IMPERIAL COLLEGE LONDON

MEng EXAMINATION 2023

PART II

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

CIVE 50007: Soils and Engineering Geology

Friday 26th May 2023: 14:00 - 17:00 hrs (BST)

Answer all FIVE questions.
All questions carry equal marks.

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

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1) The water-tight sheet-pile cofferdam shown in Figure Q1 is to be constructed in a layer of silty sand, overlain by gravel which is free draining in comparison with the silty sand. A layer of impervious clay lies below the silty sand. The excavation within the cofferdam will be made underwater, and a 1m thick layer of free-draining gravel will be placed (again underwater) in the base of the cofferdam before water is pumped down to the top of the gravel layer.

The soil properties are:

gravel: saturated unit weight 21 kN/m³;

silty sand: saturated unit weight 20 kN/m³, coeff. of permeability 1 x 10⁻⁵ m/sec.

a.) Sketch a flow net for the steady state condition after pumping down within the cofferdam. Clearly indicate the boundary conditions.

(8 marks)

b.) Estimate the total daily steady state flow into the excavation per metre run.

(4 marks)

c.) Estimate the total head and pore water pressure at Point A and consider if uplift (piping) is likely to occur.

(5 marks)

d.) If the silty sand had anisotropic permeability, with $k_v = 1 \times 10^{-5}$ m/sec and $k_h = 9 \times 10^{-5}$ m/sec, how would this affect the results? It is **not** necessary to redraw the flow net to answer this. just explain. scale x by $\sqrt{\frac{k_v}{k_h}}$.

set $k = \sqrt{k_x k_y}$ and find $q = kH \frac{Nf}{Nd}$

(3 marks)

(b) $q = kH \frac{Nf}{Nd}$

$Nf = 6, Nd = 8$

$q = 1 \times 10^{-5} \times 7 \times \frac{6}{8} = 5.25 \times 10^{-5} \, m^2/s$

$= 4.536 \, m^3/day/m$

(c) A is between the 6th and 7th EP.

Δh across one $EP = \frac{H}{Nd} = \frac{7}{8} m$

$h_A = 14 - 6.5 \left(\frac{7}{8} \right) = 8.3125 m$

total head at A.

$\frac{u_A}{\gamma_w} + z_A = h_A$

$\frac{u_A}{\gamma_w} = 8.3125 - 4$

$u_A = 42.2625 \, kPa$

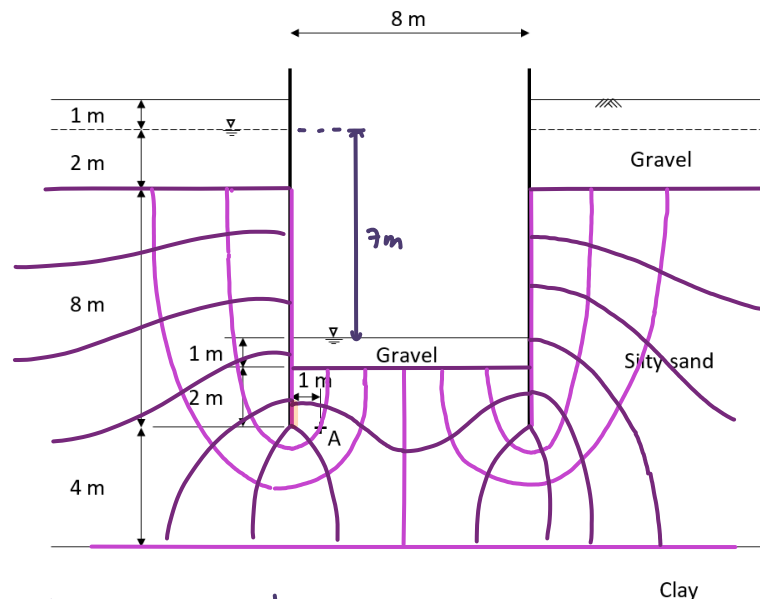to check if piping occurs or not.
piping occurs if $i > i_{crit}$

$i_{crit} = \frac{\gamma_s}{\gamma_w} - 1 : \frac{20}{9.8} - 1 = 1.04$

γ_s is γ of silty sand not gravel!

$i = \frac{\Delta h}{\Delta s}$ checking for biggest i since Δh across EP is fixed, $\Delta h = \frac{7}{8} m$, we find smallest Δs

smallest $\Delta s \approx 1m$

$i \approx \frac{7}{8} = 0.875$

$i = 0.875 < i_{crit} = 1.04$ (no piping)

Figure Q1 (labels: 8 m; 1 m; 2 m; 7m; 8 m; 1 m; 2 m; 1 m; A; 4 m; Gravel; Gravel; Silty sand; Clay; free draining shouldn't draw flownet even if there is water. no Δh = no flowline.)

2.   A wide embankment 6 m high was constructed on ground made up of 2 m of sand, underlain by 8 m of firm clay, beneath which is an impermeable layer.   The water table is located 1 m below ground level and the initial conditions are hydrostatic.   Field monitoring was performed to establish how much the ground settled with time after the embankment was placed (assume that this took place very quickly).   Take the bulk unit weight of the soils as follows: embankment fill 20 kN/m^3, sand 18 kN/m^3, and the clay 17 kN/m^3.

   a.)   Describe the mechanism of consolidation that takes place in the clay layer after embankment construction.   Comment on the embankment being wide and the significance of the boundaries above and below it.   How does the sand layer influence the overall measured ground settlement?

