National Exams **May 2015**

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)

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

a. Ultimate limit state and serviceability limit state for shallow foundations. (1.5 marks)
b. Overburden pressure, and distribution of stress increase within the supporting soil due to a shallow foundation's load. (1.5 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 5.5 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.

a) Using an overall factor of safety of 3, design the square footing to support the specified loads. (9 marks)
b) 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 section (a) satisfies the serviceability (settlement) limit state? (9 marks)
c) Check if the foundation designed in (a) satisfies the ultimate limit state (bearing resistance) using limit states design. 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. (9 marks)

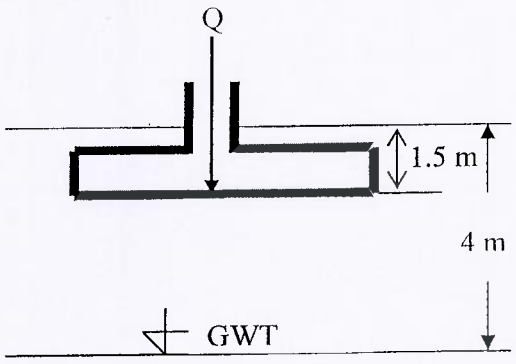

Figure for Question 1

2. Deep Foundations (30 marks)

A dead load of 7000 kN and a live load of 3000 kN are to be supported on a square pile group at a depth 1 m below the ground surface. The piles extend between depths of 1m and 13m in a deposit of stiff clay 25 m thick overlying rock. Consider either circular precast concrete piles of 0.6 m diameter or steel pipe piles of 0.6 m diameter. The recommended pile spacing is 2.0 m centre-to-centre. The representative undrained shear strength of the clay at the pile base level is 175 kN/m^2 and the average representative value over the pile length is 105 kN/m^2. The following parameters have also been determined for the clay: E_u = 65 MN/m^2; the coefficient of volume compressibility, m_v = 0.07 m^2/MN. The allowable settlement is 30 mm.

a) Design the pile group using a total (overall) factor of safety = 2.5 and considering short term conditions. (8 marks)
b) Design the pile group using a total (overall) factor of safety = 2.5 and considering long term conditions. (8 marks)
c) 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). (7 marks)
d) Check that the serviceability limit state (total settlement) is satisfied (use modified 1-D theory). (7 marks)

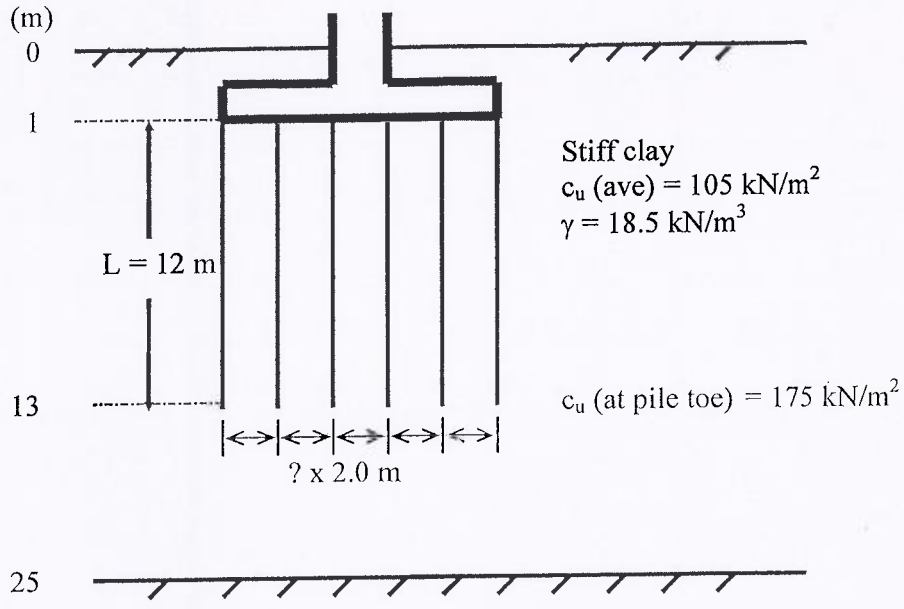

Figure for Question 2

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)

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

Part 2

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 $\beta = 26°$.

c) Determine the factor of safety of the given slope using Spencer's chart. (10 marks)

d) What is the allowable slope angle if a factor of safety of 1.25 is specified? (10 marks)

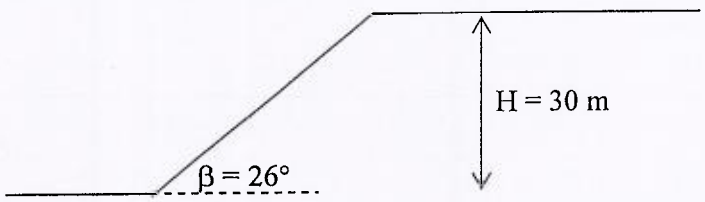

Figure for Question 3.

