National Exams December 2019

07-Str-B5, Foundation Engineering

3 hours duration

NOTES:

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.

2. This is an OPEN BOOK EXAM.
   Any non-communicating calculator is permitted.

3. FIVE (5) questions constitute a complete exam paper.
   The first five questions as they appear in the answer book will be marked.

4. Each question is of equal value.

5. Clarity and organization of the answer are important.

1. Shallow Foundations (30 marks)

An advertisement board is to be supported on a square spread footing. The bottom of this footing will be 1.8 m below the adjacent ground surface. The footing is 1.8 m x 1.8m and is subjected to a vertical load of 1800 kN, and moments M_x = 450 kN.m; M_y = 360 kN.m. The underlying soils are silty sands and the groundwater table is at a depth of 6.5 m. The soil unit weight above the water table is γ = 18.0 kN/m^3 and below the water table the saturated unit weight is γ_{sat} = 19.81 kN/m^3. The representative soil properties obtained from laboratory tests are ϕ' = 36° and c′ = 20 kPa. It is specified that the settlement of the foundation should not exceed 30 mm.

a) Using the Brinch Hansen's bearing capacity formula, calculate the total factor of safety of the square footing. (10 marks)

b) For the estimated drained values of the soil Young's modulus E_s = 40 MPa and Poisson's ratio ν = 0.3, check if the foundation satisfies the settlement tolerance. If the foundation does not satisfy the settlement requirement, re-design it to ensure satisfactory performance. (10 marks)

c) If the given axial load is a specified dead load (DL) and the given moments M_x and M_y are specified wind loads (W), check if the foundation satisfies the ultimate limit state (bearing resistance). Use the footing designed in (b) if different than the given design (in Figure 1). Use bearing capacity resistance factor f_{bc} = 0.5, and load factor 1.25 for DL and 1.4 for W. Comment on the results. (10 marks)

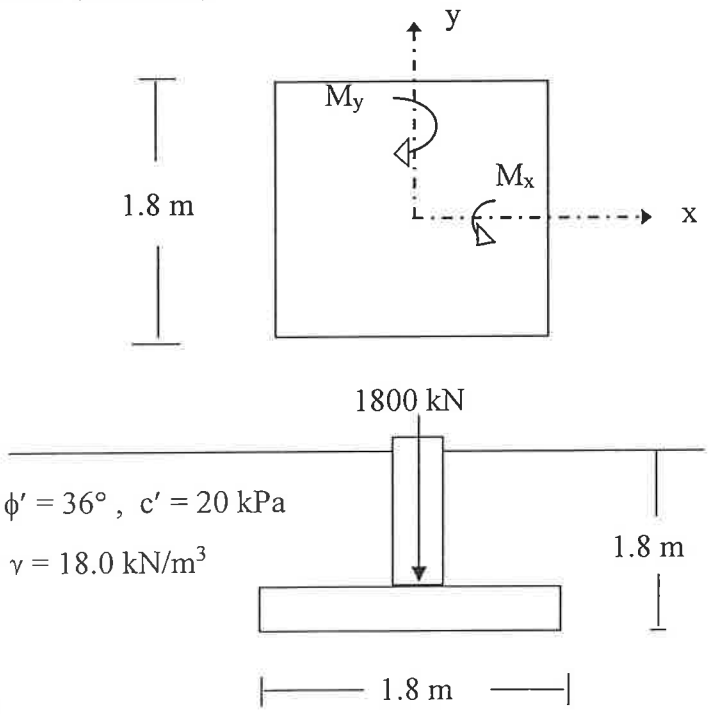

Figure 1 for Question 1

2. Deep Foundations (30 marks)

A square pile group consists of 16 piles (4x4) and is designed to support a dead load of 8 MN and a live load of 4 MN. The piles are precast concrete with a circular cross-section of 0.6 m outside diameter and are spaced at 1.8 m centre to centre. The piles are driven through a layer of clay 15 m thick, with the pile toe resting on a medium dense sand layer. The average representative undrained shear strength of the clay, c_u = 60 kN/m^2 and its bulk unit weight is 18 kN/m^3. The sand layer has an average SPT value of 20. The elastic modulus of the pile is 200 GPa and the elastic modulus of the clay layer is assumed to be constant with depth and equal to 400 c_u.

a) Determine the total (overall) factor of safety of this foundation. (8 marks)
b) Check that the bearing resistance limit state is satisfied (use load factors 1.25 for dead load and 1.5 for live load and resistance factor f_c = 0.6). (8 marks)
c) Compute the group settlement under the prescribed loads, using
   i) the settlement ratio method (the group settlement as a ratio of the single pile settlement. (Assuming the elastic modulus of the sand layer, E_s = 24 MPa) (8 marks)
   ii) the equivalent raft method based on the SPT values (Meyerhof approach) (6 marks)

