National Exams May 2011

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. (2.5 marks)
b. Overburden pressure, and distribution of stress increase within the supporting soil due to a shallow foundation's load. (2.5 marks).

An oil storage tank 35m in diameter and its base is located 2m below the surface of a deposit of soft clay 32m thick, with 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. 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 for the foundation bearing capacity. Use the 1-D theory for settlement calculations (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 (5 marks).

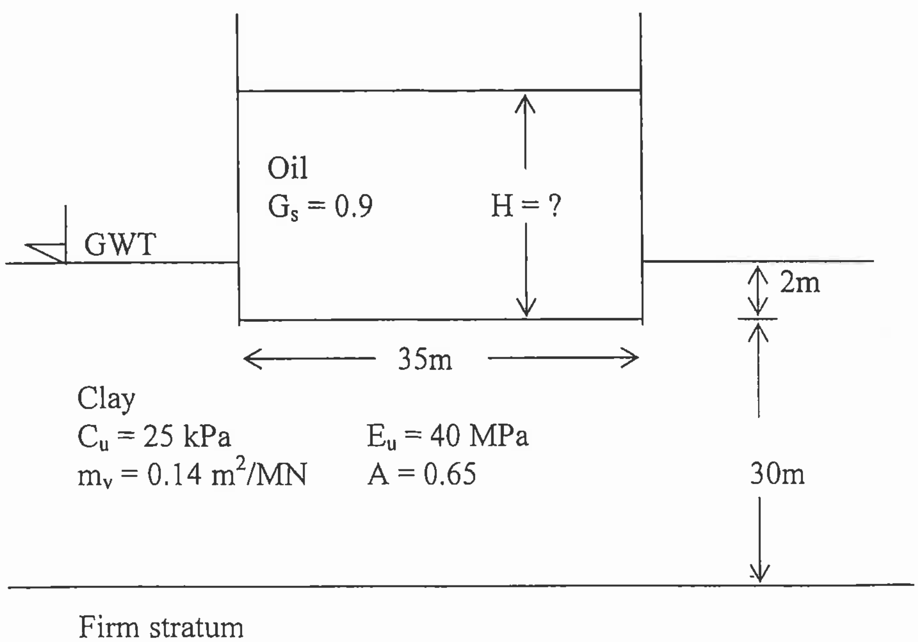

Figure 1 for Question No. 1

2. Deep Foundations (30 marks)

For the design of a pile foundation for a pier supporting a bridge across Hwy 401, soil samples were recovered from boreholes and laboratory tests were carried out. The results of the soil investigation at the test site are shown in Fig. 2. Two pile types are to be considered in the design, the first type is an H-pile of width 310-mm and the second is a 460-mm diameter steel pipe-pile, which has wall thickness of 12.7 mm and is to be filled with concrete. The axial load of the pier is 5 MN. The single pile design load is to be limited to 600 kN for driveability requirements.

a) Use the results of soil investigation to calculate the required length of each of the piles. (use a factor of safety FS=2.5). (10 marks)
b) Design the pile group foundation to support the pier (use a factor of safety FS = 2.5). Consider spacing to diameter ratio, S/d = 3. (5 marks)
c) Calculate the settlement of the pile group using the approximate method for pile groups in cohesive soils assuming that the bedrock is at a depth 45 m from the ground surface (10 marks)

