

The Open University of Sri Lanka
Faculty of Engineering Technology
Department of Civil Engineering



Study Programme : Bachelor of Science Honours in Engineering
Name of the Examination : Final Examination
Course Code and Title : CVX7241 Geotechnical Design
Academic Year : 2024/25
Date : 05th February 2026
Time : 0930 – 1230 hours
Duration : 3 hours

General instructions

1. Read all instructions carefully before answering the questions.
2. This is a **Closed Book Test**; texts or other printed material and electronic communication devices are not permitted to be kept in your possession. **You are allowed to use an approved non-programmable calculator.**
3. This paper consists of **FOUR (4) questions** and **TEN (10) printed pages**.
4. Answer **ALL** questions. The marks associated with each question is indicated.
5. Remember to write your registration number in the answer script. **Do not write your name.**
6. In case of doubt, consult the supervisor or an invigilator conducting the examination.

Question 1

A proposed warehouse building is to be founded on shallow strip footings. Consider a strip footing of 1.5 m width (and 15 m length) loaded vertically along the longitudinal axis. The footing is to be founded at a depth of 1.0 m below ground surface. The subsurface ground profile at the site (as shown in Figure Q1.1) consists of a clayey sand overlying a normally consolidated (NC) clay layer. The clayey sand extends to a depth of 5 m below ground surface. The characteristic values of soil parameters are given in Table Q1.1. The groundwater table is located 1 m below the base of the footing and the unit weight of water can be taken as 9.81 kN/m³.

- Determine the design bearing resistance of the footing in accordance with the Design Approach 1-Combination 2 of the Eurocode 7 using Vesic's form of the general bearing capacity equation. Combinations of sets of partial factors (A2 + M2 + R1) to be used with Design Approach 1 of Eurocode 7 are given in Table Q1.2, Table Q1.3, and Table Q1.4. Clearly state any assumptions that may be used in the calculations.

Following equations with usual notations may be used in the calculations.

The general bearing capacity equation:

$$q_u = c' N_c F_{cs} F_{cd} F_{ci} + q N_q F_{qs} F_{qd} F_{qi} + \frac{1}{2} \gamma B N_\gamma F_{\gamma s} F_{\gamma d} F_{\gamma i}$$

The bearing capacity factors N_c , N_q , and N_γ may be obtained from Table Q1.5.

F_{cs} , F_{qs} , and $F_{\gamma s}$ are the shape factors.

F_{cd} , F_{qd} , and $F_{\gamma d}$ are the depth factors.

F_{ci} , F_{qi} , and $F_{\gamma i}$ are the inclination factors

Shape factors

$$F_{cs} = 1 + \frac{B}{L} \frac{N_q}{N_c}$$

$$F_{qs} = 1 + \frac{B}{L} \tan \varphi'$$

$$F_{\gamma s} = 1 - 0.4 \frac{B}{L}$$

Depth factors when $\frac{D_f}{B} \leq 1$

$$F_{cd} = F_{qd} - \frac{1 - F_{qd}}{N_c \tan \varphi'}$$

$$F_{qd} = 1 + 2 \tan \varphi' (1 - \sin \varphi')^2 \frac{D_f}{B}$$

$$F_{\gamma d} = 1$$

Depth factors when $\frac{D_f}{B} > 1$

$$F_{cd} = F_{qd} - \frac{1 - F_{qd}}{N_c \tan \varphi'}$$

$$F_{qd} = 1 + 2 \tan \varphi' (1 - \sin \varphi')^2 \tan^{-1} \left(\frac{D_f}{B} \right)$$

$$F_{\gamma d} = 1$$

Inclination factors

$$F_{ci} = F_{qi} = \left(1 - \frac{\beta}{90^\circ}\right)^2$$

$$F_{\gamma i} = \left(1 - \frac{\beta}{\varphi'}\right)^2$$

β = inclination of the load on the foundation with respect to the vertical

[14.0 Marks]

- b. Determine the design load. [2.0 Marks]
- c. Settlement of subsurface soils upon transfer of loads from the superstructure to the subsurface causes a serviceability concern. The immediate settlement that occurs in fine grained sediments is referred to as "undrained distortion". Briefly explain the conditions under which this kind of settlement occurs. You may use a suitable sketch to facilitate your explanation.

