National Exams December 2018

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).

It is required to design a foundation system for a telecommunication tower to satisfy the vertical bearing capacity requirements. The tower is 60 m high steel structure supported on three legs and each leg is supported by a square shallow foundation system. The axial compressive load per each leg is 1850 kN and the corresponding shear load is 225 kN. The soil design parameters obtained from the borehole conducted at the location of the tower are given below. (27 marks).

SOIL DESIGN PARAMETERS		
▸ Soil Description	0.0 – 0.1 m	TOPSOIL
	0.1 – 8.8 m	SAND – compact to very dense sand, trace to some silt, trace gravel, occasional cobbles and boulders
	8.8 m	Auger refusal on possible bedrock or boulder
▸ Groundwater		Observed at a 3.6 m depth in open borehole
▸ Design for Submerged Conditions		No*
▸ Frost-Free Depth		1.9 m
▸ Caisson Bearing at or below 1.9 m* depth	ULS (resistance)	300 kPa
	SLS (capacity)	200 kPa
▸ Pier and Pad at or below 1.9 m* depth	ULS (resistance)	300 kPa
	SLS (capacity)	200 kPa
▸ Soil 0.0 to 0.1 m	ϕ (insitu) = 26° γ (insitu) = 16 kN/m^3	
▸ Soil 0.1 to 1.9 m	ϕ = 30° γ (insitu) = 20 kN/m^3	
▸ Soil 1.9 to 8.8 m	ϕ = 30° γ (insitu) = 20 kN/m^3 γ' (insitu) = 10 kN/m^3 (below 3.0 m depth) k_p = 3.00 k_a = 0.33	

Notes: *Significant groundwater inflow must be expected for excavations extending below a 3.0 m depth. It is therefore recommended that footings be founded above a 3.0 m depth (Elevation 186.4 m).

2. Deep Foundations (30 marks)

As part of a residential development, it is required to design several pile foundations. The proposed piling system involves 18 m long steel H-piles of flange width 310 mm and depth of 307 mm, web and flange thickness of 15.5 mm, driven into a clayey soil profile. 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 lightly overconsolidated clay layer with a unit weight equal to 18 kN/m^3 and undrained shear strength equal to 110 kPa; this is 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 square group of these piles 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 18 m 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 an appropriate slip surface for this cutting and state the expected form of 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)

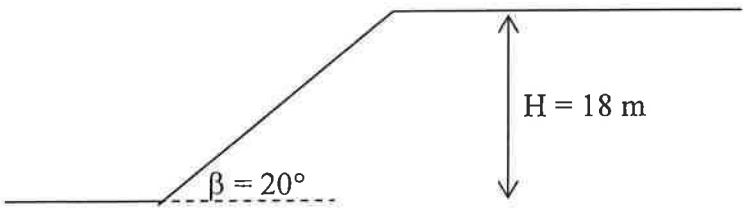

Figure 1 for Part 1 of Question 3.

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 drained 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 2. The proposed backfill material is 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 distributions 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)

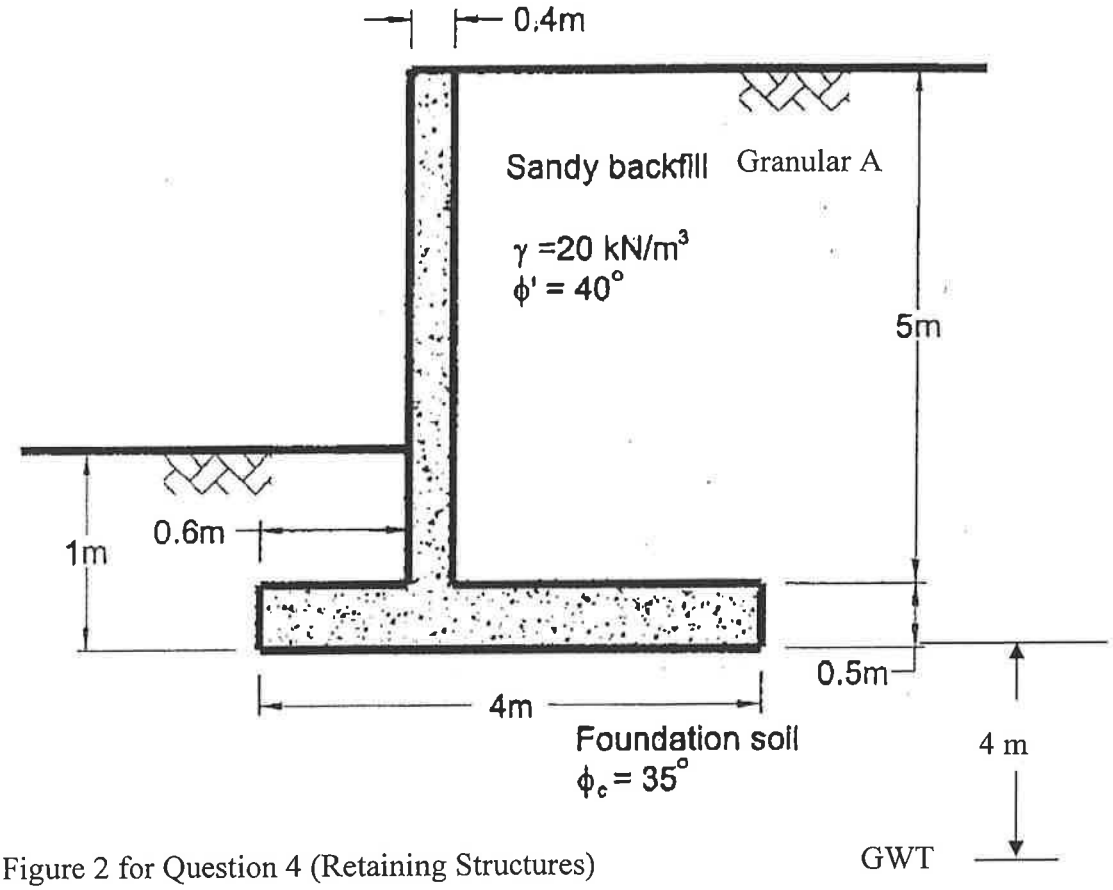

Figure 2 for Question 4 (Retaining Structures)

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 10 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 2.5 m below the ground surface. The submerged unit weight of the soil is γ_{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	0.45
Native silty clay	7.5	40	0	24	20	40	0.45
Native silty clay	18	50	0	24	20	50	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