National Exams December 2010

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.
   A Casio or Sharp 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 clayey silt 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 = 0.4, check if the foundation satisfies the serviceability (settlement) limit state. 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 resistance factors f_c = 0.6 and f_ϕ = 0.8, and load factor 1.25 for DL and 1.4 for W. Comment on the results. (10 marks)

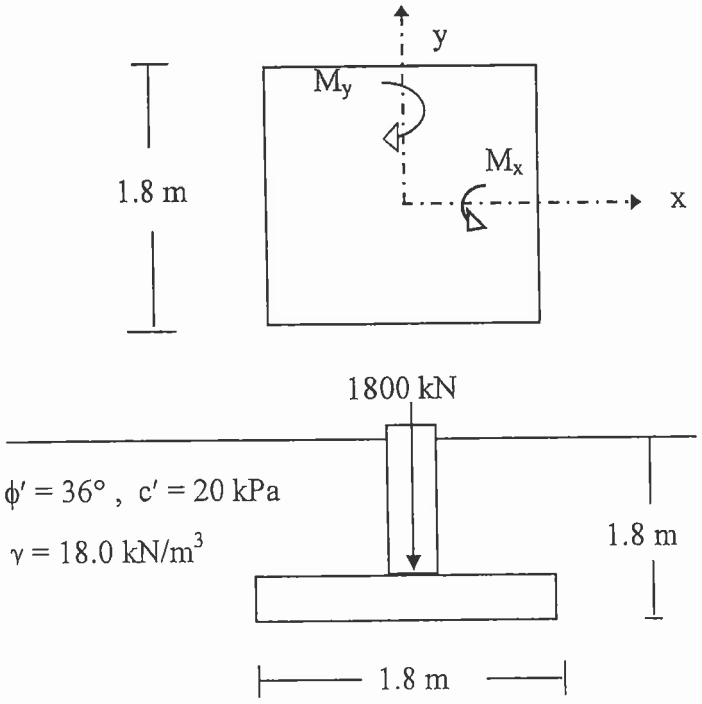

Figure 1 for Question 1

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. (9 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 = 0.7). (9 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, Figures 20.4, 20.5 and 20.6 of CFEM are attached) (9 marks)
   ii) the equivalent raft method based on the SPT values (Meyerhof approach) (3 marks)

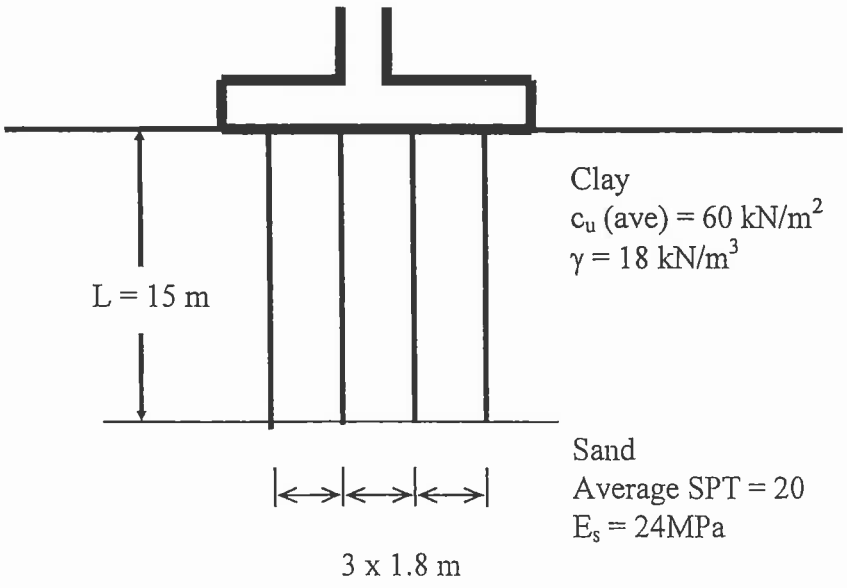

Figure 2 for Question No. 2

3. Slope Stability (30 marks)

Part 1

a) State the approximations made in derivations of the ordinary method of slices; Bishop's simplified method of slices; and Spencer's method. (5 marks)

A slope 30 m high is to be constructed in a soil of unit weight 19.1 kN/m^3. The relevant shear strength parameters are $c' = 36$ kN/m^2, $\phi' = 20°$ and the pore pressure ratio $r_u = 0.25$. The slope angle $\beta = 26°$.

b) Determine the factor of safety of the given slope using Spencer's chart. (5 marks)

c) What is the allowable slope angle if a factor of safety of 1.25 is specified? (5 marks)