[6.0 Marks]

Question 2

- a. Identify three (3) situations in which pile foundations are required. [3.0 Marks]
- b. There is a proposal to construct a multistorey building. Sub-surface soil profile at the site is shown in Figure Q2.1 together with SPT-N values, and Core Recovery (CR) and Rock Quality Designation (RQD) of bed rock obtained from the site investigation. A series of laboratory tests were conducted to find the engineering properties of soil and results are included in Table Q2.1. The water table was found to be at the existing ground surface. The unit weight of water can be taken as 9.81 kN/m³.

Following equations with usual notations and the information presented in Table Q2.2 may be useful in performing the calculations.

$$Q_p = A_p q' N_q^* \leq A_p q_1 \text{ where } q_1 = 50 N_q^* \tan \varphi$$

$$\eta = 1 - \frac{\theta}{90} \left[\frac{(n-1)m + (m-1)n}{mn} \right] \text{ where } \theta = \tan^{-1}(d/s)$$

- i. Assuming that 0.4 m x 0.4 m precast concrete piles are to be used and driven to depth of 12.0 m, estimate the ultimate axial load carrying capacity of a pile in compression and determine the structural load that can be allowed to be carried by the pile when an overall factor of safety of 2.5 is assumed. [18.0 Marks]
- ii. Given the magnitude of structural loads transferred via a certain set of columns at the proposed construction are high, it is required to consider grouping of piles. Estimate the ultimate capacity of a group of precast piles arranged into a grid of 2 x 2 piles assuming 1.0 m grid spacing. [4.0 Marks]
- c. Pile load testing is often recommended to verify pile capacity estimates. Briefly comment on the capability of the load tests on single piles to capture the group behaviour of piles. You may use a suitable sketch to support your answer. [5.0 Marks]

Question 3

Construction of a gravity wall is proposed to retain a cut slope in clayey sand. The base width of the wall is 3.0 m and the retained height of backfill is 5.0 m. A schematic drawing of the proposed wall with the geometric parameters is provided in Figure Q3.1. The groundwater table is located far below the base of the wall. The base of the wall can be considered as cast against soil. The unit weight of wall material can be taken as 20 kN/m³. The characteristic values of soil parameters to be used in the design calculations are provided in Table Q3.1. The wall may be assumed to have a 'smooth back' resulting in 'zero' wall-soil interface friction. Perform following design calculations in accordance with the Design Approach 1-Combination 2 of the Eurocode 7. Combinations of sets of partial factors ($A2 + M2 + R1$) to be used with Design Approach 1 of Eurocode 7 are given in *Table Q1.2*, *Table Q1.3*, and Table Q3.2. Clearly state any assumptions that may be used in the calculations. Following equations with usual notations may be used in the calculations.

$$K_a = \frac{1 - \sin \phi'_d}{1 + \sin \phi'_d}, K_p = \frac{1}{K_a}, \text{ and } (\delta_{base})_d = k \cdot \phi_{cv,d}$$

- Construct a diagram to illustrate the lateral stress distribution on the wall and determine the force components that act on the wall. [8.0 Marks]
- Check if the wall has adequate resistance against sliding at the base. [Note: Adhesion between the base of the wall and the foundation soil can be neglected in the calculations.] [6.0 Marks]
- Check if the wall has adequate stability against overturning. [6.0 Marks]
- Explain how the design resistance to sliding calculated in Section (b) above will be affected if the groundwater table in the area should rise above the foundation depth after a prolonged rainy season, causing seepage at the base of the wall. You may use a suitable sketch to support your explanation. [4.0 Marks]

