National Exams December 2012

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. Effective stress and total stress. (1.5 marks).

A bridge pier is to be supported on a square shallow footing founded at a depth 1.3m (F.L.) below the ground level (G.L.). The foundation soil is a deposit of silty sand and the ground water table (GWT) is located at a depth of 3m below G.L. as shown in Figure 1. The soil unit weight above the water table is γ = 17.6 kN/m^3 and below the water table the saturated unit weight is γ_{sat} = 18.4 kN/m^3. The representative soil properties obtained from laboratory tests are $\phi' = 33°$ and $c' = 0$ kPa. Underneath the silty sand, there is a 4m thick clay layer with compression index, $C_c = 0.35$ and void ratio, $e_0 = 0.9$. The clay layer is underlain by a dense sand layer as shown in Figure 1. The footing is subjected to a vertical load of 8000 kN. It is specified that the settlement of the foundation should not exceed 30 mm.

a) Determine the plan dimensions of the square footing using a total (overall) factor of safety of 3 against bearing capacity failure. (10 marks)
b) Estimated the settlement due to the consolidation of the clay layer and check if the foundation satisfies the settlement requirement. (10 marks)
c) If the foundation is subjected to a lateral load of 1000 kN, in addition to the vertical load, what would be the factor of safety of the foundation you designed in part (a)? (10 marks).

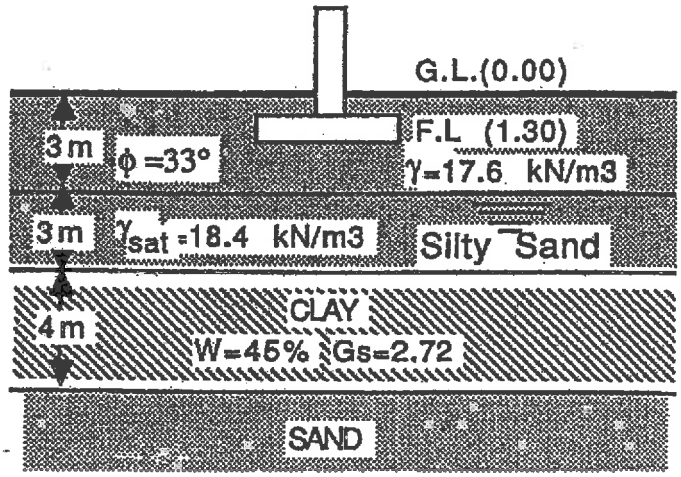

Figure 1 for Question 1 (Shallow Foundations)

2. Deep Foundations (30 marks)

As part of a residential development, it is required to design several pile foundations. The proposed piling system involves 20 m long steel H-piles of width 310 mm driven into a clayey soil profile. The top 8m of the site soil is normally consolidated clay with a unit weight of 16 kN/m^3 and undrained cohesion equal to 60 kPa; underlain by a 18 m thick slightly overconsolidated clay layer with a unit weight equal to 18 kN/m^3 and undrained shear strength equal to 110 kPa; and underlain by a very dense sand layer that extends to the end of the available borehole.

a) Determine the design axial capacity of this pile considering a factor of safety of 2.5. (10 marks)
b) Design a group of this pile to support a structural load of 2 MN. (10 marks)
c) Considering that the normally consolidated clay has compressibility index, Cc = 0.35 and void ratio, e_0 = 0.95, and the overconsolidated clay has C_c = 0.15 and e_0 = 0.6, calculate the consolidation settlement using the equivalent raft method. (10 marks)

3. Slope Stability (30 marks)

Part 1

A cutting 20m deep is to be excavated with a slope angle, $\beta = 20°$ in a clay soil of unit weight 19 kN/m^3. The relevant shear strength parameters are $c' = 30$ kN/m^2 and $\phi' = 25°$. The pore water pressure ratio for the slope, $r_u = 0.25$.

a) Sketch the slip surface for this cutting and state the expected form of failure surface (i.e. based on the location of the failure surface). (5 marks)

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

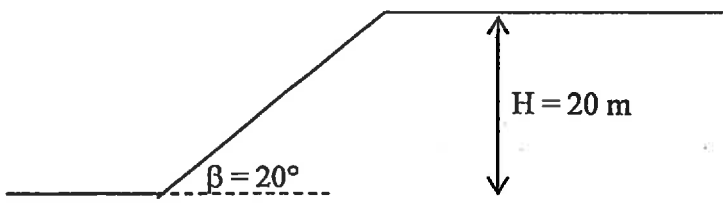

Figure 2 for Part 1 of Question 3.