4. Retaining Structures (30 marks)

The figure 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 the soil, ii) due to the surcharge. (5 marks)
b) Determine the required depth of embedment of the piling, d, using FS = 1.4. (15 marks)
c) Determine the force in each tie (the spacing being 2.0 m). (10 marks)

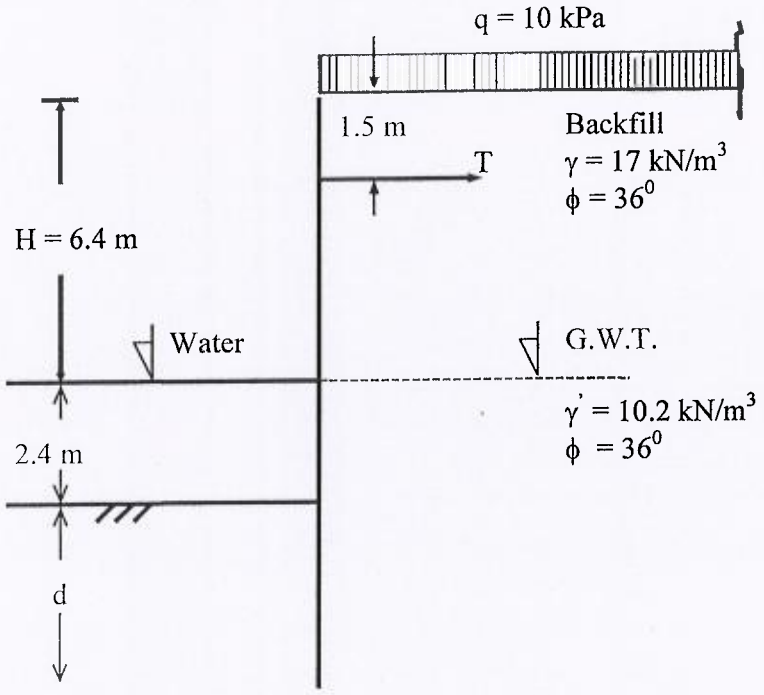

Figure for Question No. 4

5. Deep Foundations (30 marks)

A pile foundation will be installed in uniform clay of undrained shear strength of C_u = 50 kPa, Elastic Modulus, E = 50 MPa, Poisson's ratio, ν = 0.5 and bulk unit weight, γ = 20 kN/m^3. The clay's coefficient of volume change, $m_v = 2.3 \times 10^{-4}$ m^2/kN and initial void ratio, e_o = 1.47. There is a layer of very dense sand at a depth of 34 m below the ground surface. The foundation consists of 25 circular pre-cast concrete piles each 18m long and 0.4m in diameter. The pile cap is 5 x 5 m and is founded 1m below the ground level. 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) Calculate the ultimate capacity of the pile group. (8 marks)
c) If this foundation is subjected to a vertical centric load of 10 MN, what is the factor of safety against failure? Comment on the design of this pile group foundation. (6 marks)
d) Check that the serviceability limit state (total settlement) is satisfied using the equivalent raft method (i.e. using elastic analysis) (8 marks)