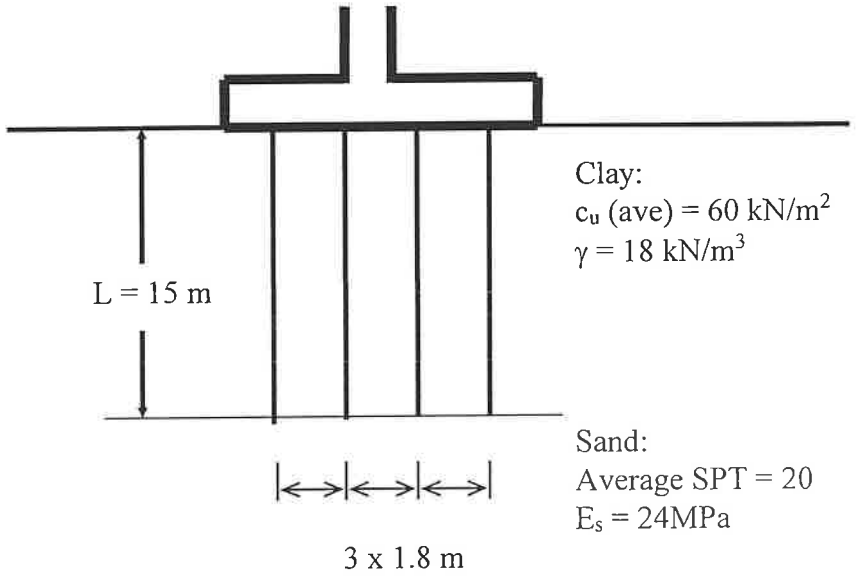

Figure 2 for Question No. 2

3. Slope Stability (30 marks)

Part 1

A cutting 9m deep is to be excavated in a saturated clay of unit weight 19 kN/m^3. The relevant shear strength parameters are c_u = 30 kN/m^2 and $\phi_u = 0°$. A hard stratum underlies the clay at a depth of 11 m below ground level.

a) Using Taylor's stability coefficients, determine the slope angle at which failure would occur. (4 marks)
b) Sketch the slip surface for this cut and state the type of failure surface (i.e. based on the location of the failure surface). (4 marks)
c) What is the allowable slope angle if a factor of safety of 1.2 is specified? (4 marks)

Part 2

What inclination is required to have a factor of safety of 1.2 for a slope 40 m high in an area where the soil is uniform clay with $c' = 25$ kN/m^2, $\gamma = 16.5$ kN/m^3 and $\phi' = 12°$. The factor of safety is to apply to the angle of internal friction as well as cohesion. (10 marks)

Part 3

As part of a reservoir project, it is required to construct an embankment with a slope of 18.5° and is 25 m high consisting of compacted soil with $c' = 40$ kN/m^2, $\gamma = 19.0$ kN/m^3 and $\phi' = 10°$. Determine the factor of safety if a sudden drawdown of the reservoir occurs. (8 marks)

4. Retaining Structures (30 marks)

A 5.4 m reinforced concrete retaining wall is to be constructed to support a cohesionless soil as shown in Fig. 4. The properties of the backfill material are $\phi = 40^0$ and $\gamma = 17$ kN/m^3. The friction angle between the base of the wall and the soil, $\delta = 30^0$. The ground water table is at a depth of 4 m from the ground surface. The effective unit weight of the soil below the ground water table, $\gamma' = 10$ kN/m^3. There is a uniformly distributed surcharge of 40 kPa at the ground surface as shown in the figure. Assume the unit weight of the reinforced concrete $\gamma_c = 23.5$ kN/m^3.

a) Use Rankine's theory to determine the distribution of the lateral pressure on the wall i) due to soil, ii) due to pore pressure and iii) due to surcharge. (10 marks)
b) Check the stability of the retaining wall against sliding, $(FS)_S$. (5 marks)
c) Check the stability of the retaining wall against overturning, $(FS)_O$. (5 marks)
d) Check the stability of the retaining wall against bearing capacity failure, $(FS)_b$ and calculate the minimum contact pressure, q_{min}. (10 marks)