Question 4

- With the use of neatly drawn sketches, briefly explain how filter/drain at the toe, chimney drains and cut-off walls can facilitate seepage control through an earthen embankment dam. [12.0 Marks]
- Rehabilitation of a small homogeneous earthen embankment dam considers reconstruction of a particular section of the embankment. A preliminary analysis of the section assumes the dam body to be consisting of a very stiff sandy clay in *undrained behaviour* to assess the factor of safety against failure along the circular trial slip surface AC as shown in Figure Q4.1. The design soil engineering parameters and the dimensional parameters are provided in Table Q4.1.
 - Estimate the destabilizing moment that tends to cause slip along the circular trial surface AC. [Note: Ignore the possibility of a tension crack developing near the crest of the slope for simplification.] [4.0 Marks]

- ii. Estimate the limiting resistance that can develop in soil against slip along the trial surface. Hence, determine the factor of safety (F_s) against slip along the trial surface AC.

[8.0 Marks]

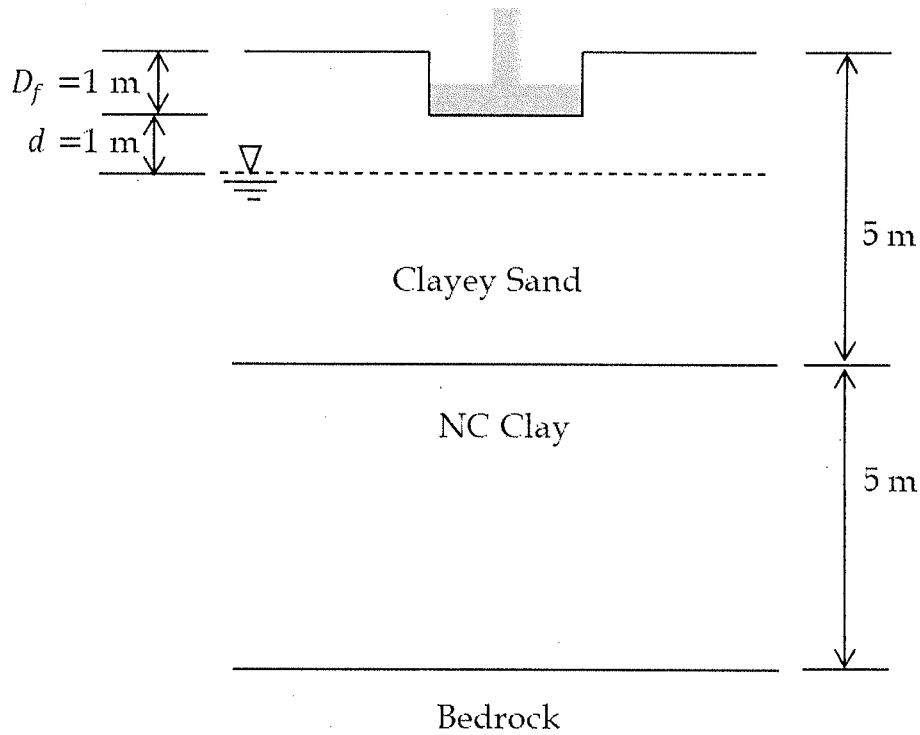


Figure Q1.1: Subsurface profile at the site

Table Q1.1: Characteristic values of soil parameters

Soil parameters	Clayey Sand	NC Clay
Dry unit weight, γ_{dry} (kN/m ³)	18	19
Saturated unit weight, γ_{sat} (kN/m ³)	20	20.5
Friction angle, ϕ' (deg)	30	25
Cohesion, c' (kN/m ²)	5	15
Constrained Modulus, E'_s (MN/m ²)	17	8

Table Q1.2: Partial factors on actions (γ_F) or the effects of actions (γ_E)

Action		Symbol	Set	
			A1	A2
Permanent	Unfavourable	γ_G	1.35	1.0
	Favourable		1.0	1.0
Variable	Unfavourable	γ_Q	1.5	1.3
	Favourable		0	0