   (8 marks)

   b.)   The field measurements indicate that, after the embankment was placed, in the long term the ground surface settlement was 86 mm and the top of the impermeable layer did not settle.   Determine the coefficient of compressibility, m_v, of the clay for this stress increment.

   (4 marks)

   c.)   Measurements of ground settlement with time immediately after embankment construction are given in the table below.   Determine the coefficient of consolidation, c_v, and permeability, k, of the layer for this stress increment, assuming that only primary consolidation takes place.

   Recall that the linear portion of the relation between U and T_v can be described by the equation $U = \sqrt{(4T_v/\pi)}$.

   (6 marks)

Time after embankment construction (days)	Ground surface settlement (mm)
0	0
1	8.2
4	16.4
9	24.6
16	32.8
25	41.0
49	53.3
81	62.5
196	76.1
729	86.0

   d.)   What is secondary compression and is it likely to occur if the clay layer is found to contain organic material?

   (2 marks)

3.   The shear strength parameters of a soil can be determined in several ways, both in the field and laboratory.

   a.)   Describe, with the aid of an annotated sketch, the main components of the triaxial apparatus, along with what is controlled and measured in a 'consolidated-undrained' triaxial test.

   (7 marks)

   b.)   Consolidated-undrained triaxial tests were performed on three identical clay specimens from the same soil horizon where isotropic consolidation was carried out prior to shearing.   The results given in the table below relate to values at failure.   Determine the effective stress shear strength parameters for the soil.

Specimen no.	Cell pressure (kPa)	Deviator stress (kPa)	Pore water pressure (kPa)
1	200	98	166
2	300	156	232
3	400	256	279

   (6 marks)

   c.)   What is the nature (or state) of the clay?   Express how it would behave during shearing using sketches of change of (i) shear stress; (ii) pore water pressure; and (iii) void ratio, all plotted against axial strain (on the x-axis).

   (4 marks)

   d.)   In order to determine the inclination of the failure plane to the horizontal, it is necessary to identify the pole of planes on the failure Mohr circle.   Explain where it is for these tests and why it is located there.   What is the angle to the horizontal of the failure plane for these tests?

   (3 marks)

4.   A design for a road cutting should assess the stability of an excavated slope, with its geometry shown in Figure Q4. The 15 m high slope is shallower over the top one third of the slope height, with a gradient 1:2 (vertical to horizontal, V:H). It then becomes steeper, with a gradient 2.5:1 (V:H) all the way to the toe. The ground conditions comprise an over-consolidated stiff clay, which is characterised by an undrained shear strength, S_u, and a saturated bulk unit weight $\gamma = 18$ kN/m^3.

In your solution, you should apply the Limit Equilibrium method of analysis and assume that the Tresca failure criterion is mobilised along the assumed planar failure surface depicted in Figure Q4.

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

(3 marks)

b.)   Resolve the forces identified in (a) into the directions parallel and normal to the assumed failure surface and write the appropriate force equilibrium equation for each of the two directions. Calculate the critical value of the angle θ shown in Figure Q4 and of the magnitude of S_u in the clay that would satisfy the stability requirement of this slope for the assumed failure surface.

(9 marks)

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

(3 marks)

d.)   If the geometry of the failure surface (its length and the angle θ) are assumed to remain the same as calculated in (b) above, calculate the magnitude of S_u in the clay if the slope is excavated with a single inclination of 2.5:1 (V:H) from the ground surface to the toe? Comparing this value of S_u with that calculated in (b), is the result what you would have expected and why (e.g. the new value being smaller / larger than the previous)?
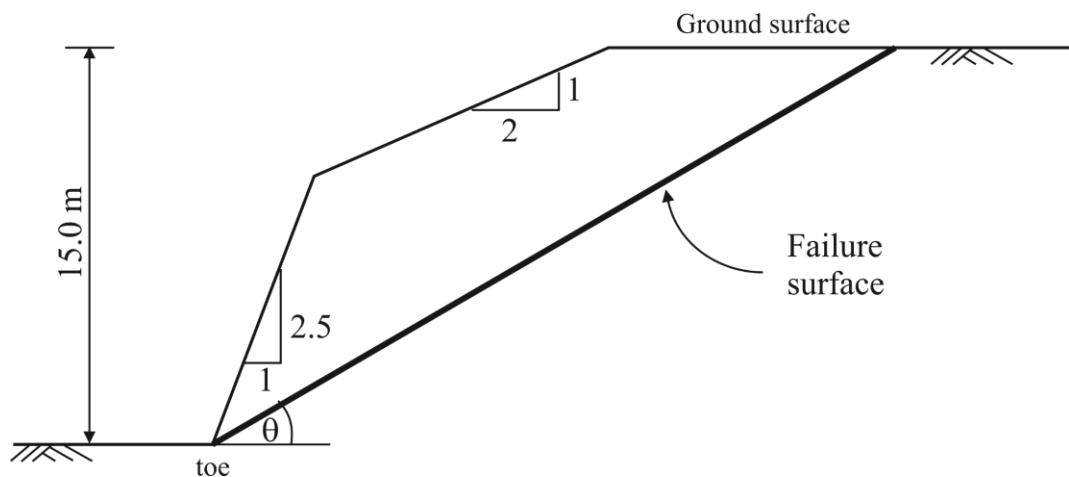
(5 marks)

Figure Q4

5.   From your recollection of your site visit and using the colour image (in 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)