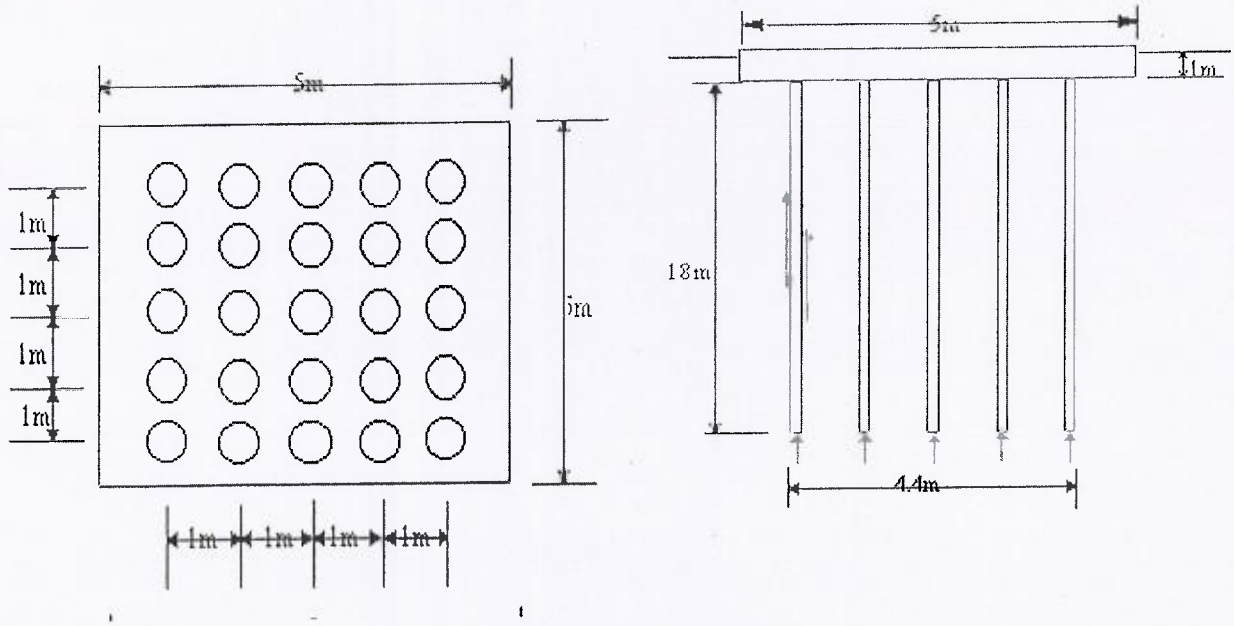

Figure for Question 5: a) Plan view; b) elevation view

6. **Shallow Foundations (30 marks)**

An oil storage tank 35m in diameter is located 2m below the surface of a deposit of clay 32m thick, the water table being at the surface. A firm stratum underlies the clay. The undrained shear strength of the soft clay is 25 kPa determined from unconfined compression tests on thin wall 51 mm Shelby tube samples, and its unit weight is 16.5 kN/m^3. The average value of m_v for the clay is 0.14 m^2 / MN, and pore pressure coefficient A is 0.65. The undrained value of Young's modulus is estimated to be 40 MN/m^2. The specific gravity of oil is 0.9. It is specified that the long-term total settlement of the tank should not exceed 300 mm.

a) To what height can the tank be filled such that ultimate (bearing resistance) and serviceability (settlement) limit states are satisfied? Neglect the weight of the tank and use load factor = 1.5 for oil weight, and resistance factor f_c = 0.6. (15 marks)

b) What is the total (overall) factor of safety against bearing capacity failure of the tank for the oil height determined in (a)? Comment on the results. (5 marks)

c) Calculate the total (overall) factor of safety if a strong wind results in an inclination of 20^0 of the load at the foundation level. (10 marks)

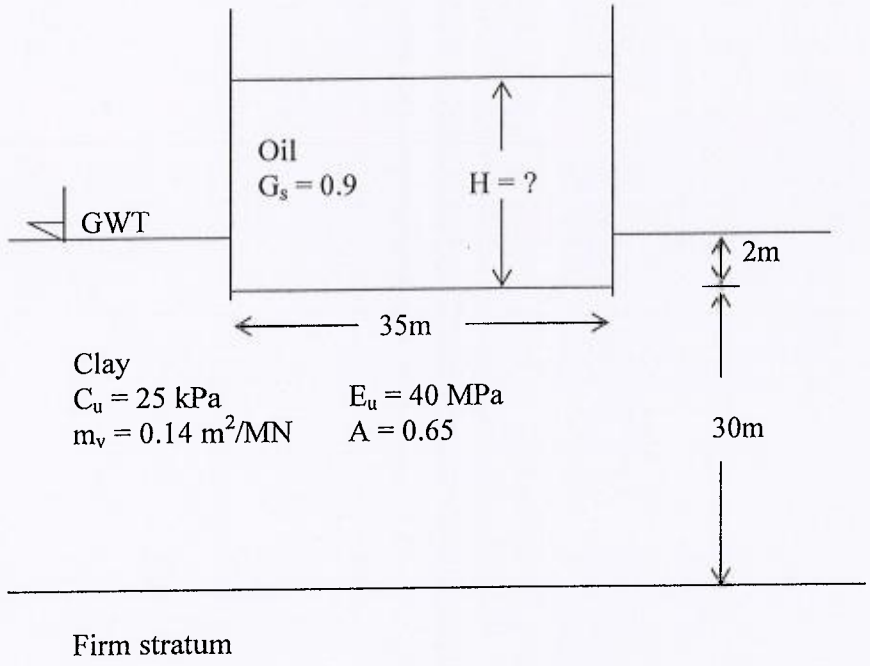

Figure for Question No. 6