Table Q1.3: Partial factors for soil parameters (γ_M)

Soil Parameter	Symbol	Set	
		M1	M2
Angle of shearing resistance ^a	$\gamma_{\phi'}$	1.0	1.25
Effective cohesion	$\gamma_{c'}$	1.0	1.25
Undrained shear strength	γ_{cu}	1.0	1.4
Unconfined strength	γ_{qu}	1.0	1.4
Weight Density	γ_γ	1.0	1.0

^a The factor is applied to $\tan \phi'$

Table Q1.4: Partial resistance factors (γ_R) for spread foundations

Resistance	Symbol	Set		
		R1	R2	R3
Bearing	$\gamma_{R,v}$	1.0	1.4	1.0
Sliding	$\gamma_{R,h}$	1.0	1.1	1.0

Table Q1.5: Vesic's Bearing Capacity Factors N_c , N_q , and N_γ

ϕ'	N_c	N_q	N_γ	ϕ'	N_c	N_q	N_γ
0	5.14	1.00	0.00	26	22.25	11.85	12.54
1	5.38	1.09	0.07	27	23.94	13.20	14.47
2	5.63	1.20	0.15	28	25.80	14.72	16.72
3	5.90	1.31	0.24	29	27.86	16.44	19.34
4	6.19	1.43	0.34	30	30.14	18.40	22.40
5	6.49	1.57	0.45	31	32.67	20.63	25.99
6	6.81	1.72	0.57	32	35.49	23.18	30.22
7	7.16	1.88	0.71	33	38.64	26.09	35.19
8	7.53	2.06	0.86	34	42.16	29.44	41.06
9	7.92	2.25	1.03	35	46.12	33.30	48.03
10	8.35	2.47	1.22	36	50.59	37.75	56.31
11	8.80	2.71	1.44	37	55.63	42.92	66.19
12	9.28	2.97	1.69	38	61.35	48.93	78.03
13	9.81	3.26	1.97	39	67.87	55.96	92.25
14	10.37	3.59	2.29	40	75.31	64.20	109.41
15	10.98	3.94	2.65	41	83.86	73.90	130.22
16	11.63	4.34	3.06	42	93.71	85.38	155.55
17	12.34	4.77	3.53	43	105.11	99.02	186.54
18	13.10	5.26	4.07	44	118.37	115.31	224.64
19	13.93	5.80	4.68	45	133.88	134.88	271.76
20	14.83	6.40	5.39	46	152.10	158.51	330.35
21	15.82	7.07	6.20	47	173.64	187.21	403.67
22	16.88	7.82	7.13	48	199.26	222.31	496.01
23	18.05	8.66	8.20	49	229.93	265.51	613.16
24	19.32	9.60	9.44	50	266.89	319.07	762.89
25	20.72	10.66	10.88				

