National Exams December 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. (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).

A reinforced concrete building of overall dimensions of 30x24 m exerts a specified dead load of 10 kN/m^2 over the building plan area. The specified live load is 8 kN/m^2. Columns 6m apart in both directions, resting on square footings, will support the load. A sand layer of 3m in depth, bulk unit weight, γ_{bulk} = 17 kN/m^3 and saturated unit weight, γ_{sat} = 19 kN/m^3 is underlain by normally consolidated clay 9 m deep with bulk unit weight, γ_{bulk} = 19 kN/m^3. The water table is 2 m below the ground surface. The angle of internal friction of the sand, ϕ = 36°. Based on the results of testing clay samples subjected to conventional triaxial tests, the undrained shear strength, cu = 60 kPa, and the effective strength parameters are, c' = 0 kPa and ϕ' = 28°. An oedometer test was conducted and the coefficient of volume change, m_v, was evaluated to be 2.3 x 10^{-4} m^2/kN and initial void ratio, e_0 = 1.47.

a) Design a square footing for an interior column using the permissible stress method with a total factor of safety, F = 3 for the following cases:
   i. Short term stability (Undrained analysis) (5 marks)
   ii. Long term conditions (Drained analysis) (5 marks
   (Recommend the embedded depth and size of the footing).
b) Design a square footing for an interior column using the Limit States Design approach for the following cases.
   i. Short term stability (Undrained analysis) (5 marks)
   ii. Long term conditions (Drained analysis) (5 marks)
c) Determine the immediate and final settlements. (7 marks)

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 a drilled shaft with diameter = 600 mm and the second is a 460-mm diameter steel pipe-pile, which has a wall thickness of 12.7 mm. The axial load on the pier is 5 MN. The single pile design load is to be limited to 800 kN for constructability requirements.

a) Use the results of the 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. (10 marks)
c) Calculate the settlement of the pile group using the approximate method for pile groups in cohesive soils assuming that bedrock is at a depth 45 m from the ground surface (10 marks)

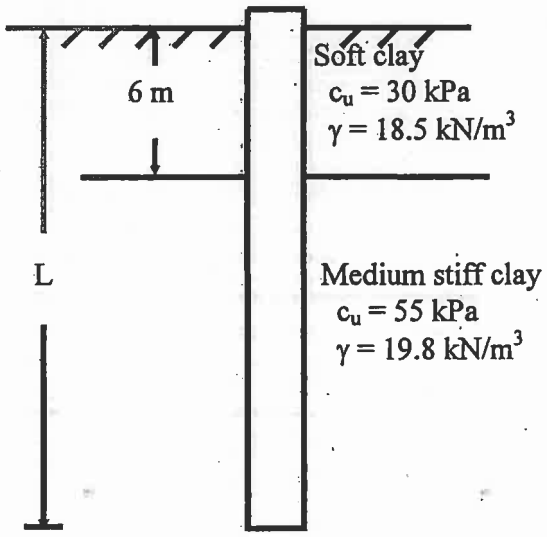


Figure 2 for Question No. 2

3. Slope Stability (30 marks)

Part 1

A cutting 23m 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 of slices; and Spencer's method. (5 marks)

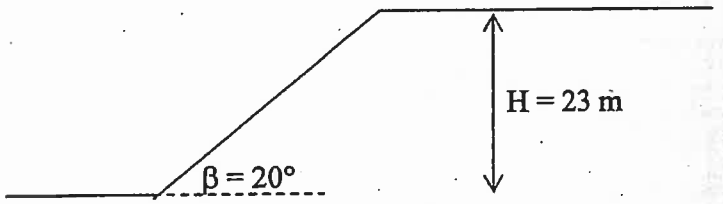


Figure 3 for Part 1 of Question 3.

Part 2

For the construction of a railway, a slope was excavated in a deep over-consolidated clay deposit. The slope is 2H:1V and 8 m high. A large number of laboratory triaxial drained tests showed that $\phi' = 25°$ and $c' = 6.8$ kN/m^2. The bulk unit weight of the soil is 17 kN/m^3.

(a) Use Bishop and Morgenstern's method to estimate the factor of safety of the slope when the ground water reached steady seepage (the calculated average values of r_u was 0.2, 0.3 and 0.4 for trial circle D of 1, 1.25 and 1.5, respectively. (10 marks)

(b) The slope failed in a rainy season. The observed failure circle passed through the toe of the slope. Estimate how much the pore pressure has increased in terms of r_u. (10 marks)

4. Retaining Structures (30 marks)

The section through a gravity retaining wall is shown in Fig. 4, the unit weight of the wall material being 23.5 kN/m^3. The unit weight of the backfill is 19 kN/m^3 and design values of the shear strength parameters are $c' = 0$ and $\phi' = 36°$. The value of friction angle between wall and backfill and between base and foundation soil is 25°. The ultimate bearing capacity of the foundation soil is 250 kN/m^2.