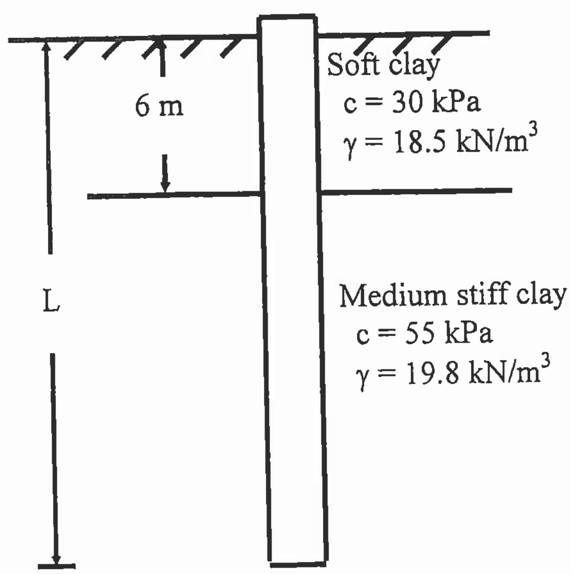

Figure 2 for Question No. 2

3. Slope Stability (30 marks)

Part 1

An excavation with slope of 30° failed when a depth of 10 m was reached. The soil is clay with approximately constant shear strength from top of slope down to 20 m where a hard stratum exists. Calculate the average undrained shear strength of the clay, if the bulk unit weight of the clay is 18.9 kN/m^3. (10 marks).

Part 2

A slope of 20 degrees with a height of 10 m is composed of homogeneous soil, with a bulk unit weight of 19.6 kN/m^3, a drained cohesion of 5 kPa, and a drained angle of friction of 25 degrees. The position of the water table is given in Figure 1.

a) Determine the factor of safety and the type of failure surface using Spencer's method. Make some conservative assumption about the height of the water table to simplify your analysis. (25 Marks). State clearly and justify any assumptions you make.

b) Describe the procedure to determine the factor of safety using Bishop and Morgenstern's method. (5 Marks)

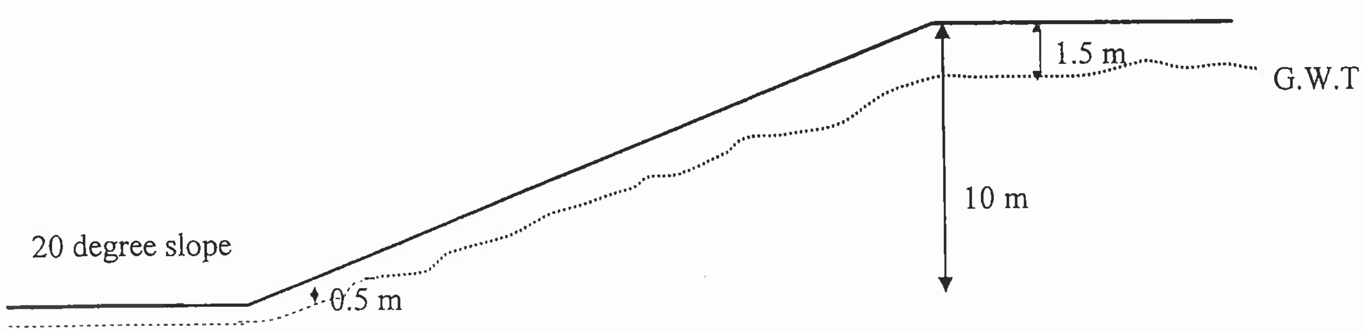

Figure 3 for Question 3

4. Retaining Structures (30 marks)

It is required to design a retaining wall with galvanized steel-strip reinforcement to support a cut 9 m high. The proposed backfill material is a granular A with the following properties: $\phi = 36°$, and $\gamma = 16$ kN/m^3. The properties of the foundation soil are: $\gamma = 17$ kN/m^3, $\phi' = 28°$ and $c' = 45$ kPa. The reinforcement galvanized steel-strips have the following properties: width w = 75 mm, $f_y = 240$ MPa and soil-steel friction angle $\delta = 20°$. The recommended spacing for the strips is as follows: $S_V = 0.6$ m centre-to-centre and $S_H = 1.0$ m centre-to-centre. Assume the corrosion rate of the galvanized steel to be 0.025 mm/year and the life span of the structure to be 50 years. It is required to maintain a factor of safety FS = 3 for all possible failure modes.

a) Use Rankine's theory to determine the distribution of the lateral pressure on the wall (2 marks)
b) Determine the required thickness of the steel-strips. (9 marks)
c) Determine the required length of the steel-strips. (9 marks)
d) Check the stability against overturning. (4 marks)
e) Check the stability against sliding. (2 marks)
f) Check the stability against bearing capacity failure. (4 marks)