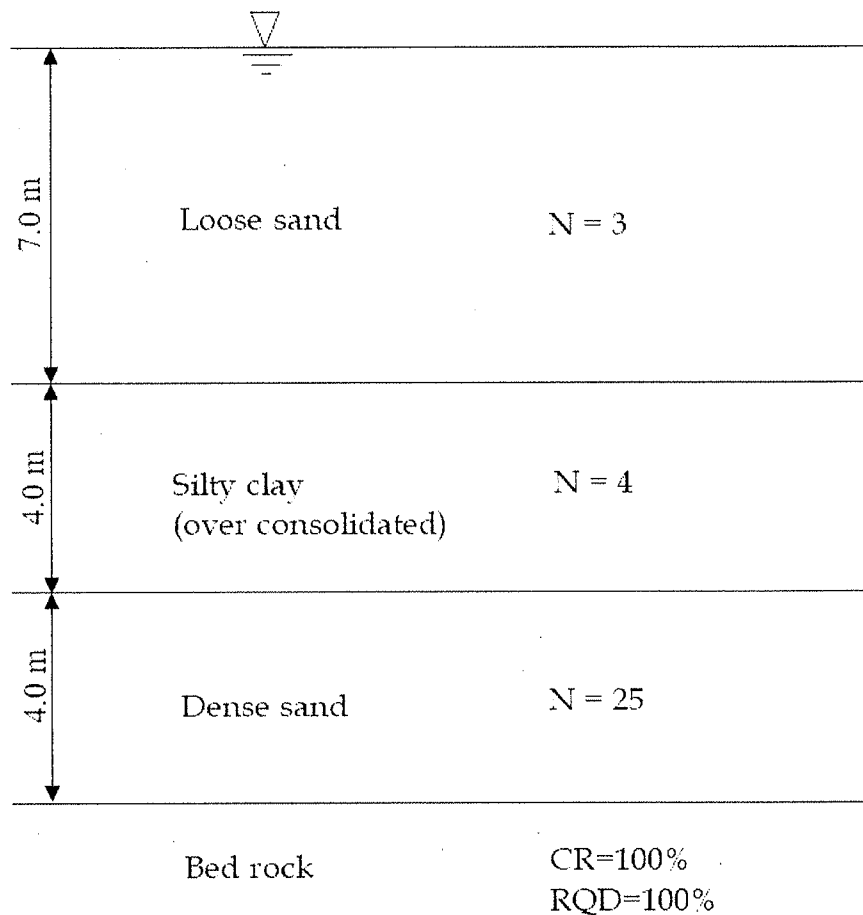


Figure Q2.1 Sub-surface soil profile at the proposed site

Table Q1.1: Design parameters

Soil Parameters	Loose sand	Silty clay	Dense sand
Drained cohesion, c' (kN/m ²)	0	5	0
Undrained cohesion, c_u (kN/m ²)	-	30	-
Friction Angle, ϕ' (deg)	20	18	35
Saturated unit weight, γ_{sat} (kN/m ³)	17.0	16.0	18.0
Poisson's ratio	0.25	0.40	0.50
Young's Modulus (kN/m ²)	30,000	20,000	50,000
Dimensionless shaft resistance factor, β	0.3	-	0.46
Unconfined Compressive strength of bed rock = 50 MPa			
Drained friction angle of bed rock = 40°			
α_s = A factor that depends on the distribution of the unit frictional resistance, q_s along the pile shaft in clay. The magnitude of α_s varies between 0.5 and 0.67.			

Table Q2.2 - Variation of N_q^* with soil friction angle

Soil friction angle, ϕ (deg)	Bearing capacity factor, N_q^*	Soil friction angle, ϕ (deg)	Bearing capacity factor, N_q^*
20	12.4	33	96.0
21	13.8	34	115.0
22	15.5	35	143.0
23	17.9	36	168.0
24	21.4	37	194.0
25	26.0	38	231.0
26	29.5	39	276.0
27	34.0	40	346.0
28	39.7	41	420.0
29	46.5	42	525.0
30	56.7	43	650.0
31	68.2	44	780.0
32	81.0	45	930.0