Part 2

d) Describe the main mechanisms that may lead to slope failures during an earthquake. (5 marks)

e) The slope shown in Figure 3 is intersected by two 0.15 m thick seams of clayey material. The intact slope materials can be characterized by the parameters, $c_u = 120$ kPa, $\phi_u = 0°$ and $\gamma = 20.4$ kN/m^3. The clayey seams exhibit $c_u = 36$ kPa, $\phi_u = 0°$ and $\gamma = 19.4$ kN/m^3.

i) Describe the possible failure mechanisms under static loading conditions for the given soil profile (5 marks)

ii) Describe the procedure that you would use to evaluate the slope stability under earthquake conditions for the given soil profile (5 marks)

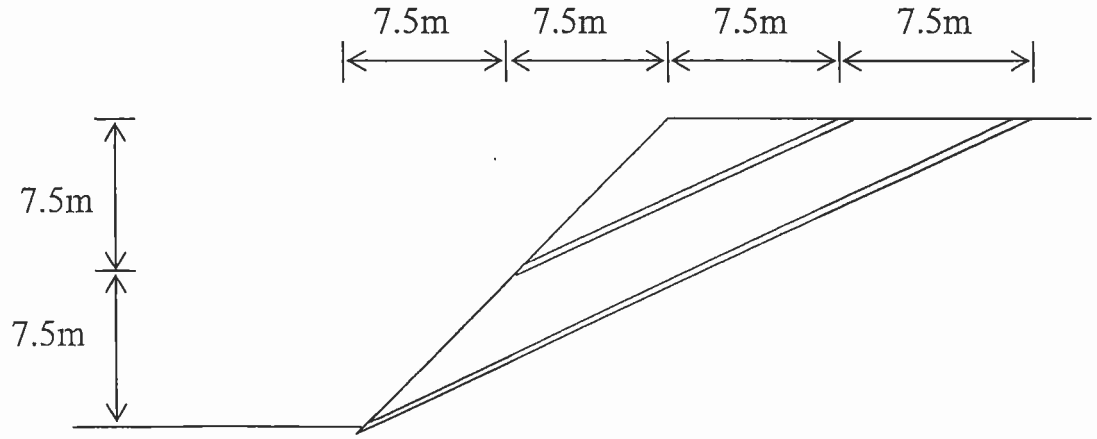

Figure 3 for Question No. 3

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. (9 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, $(FS)_O$. (6 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)

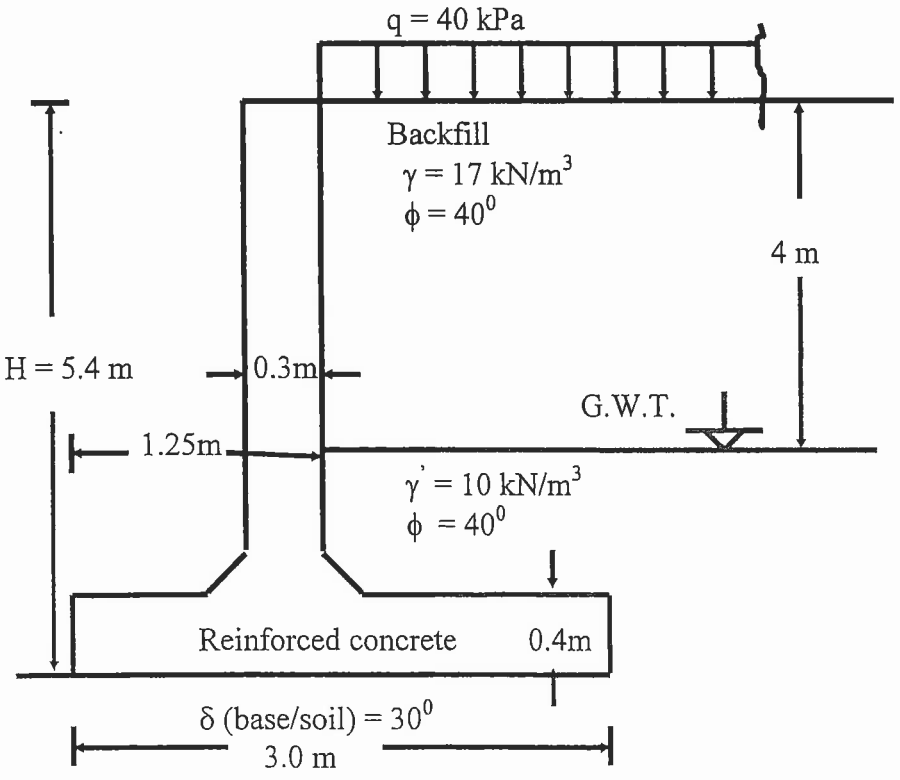

Figure 4 for Question No. 4 (Retaining structures)