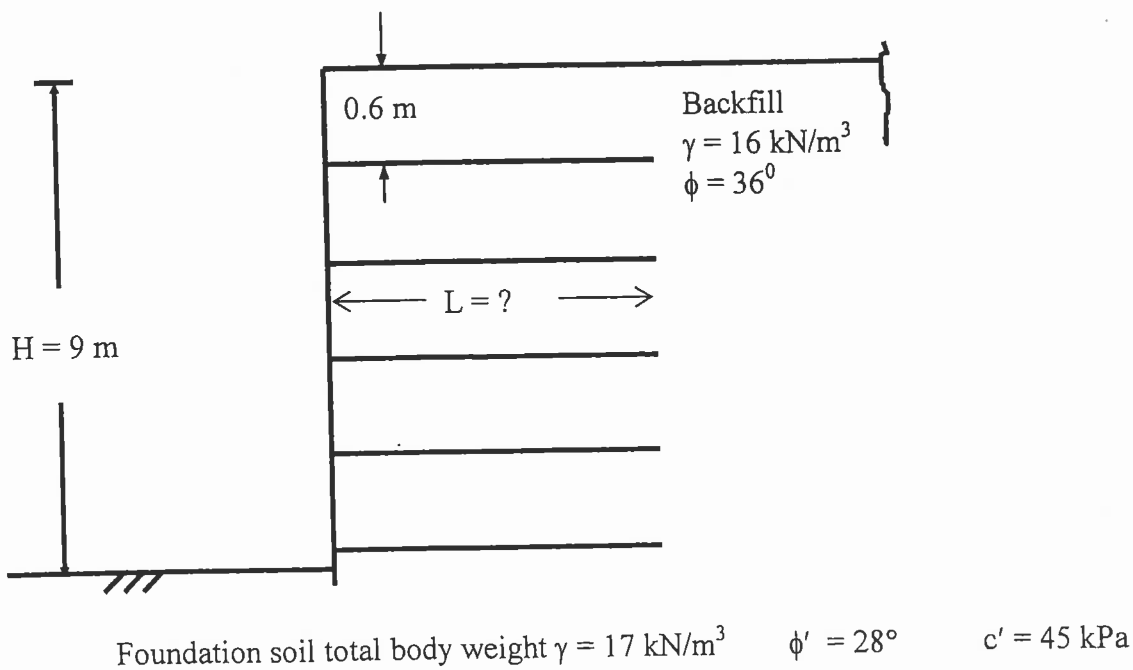

Figure 4 for Question No. 4 (Retaining structures)

5. Shallow Foundations (30 marks)

A power line tower is to be installed on four independent square footings. The footings are labeled N, E, S and W. Because the prevailing wind direction, the load on footing S is expected to be 30% higher than the load on E and W, and the load on N is expected to be 30% lower than the load on E and W. In addition, footings S and N will be subjected to a horizontal force of 5% of the total vertical load, directed towards the south. The layout of tower footings is illustrated in Figure 5. The total vertical load applied by the tower is 20000 kN. The subsurface profile is characterized by a 4 m thick sand layer underlain by a 3 m thick firm clay deposit, which lies on the bedrock. The water table is located at 2 m below the ground surface. The following properties have been determined for the subsurface:

Sand: $\phi' = 34°$, $E_u = 45$ MPa, $\gamma = 21$ kN/m^3

Clay:	Bulk unit weight	$\gamma = 19$ kN/m^3
	Friction angle	$\phi' = 30°$
	Cohesion	$C' = 10$ kPa
	Undrained shear strength	$C_u = 100$ kPa
	Undrained Poisson's ratio	$\nu_u = 0.5$
	Undrained elastic modulus	$E_u = 30$ MPa
	Compression index	$C_c = 0.4$
	Initial void ratio	$e_0 = 1.384$
	Preconsolidation pressure	$\sigma'_c = 130$ kPa

a) Design the footing S using the given loads and total factor of safety of 3 considering:
   i. Short term stability (Undrained condition). (7.5 Marks)
   ii. Long term stability (Drained condition). (7.5 Marks)

b) Check if the foundation designed in part (a) satisfies the ultimate limit state of shear failure for an undrained condition. (5 Marks)

c) If the allowable vertical settlement is 35 mm, check if the foundation satisfies the serviceability limit state. (10 Marks)

