ORDRE DES INGÉNIEURS DU QUÉBEC

MAY 2022 SESSION

Open-book examination
Calculators : only authorized models
Duration : 3 hours

14-EN-A3 GEOTECHNICAL AND HYDROGEOLOGICAL ENGINEERING

Question 1 (20 points)

The soil profile in Figure 1 shows two layers. The water content (w) and specific gravity of solids (G_s) for each layer are given in Figure 1. Layer 1 is composed of a fine-grained soil with a mass percentage passing the 75 µm sieve close to 100 %. The liquid limit (w_L) and plastic limit (w_P) for layer 1 are given in Figure 1. The water table is located at the ground surface.

a) Calculate the unit weight (γ) for each layer (5 points).
b) Based on the Unified Soil Classification System (USCS), give the classification for the material in layer 1 (5 points).
c) Calculate the vertical effective stress (σ'_v) at the centre of layer 2 (point A in Figure 1) (6 points).
d) Calculate the horizontal effective stress (σ'_h) at point A in Figure 1 assuming that layer 2 is a uniform loose sand with rounded particles (4 points).

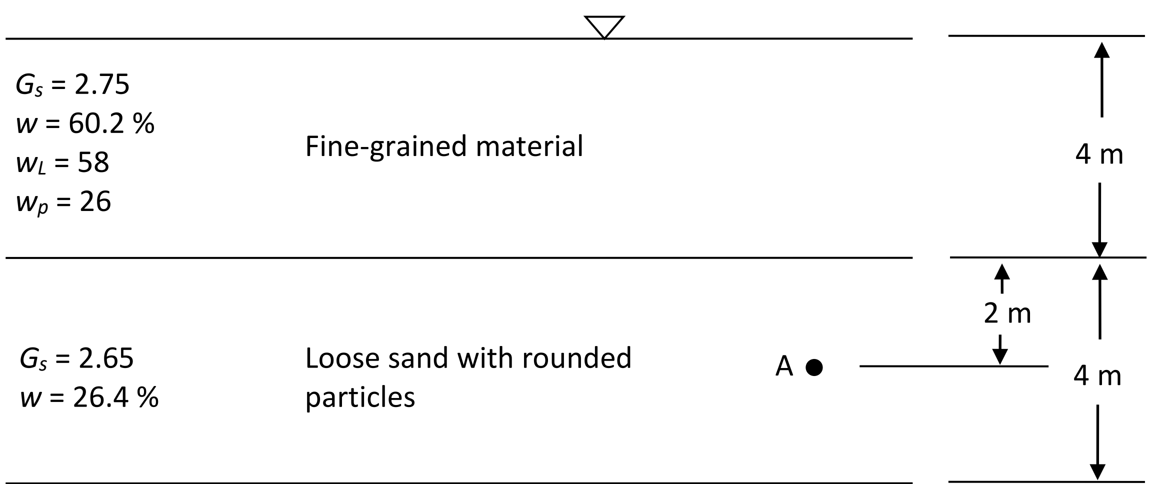

Figure 1: Soil profile for question 1.

Question 2 (20 points)

Piezometers P1, P2 and P3 were installed in a confined aquifer. Figure 2 shows a plan view with the position of the three piezometers. If the hydraulic conductivity of the aquifer is $K = 2\times10^{-4}$ m/s, calculate the hydraulic gradient (i), the Darcy velocity (v) and the average interstitial velocity or tracer velocity (v_a) of the groundwater in the triangle formed by the three piezometers. You can assume a porosity of 35 % for the aquifer. The depth of the water level in the piezometers with respect to the ground surface and the ground surface elevation are given in Table 1.

Table 1: Ground surface elevation and water level depth.

Piezometer	**Depth of the water level with respect to the ground surface (m)**	**Ground surface elevation (m)**
P1	1.64	23.22
P2	1.75	23.33
P3	1.93	24.17

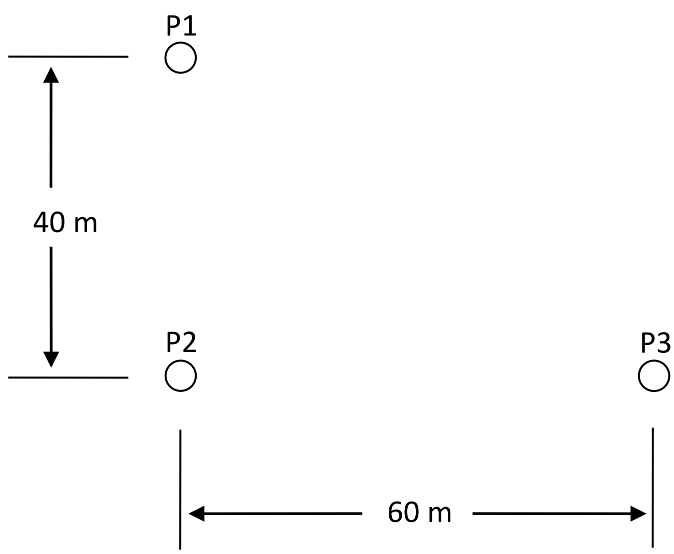

Figure 2: Plan view showing the position of the three piezometers.