a) Use Rankine's theory to determine the distribution of the lateral pressure on the wall (3 marks)
b) Check the stability against overturning. (9 marks)
c) Check the stability against sliding. (9 marks)
d) Check the stability against bearing capacity failure. (9 marks)

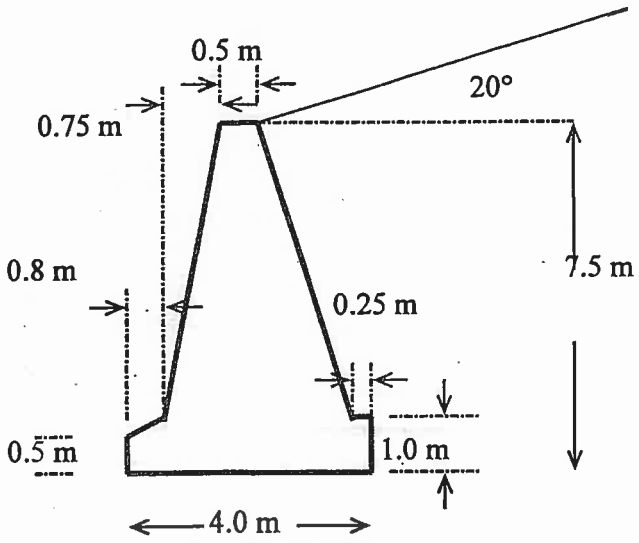
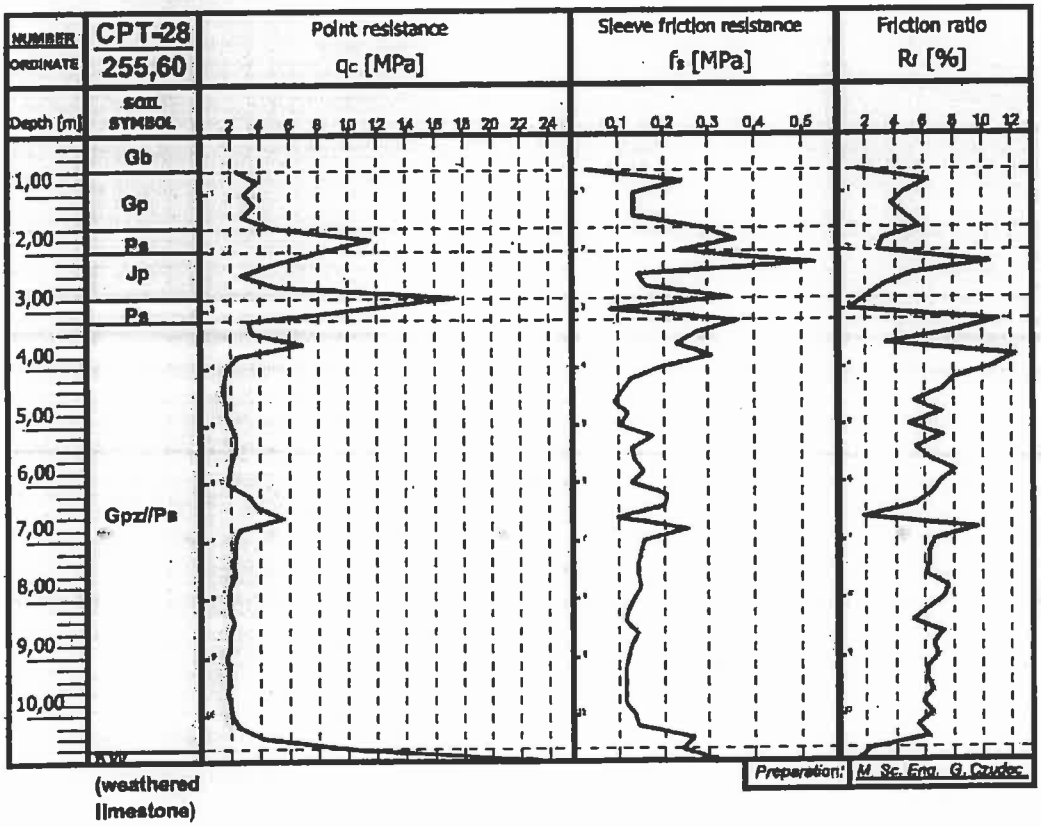


Figure 4 for Question No. 4 (Retaining structures)