5. Shallow Foundations (30 marks)

The pier of a highway bridge is to be supported on a square spread footing. The bottom of this footing will be 1.50 m below the adjacent ground surface. The footing is subjected to Ontario Highway Bridge Design Code vertical loads as follows: dead load, including the weight of the foundation, DL = 2500 kN; live load, LL = 1250 kN. The underlying soils are silty sands and the groundwater table is at a depth of 5 m from the ground surface. The soil unit weight above the water table γ = 18.1 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' = 38° and c′ = 0 kPa. It is specified that the settlement of the foundation should not exceed 25 mm.

d) Using an overall factor of safety of 3, design the square footing to support the specified loads. (10 marks)

e) For the estimated drained values of the soil Young's modulus E_s = 60 MPa and Poisson's ratio ν = 0.3, check if the foundation designed in (a) satisfies the serviceability (settlement) limit state? (10 marks)

f) Check if the foundation designed in (a) satisfies the ultimate limit state (bearing resistance) using the limit states design approach. Use resistance factors f_c = 0.6 and f_ϕ = 0.8, and load factor 1.25 for DL and 1.5 for LL. Comment on the results. (10 marks)

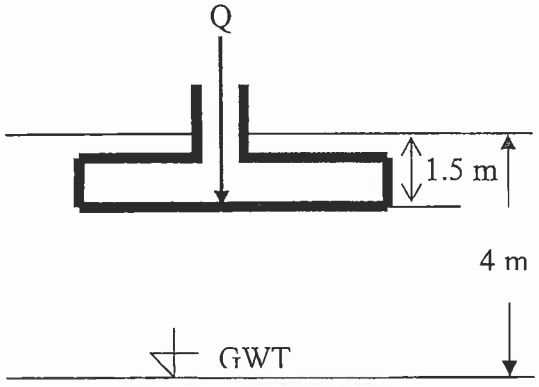

Figure 5 for Question 5

6. **Retaining Structures (30 marks)**

Figure 6 below shows the details of an anchored sheet pile wall. The properties of the backfill material are $\phi = 36^0$, and $\gamma = 17$ kN/m^3. The effective unit weight of the soil below the ground water table $\gamma' = 10.2$ kN/m^3 and $\phi = 36^0$. There is a uniformly distributed surcharge of 10 kPa at the ground surface as shown in the figure.

a) Use Rankine's theory to determine the distribution of the lateral pressure on the wall i) due to soil, ii) due to surcharge. (5 marks)
b) Determine the required depth of embedment of the piling (FS = 1.4). (15 marks)
c) Determine the force in each tie (the spacing being 2.0 m). (10 marks)

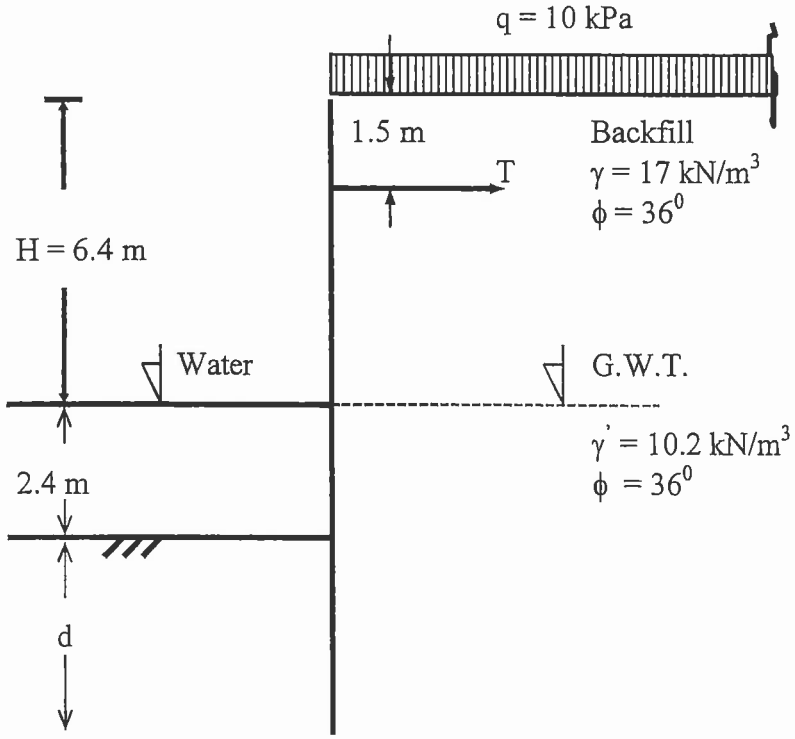

Figure 6 for Question No. 6 (Retaining structures)