National Exams December 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 concepts for shallow foundations. (1.5 marks)
b. Effective stress and total stress. (1.5 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 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 2.5 m below the ground surface. The submerged unit weight of the soil is $\gamma' = 10$ 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. (9 marks)

b. Design the foundation using a total (overall) factor of safety = 3. (9 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. (9 marks)

Table 1 Soil Properties for Question 1

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	0.5
Till (bedrock)	---	400	50	32	22	400	0.3

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

2. Deep Foundations (30 marks)

A pile foundation will be installed in uniform slightly over-consolidated clay of undrained shear strength of C_u = 50 kPa, Elastic Modulus, E_u = 50 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 consists of 25 large diameter helical piles. Each pile is 18 m long and has a diameter of 305 mm and wall thickness of 12.7 mm. The pile can have 2 helices, each 610 mm in diameter and are spaced at 1.22m. The pile cap is 6 x 6 m and is founded 1m below the ground level. The piles are equally spaced in both directions with spacing equal to 1.2 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) 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 (8 marks)

3. Slope Stability (30 marks)

Part 1

Determine the factor of safety for a slope of 30°, which is 30m high in an area where the soil is primarily uniform clay with $c_u = 96$ kN/m^2, $\gamma = 17.0$ kN/m^3 and $\phi = 0°$. A rock stratum exists 45 m below the toe of the slope. (10 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. (10 marks)

4. Retaining Structures (30 marks)

The figure below shows the details of a cantilever retaining wall. The properties of the backfill material are $\phi' = 34^0$, and $\gamma = 18$ 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 that extends from the edge of the highway to the edge of the retaining wall.

a) 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)

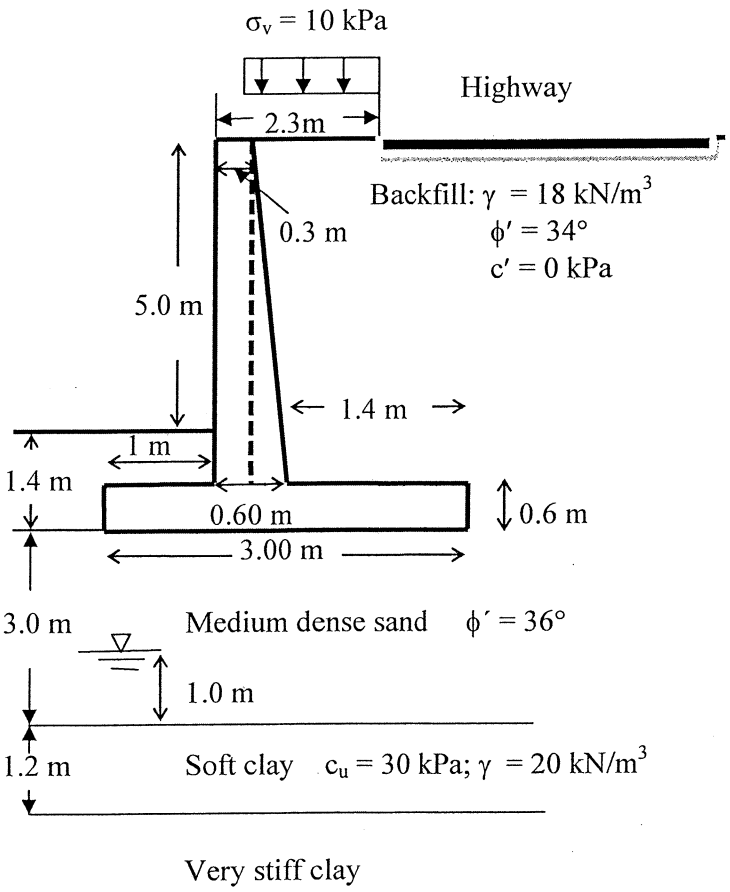

Figure for Question No. 4

5. 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 pipe piles with diameter of 406 mm driven closed-ended into a clayey soil profile. The pile wall thickness will be 12.7 mm. The top 8 m 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 specified dead load of 1.4 MN and a specified live load of 0.6 MN. (6 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).
d) Check if the design of the pile group considered in part (b) satisfies the ultimate limit state criterion. (4 marks).

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

A footing 4 m square is located at a depth of 1 m in a layer of saturated clay 13 m thick, the water table being at ground level. The following parameters are known for the clay: c_u = 100 kN/m^2, γ_{sat} = 21 kN/m^3, c' = 15° and ϕ' = 27°, m_v = 0.065 m^2/MN, A (pore-pressure coefficient) = 0.42. Determine the allowable bearing capacity of this foundation:

a) if the factor of safety with respect to shear failure is not to be less than 3. (15 marks)
b) if the maximum consolidation settlement is to be limited to 30 mm. (15 marks)