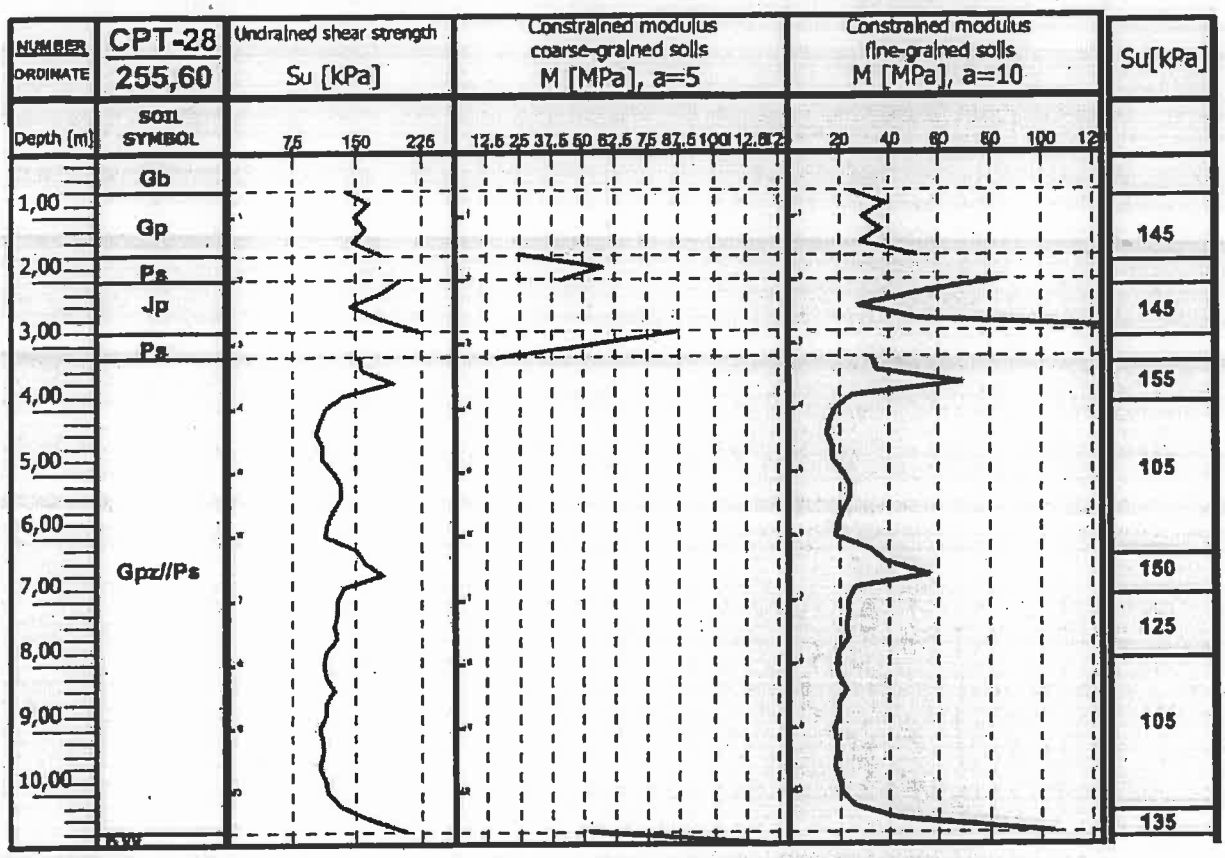
5. Deep Foundations (30 marks)

As part of the foundation design for a cement production facility, it is required to establish the pile capacity for 0.60 m and 0.90 m diameter piles for a foundation that will be situated at the location of CPT28 shown in Figure 1, which provides the interpretation of the CPT sounding at that location. Based on the CPT test data, establish the shaft frictional resistance and the toe bearing pressures. Using these shaft and toe resistance values, establish the pile capacity for a 10 m pile for the following two cases:

a) The pile head is at the existing grade. (10 marks)
b) The pile head is at 2.00 m below existing grade. (10 marks)
c) Choose one of the pile options considered in part (a) and 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. (10 marks)



a)



b)

Figure 5 for Question 5: a) CPT28 sounding; b) interpretation of CPT28 data

6. Shallow Foundations (30 marks)

It is proposed to use a shallow foundation as part of a petrochemical plant in Sarnia. The foundation is expected to support a total specified (unfactored) vertical dead load of 14000 kN (including the weight of the foundation). The foundation will also support a live load of 2000 kN due to the emergency loads of the equipment. A lateral load of 1000kN may act on the foundation due to thermal friction forces. The foundation will be embedded to a depth of 2.5 m in silty clay layers whose properties are given in Table 1. The ground water table (GWT) may rise to 15m below the ground surface. The submerged unit weight of the soil is γ_{sub} = 10 kN/m^3. The allowable vertical settlement is 25 mm. The supported equipment layout requires that the dimensions of the foundation be at least 20 m x 10 m.

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. (10 marks)

Table 1 - Soil Properties

Soil Type	Thickness (m)	Cu (kPa)	c′ (kPa)	ϕ′ (°)	γ (kN/m^3)	E (MPa)	ν
1. Native silty clay	5.0	55	10	28	20.5	75	0.5
2. Native silty clay	7.5	30	0	24	20.0	50	0.5
3. Native silty clay	18.0	40	0	24	19.0	70	0.5
4. Silty clay	17.0	60	10	28	20.0	100	0.5
5. Silty clay	12.5	120	20	30	22.0	240	0.30
6. Till (bedrock)	---	400	50	32	22.0	500	0.30