Question 3 (20 points)

A pumping test was conducted in a confined aquifer composed of dense sand with a thickness of 5 m. The pumping well was fully penetrating the aquifer. Before the pumping test, four piezometers were installed in the aquifer at different distances from the pumping well. During the test, a constant flow rate of 35 L/minute was maintained. The water level in each piezometer was stable after 8 hours of pumping. A steady state was reached. Table 2 gives the distance and the steady-state drawdown for the four piezometers after 8 hours of pumping.

a) Calculate the transmissivity (T) and hydraulic conductivity (K) of the confined aquifer. You can use the semi-log plot in Figure 3 to plot the drawdown values if needed (14 points).
b) Estimate the storativity or storage coefficient (S) of the aquifer. Explain your reasoning (6 points).

Table 2: Drawdown values after 8 hours of pumping.

Piezometer	Distance between piezometer and pumping well (m)	Drawdown (m)
PA	5	1.85
PB	10	1.41
PC	20	1.00
PD	40	0.54

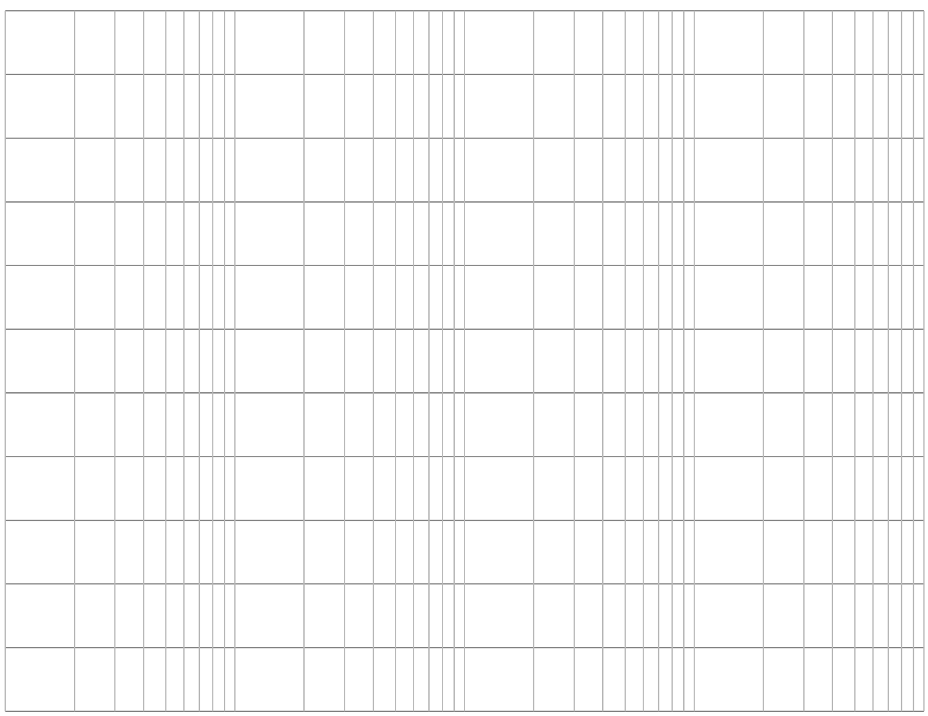

Figure 3: Semi-log plot.

Question 4 (20 points)

Figure 4 shows the soil profile for a site on which a square raft foundation with sides of 12 m will be constructed. The raft will transfer a contact stress of 300 kPa to the ground, including the weight of the foundation. Boreholes on this site have shown the presence of a clay layer under a sand layer. The properties for both layers are given on Figure 4. The properties include the saturated density (ρ_{sat}), preconsolidation pressure (p_c or σ'_p), in situ void ratio (e_0), compression index (C_c) and recompression index (C_r).

You are asked to calculate the total consolidation settlement under the centre of the raft foundation. For calculation purposes, you can assume that the raft foundation is flexible, that the settlements due to the deformation of the sand layer and bedrock are negligible, and that the water table is at the ground surface. Use the method of your choice to calculate the vertical stress increase in the clay layer.

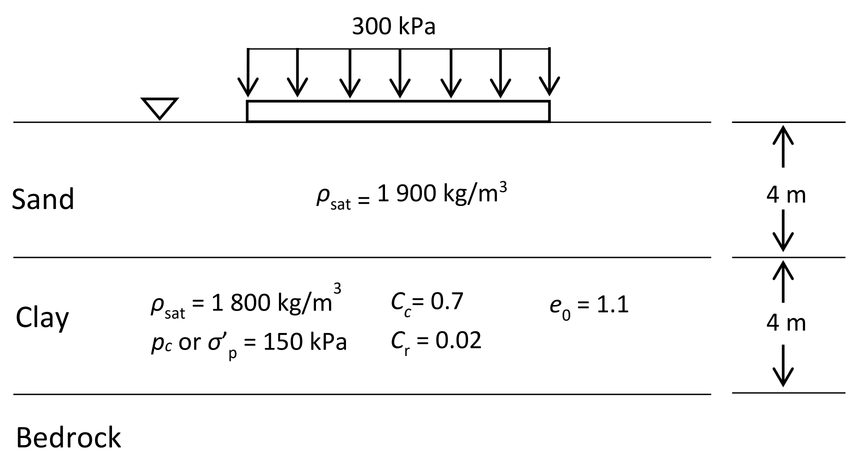

Figure 4: Soil profile for question 4.