Part 2

A slope is cut in a clayey soil. The slope is 12 m high and its slope angle is 26°. The representative properties of clay are $c' = 20$ kPa, $\phi' = 30°$ and unit weight, $\gamma = 17.8$ kN/m^3. Calculate the factor of safety for the slope.

a) The ground water table is well below the slope. (10 marks)

b) The ground water table is 6m below the ground surface. (10 marks)

4. Retaining Structures (30 marks)

A reinforced concrete retaining wall 5 m high is designed as shown in Figure 3. The proposed backfill material is a granular A with the following properties: $\phi' = 40°$, and $\gamma = 20$ kN/m^3. The backfill soil extends to the base of retaining wall. The properties of the foundation soil are: $\gamma = 19$ kN/m^3, $\phi' = 35°$ and $c' = 0$ kPa. The water table is at least 4 m below the base of the retaining wall.

a) Use Rankine's theory to determine the distribution of the lateral pressure on the wall (2 marks)
b) Calculate the factor of safety with respect to overturning. (9 marks)
c) Calculate the factor of safety with respect to sliding. (9 marks)
d) Calculate the factor of safety with respect to bearing capacity. (5 marks)
e) If the water table rises to the level of the base of the retaining wall, what would be the factor of safety with respect to bearing capacity? (5 marks)

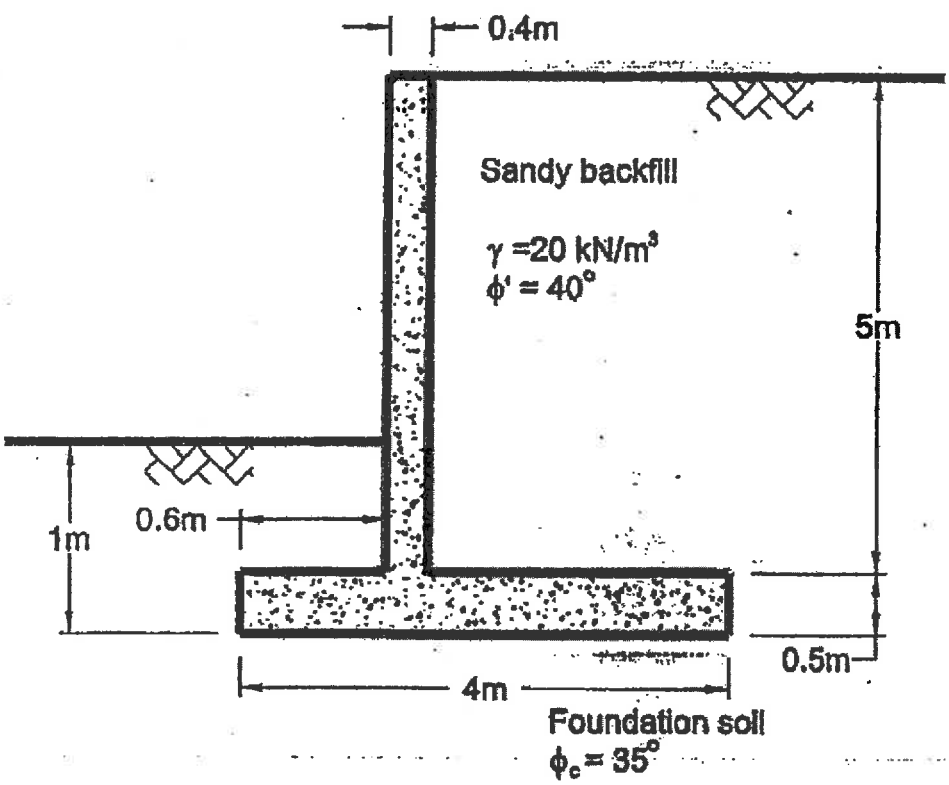

Figure 3 for Question 4 (Retaining Structures)

5. Deep Foundations (30 marks)

It is required to establish the axial capacity for a 0.90 m diameter cast-in-place concrete pile for a foundation that will be situated in the profile whose properties are provided in Table 1 below, which includes the unit weights and undrained shear strength values. Based on the provided data, establish the shaft resistance and the toe bearing pressures. Using these shaft and toe resistance values, establish the pile capacity for a 10 m long pile for the following two cases:

a) The pile head is at the existing grade. (7 marks)
b) The pile head is at 2.00 m below existing grade. (7 marks)
c) Considering the pile option in part (b), design a pile group to support a square foundation carrying a total load of 20 MN using a total (overall) factor of safety = 3, and considering a pile spacing, S = 3d, where d is pile diameter. (6 marks)
d) If the liquid limit of the clay is 40% and its specific gravity, $G_s = 2.72$, calculate the settlement of the pile group due to the applied load. (10 marks)

Table 1 soil properties for Question 5

Depth (m)	Unit weight of soil (kN/m^3)	Undrained shear strength (kN/m^2)
0	18.5	70
2	18	50
4	18	50
6	19.5	90
8	20	100
14	21	120

6. Shallow Foundations (30 marks)

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 2 and will be founded on the till (bedrock). 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 considering both undrained and drained conditions. (10 marks)
b. Design the foundation using a total (overall) factor of safety = 3. (10 marks)
c. Check that the serviceability limit state (total settlement) is satisfied. Consider the compression index for the native silty clay layers, Cc = 0.13 and voids ratio to be 0.8. (10 marks)

Table 2 Soil Properties for Question 6

Soil Type	Thickness (m)	C_u (kPa)	c′ (kPa)	ϕ′ (°)	γ (kN/m^3)	E (MPa)	ν
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