^2\times0.848}{5\times10^{-7}} = 6.1\times10^7 s$
$= \underline{1.94 \text{ years}}$

| Degree of consolidation, $U$ (%) | Time factor, $T_v$ |
|---|---|
| 10 | 0.008 |
| 20 | 0.031 |
| 30 | 0.071 |
| 40 | 0.126 |
| 50 | 0.197 |
| 60 | 0.287 |
| 70 | 0.403 |
| 80 | 0.567 |
| 90 | 0.848 |
| 100 | $\infty$ |

e.) If the bedrock were found to be fissured, how would this change the result in (d)?

(2 marks)

$t = \frac{(H/2)^2 \times T_v}{C_v} = 0.484$ years.

3. During a ground investigation, undisturbed samples were obtained from a homogeneous clay stratum. Consolidated-undrained triaxial compression tests were performed on three specimens trimmed from a sample representing one depth. During the tests, pore pressures, *u*, were measured and the stresses at failure of the three specimens were as given in the following table.

| Specimen no. | $\sigma_1$ - $\sigma_3$ (kPa) | $\sigma_3$ (kPa) $\sigma_3'$ | *u* (kPa) |
|---|---|---|---|
| 1 | 54.8 | 70 47.6 | 27.4 |
| 2 | 94.0 | 110 73.0 | 37.0 |
| 3 | 141.4 | 170 109.6 | 60.4 |

a.) Determine the shear strength parameters *c´* and *φ´* for this clay and comment on the nature of the clay.

(8 marks)

b) If the normal total stress on a plane through the clay deposit is 112 kPa and the pore pressure is 58 kPa, what is the shear strength along that plane?

(3 marks)

c) What is the significance of the pole of planes with reference to a Mohr circle?

(2 marks)

d) What angle to the horizontal do you expect the failure plane in specimen no. 2 to form?

(2 marks)

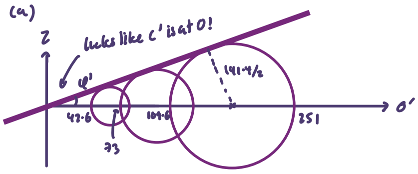
e) Calculate the normal and shear stresses on the failure plane in specimen no. 2 in terms of effective stress.

(2 marks)

f) Give three advantages that the triaxial apparatus has compared with the shear box apparatus.

(3 marks)

(a)




$\sin \varphi' \approx \frac{141.4/2}{109.6 + 141.4/2}$

$\varphi' = 23.1°$

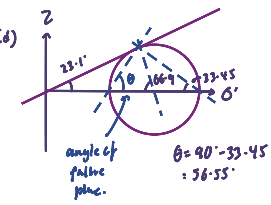
(b) $\tau = c' + \tan\varphi \cdot \sigma'$

$\sigma' = \sigma - u$
$= 112 - 58$
$= 54$

$\tau = \tan 23.1 \times 54$
$= 23.03 \text{ kNm}^{-2}$

(c) by knowing the pole of planes we can determine every angle θ's τ and σ' value.

(d)

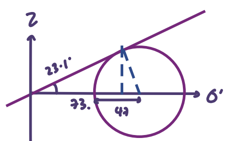



$\theta = 90° - 33.45$
$= 56.55°$



(e) $\tau_f = \cancel{c'} + \tan\varphi' \cdot \sigma_n'$
0

find $\tau_f$ or $\sigma_n'$ first and get the other one easily.




$(73+47)\cos 23.1° = 110.3786$

$\sigma_n' = 110.3786 \cos 23.1 = 101.53$ kPa

$\tau_f = 110.3786 \sin 23.1 = 43.31$ kPa check limit equilibrium example, I did the working here

4. For the design of roadworks it is necessary to investigate the stability of the side slopes of an excavation. A site investigation indicates that the soil is homogeneous to a considerable depth, with bulk unit weight $\gamma$ of 20 kN/m$^3$ and cohesion $c'$ of 8 kPa. This investigation did not provide a reliable value of the angle of shearing resistance $\varphi'$. However, during earlier works at the same site failure of an excavation was recorded, the geometry of which is presented in Figure Q4, together with the observed planar failure surface.

   Using the Limit Equilibrium analysis method and the soil properties given above, back analyse the failure in Figure Q4 to determine the value of shearing resistance $\varphi'$. Assume that the soil behaves in a drained manner, with a Mohr-Coulomb failure criterion. A surcharge of 20 kPa, representing contractor's plant, should be assumed to act on the ground surface at the crest of the slope, as indicated in Figure Q4. Sketch the forces acting on the failing soil block.

(20 marks)

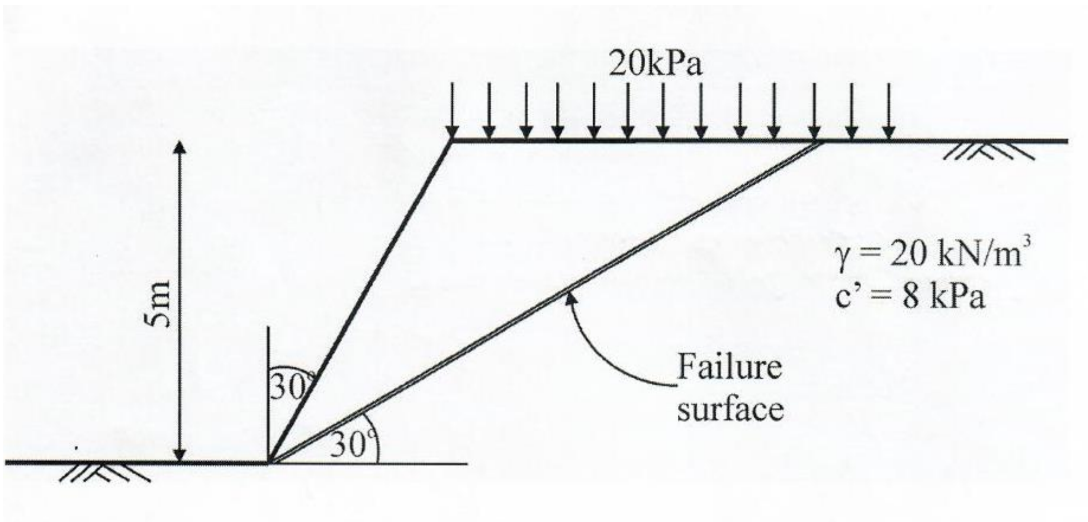



Figure Q4

5. From your recollection of your site visit and using the colour image (Figure Q5) as a guide, produce a geotechnical sketch of Figure Q5. 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 Mercia Mudstone 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.

(20 marks)

Figure Q5. Quarry, Burrington Combe