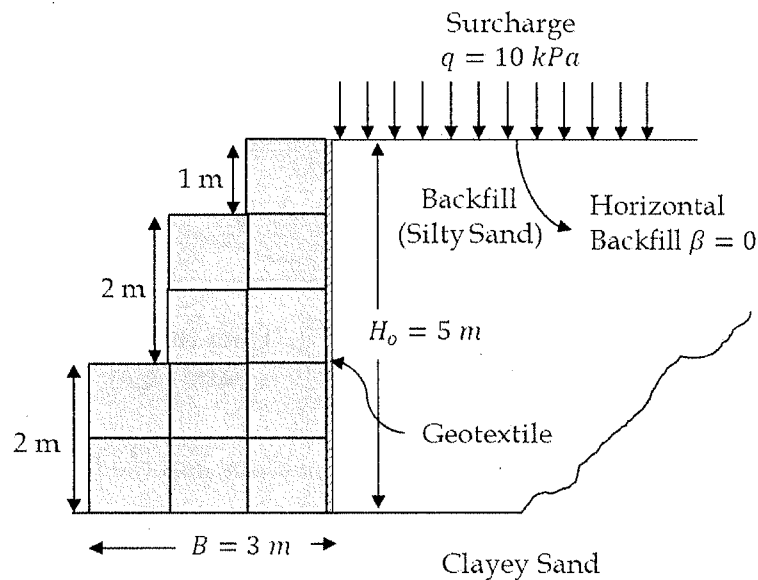


Figure Q3.1: Cross section of the proposed retaining wall

Table Q3.1: Characteristic values of soil parameters

Soil Properties	Backfill (Silty Sand)	Clayey Sand
Dry unit weight, γ_{dry} (kN/m^3)	18.5	20
Friction angle, ϕ' (deg)	33	28
Cohesion, c' (kN/m^2)	0	12

Table Q3.2: Partial resistance factors (γ_R) for retaining structures

Resistance	Symbol	Set		
		R1	R2	R3
Bearing capacity	$\gamma_{R,v}$	1.0	1.4	1.0
Sliding resistance	$\gamma_{R,h}$	1.0	1.1	1.0
Earth resistance	$\gamma_{R,e}$	1.0	1.4	1.0

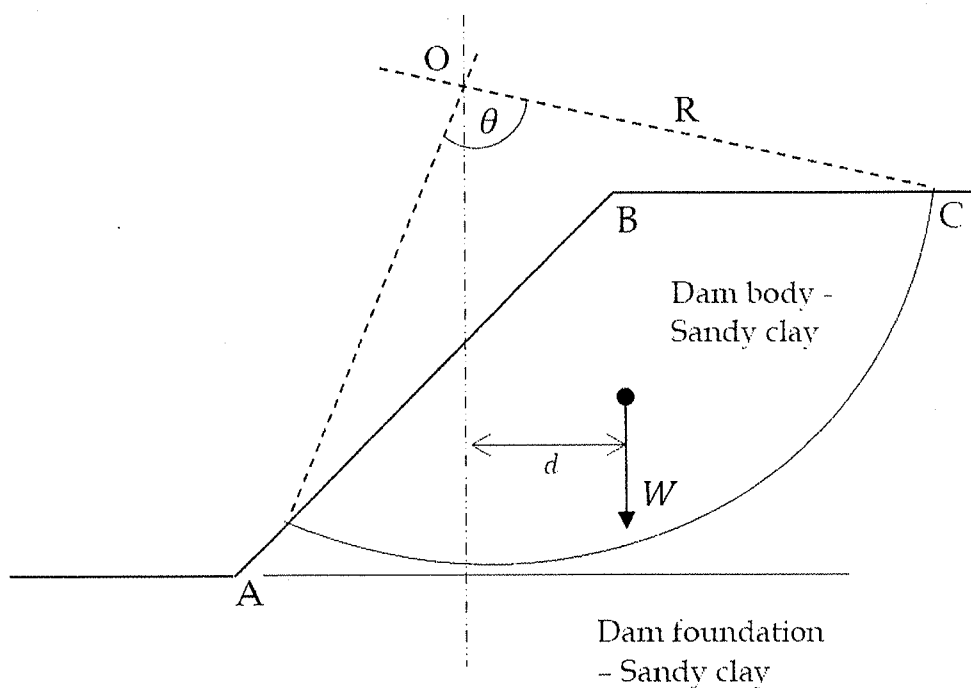


Figure Q4.1: The profile of the downstream slope and the trial slip surface AC

Table Q4.1: Soil parameters and dimensional parameters

Soil Parameters	Dam body - Sandy clay
Undrained cohesion, c_u (kN/m ²)	100
Saturated unit weight, γ_{sat} (kN/m ³)	21
Dimensional parameters	
Radius of the trial slip surface AC, R (m)	8
Radial angle, θ (degrees)	105
Weight of potentially moving soil continuum, W (kN/m)	1230
d (m)	5.2