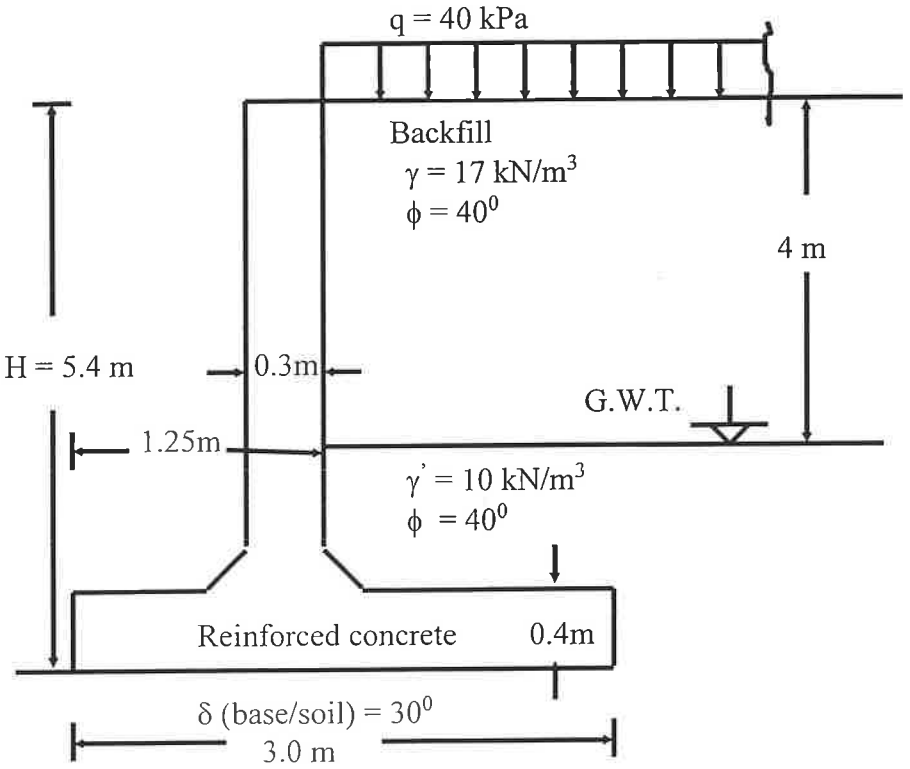

Figure 3 for Question No. 4 (Retaining structures)

5. Deep Foundations (30 marks)

A pile foundation will be installed in uniform slightly over-consolidated clay of undrained shear strength of C_u = 60 kPa, Elastic Modulus, E_u = 60 MPa, Poisson's ratio, ν_u = 0.5 and bulk unit weight, γ = 20 kN/m^3. The clay's compression index, C_c = 0.25 and initial void ratio, e_o = 1.20. There is a layer of very dense sand at a depth of 34 m below the ground surface. The foundation will comprise cast-in-place concrete piles placed in a square configuration. Each pile is 18 m long and has a diameter of 600 mm. The pile cap can not be larger than 6 x 6 m and should be founded 1m below the ground level. The piles are equally spaced in both directions with spacing equal to 1.8 m centre to centre. The adhesion factor of the soil/pile interface, α = 0.8.

a) Determine the ultimate pile capacity of a single pile using the static analysis approach (i.e. using soil strength parameters) considering undrained conditions. (8 marks)
b) If this foundation is subjected to a vertical centric dead load of 8 MN and a vertical live load of 2MN, design a pile group considering a dead load factor of 1.25, live load factor of 1.5 and a resistance factor of 0.4 (8 marks)
c) What is the global safety factor of the pile group against bearing capacity failure? (6 marks)
d) Check that the serviceability limit state (total settlement) is satisfied using the equivalent raft method (8 marks)

6. Shallow Foundations (30 marks)

Briefly discuss the following, using diagrams or equations whenever possible:

a. Effective stress and total stress. (2 mark).

It is proposed to design a circular foundation to support a silo for grain storage. The total weight of the silage material, the reinforced concrete silo and its foundation is expected to be 12 MN. The foundation will be supported on a soil profile composed of silty clay layers whose properties are given in Table 1. The foundation will be embedded to a depth of 2.5 m below the ground surface. The ground water table (GWT) may rise to 2.5m below the ground surface. The submerged unit weight of the soil is $\gamma_{sub} = 10$ kN/m^3. The allowable vertical settlement is 40 mm.

a. Determine the ultimate bearing capacity of the foundation considering both undrained and drained conditions. (12 marks)

b. Design the foundation using a total (overall) factor of safety = 3. (8 marks)

c. Check that the total settlement requirement is satisfied. Consider the compression index for the native silty clay layers, Cc = 0.13 and voids ratio to be 0.8. (8 marks)

Table 1 Soil Properties for Question 6

Soil Type*	Thickness (m)	C_u (kPa)	c' (kPa)	ϕ' (°)	γ (kN/m^3)	E_u (MPa)	ν_u
Native silty clay	5	50	10	28	20.5	50	0.5
Native silty clay	7.5	40	0	24	20	40	0.5
Native silty clay	18	50	0	24	20	50	0.5
Silty clay	17	60	10	28	20	60	0.5
Silty clay	2.5	120	20	30	22	120	0.3
Till (bedrock)	---	400	50	32	22	400	0.3

*Consecutive soil layers representing soil profile from ground surface to bedrock