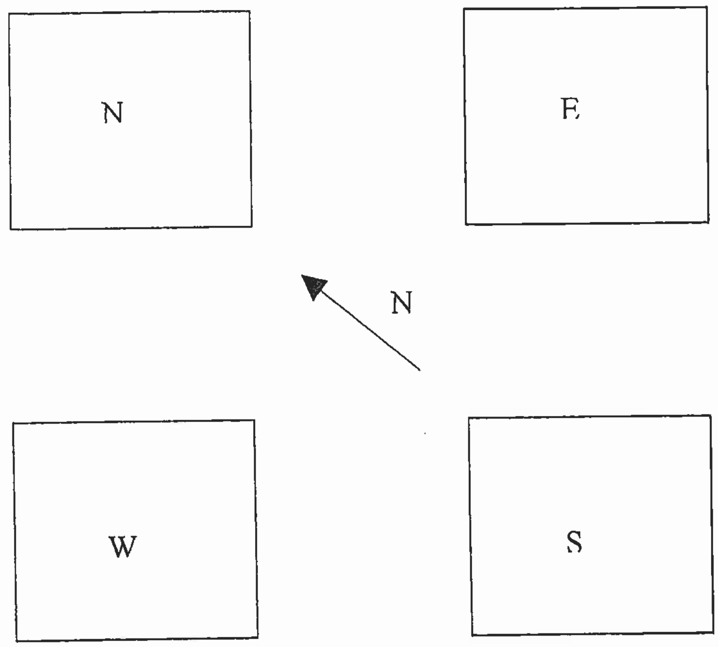

Figure 5 for Question 5

6. Deep Foundations (30 marks)

It is proposed to use a pile foundation to support a new power generating plant in Ontario. The foundation is expected to support a total specified (unfactored) vertical dead load of 14000 kN (including the weight of the pile cap). The foundation will also support a live load of 2000 kN due to the emergency loads of the equipment. The proposed piles are 50 m long steel piles with a diameter of 0.406 m. The pile wall thickness will be 12.7 mm. The piles will be driven in silty clay layers whose properties are given in Table 1 and will be founded on the till (bedrock). The ground water table (GWT) may rise to 10m below the ground surface. The submerged unit weight of the soil is γ_{sub} = 10 kN/m^3. The recommended pile spacing is 5 to 6 times the pile diameter. The elastic modulus of the pile E_P = 200 GPa and its cross-sectional area is 15,700 mm^2. The allowable vertical settlement is 25 mm. The equipment layout requires that the dimension of the pile cap be 30 m x 7.4 m. The average value of m_v for the clay is 0.05 m^2 / MN and that of pore pressure coefficient A is 0.4.

a) Determine the ultimate pile capacity of a single pile using the static analysis approach (i.e. using soil strength parameters) considering both undrained and drained conditions. (15 marks)
b) Design the pile group using a total (overall) factor of safety = 3. (5 marks)
c) Check that the foundation performance in terms of total settlement is satisfactory. (10 marks)

Table 1 Soil Properties

Soil Type	Thickness (m)	C_u (kPa)	c′ (kPa)	φ′ (°)	γ (kN/m^3)	E (MPa)	ν
Native silty clay	5	55	10	28	20.5	55	0.45
Native silty clay	7.5	30	0	24	20	30	0.45
Native silty clay	18	40	0	24	19	40	0.45
Silty clay	17	60	10	28	20	60	0.45
Silty clay	2.5	120	20	30	22	120	0.3
Till (bedrock)	---	400	50	32	22	400	0.3