Question 5 (20 points)

Figure 5 gives the compaction curve that was obtained for a modified Proctor test conducted on a silty sand. The compaction curve shows the relationship between the compaction water content (w) and the dry density (ρ_d). Answer the following questions based on this compaction curve. You can assume that the specific gravity of solids (G_s) is 2.7.

a) Give the optimum water content and maximum dry density for this material (4 points).
b) If the material is compacted at a relative compaction (RC) of 95 % with respect to the modified Proctor test, what range of compaction water content would you suggest to minimize the energy needed for compaction (8 points)?
c) A volume of 1000 m^3 of the same material will be excavated from a borrow pit. The excavated material will be used to construct an embankment. If the material has a unit weight (γ) of 17.5 kN/m^3 and a water content of 8 % in the borrow pit, what will be the final volume of the material in the embankment after compaction? Assume that the material will be compacted at RC = 95 % of the modified Proctor in the embankment (8 points).

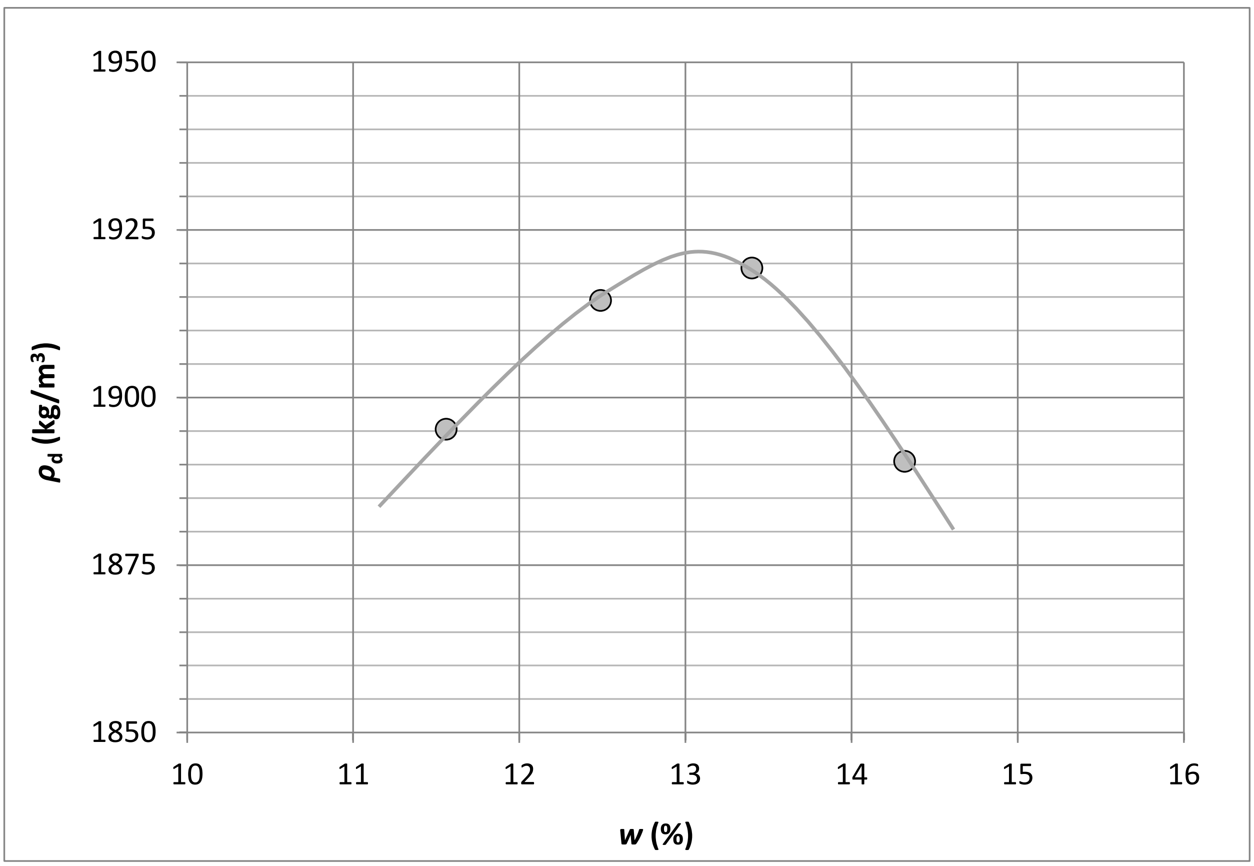

Figure 5: Compaction curve for question 5.