# UNIVERSITY OF RUHUNA

## Faculty of Engineering

Mid-Semester 7 Examination in Engineering: June 2015

**Module Number: CE7237** **Module Name: Ground Improvement Techniques**

**[Two Hours]**

[Answer **all questions**, Marks assigned for each question are indicated]

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Q1. A 100 m x 100 m play ground is to be constructed over a low lying area which is underlained by 5.0 m thick normally consolidated soft clay layer as shown in Figure Q1.1. Based on site investigations, it was revealed that a dense sand layer is below the soft clay layer. The natural water table was found to be at the ground surface. As this area is frequently subjected to flooding, it was decided to raise the elevation of the play ground by 4.0 m.

Compressibility characteristics of soft clay were determined in the laboratory by conducting laboratory oedometer test on undisturbed clay samples collected from the site. Compression index, void ratio and coefficient of consolidation of soft clay were found to be 0.5, 0.7 and 2.5 m$^2$/year, respectively. The undrained shear strength of the soft clay was found to be 10.0 kN/m$^2$. The saturated unit weight of the clay is 14.0 kN/m$^3$.

In order to construct the play ground, a compacted fill is placed with a side slope of 1:2 as shown in Figures Q1.1 and Q1.2. The volume of the embankment is 46,912 m$^3$. To construct the play ground, soil is to be excavated from a borrow pit, transported to the construction site and compacted to an embankment. The in-situ void ratio and bulk unit weight of the material are 0.828 and 16.0 kN/m$^3$, respectively. After soil has been dumped at the construction site, water is added to bring the water content up to 16.0 % which is considered to be the optimum water content of the soil. Soil is then compacted with a roller to form the embankment with an average dry unit weight of 17.5 kN/m$^3$ and void ratio of 0.485. Further, a gravel mat is placed over the soft clay layer before place the fill to facilitate the drainage.

It was decided to place the fill in stages to avoid shear failure at the edges. The maximum possible height of fill to have a factor of safety of at least 1.25 on slope instability is given in Table Q1.1. The strength gained due to consolidation with usual notations can be expressed by $\Delta C_u = 0.2\Delta\sigma$.

The information provided in Table Q1.2 may be useful in the calculations.

*Note:- You may consider the variation of the thickness of the clay layer in different stages. But consider the unit weight to be the same.*

a) What would be the suitable maximum fill height for the first step of filling without causing any shear failure at edges? Hence, calculate the expected primary consolidation settlement and time period to achieve 90% of the primary consolidation settlement.

[2.0 Marks]

b) If the second stage of filling is started after the 90% consolidation of the stage 1 filling, what would be the stage 2 fill thickness? Hence, calculate the expected primary consolidation settlement and time period to achieve 90% of the primary consolidation settlement. Further, estimate the top elevation of the fill after the

90% primary consolidation of the stage 2 filling, taking top of dense sand layer as datum.

[3.0 Marks]

c) The third stage of filling will be started after 90% consolidation of the stage 2 filling. What would be the stage 3 fill thickness? Hence, calculate the expected primary consolidation settlement and time period to achieve 90% of the primary consolidation settlement. Further, estimate the top elevation of the fill after the 90% consolidation of the stage 3 filling with respect to datum.

[2.5 Marks]

d) Based on the results of above sections (a) - (c), suggest a suitable programme for preloading technique.

[0.5 Marks]

e) What would be the expected removable preload (fill height) after the end of 90% consolidation of the stage 3?

[0.5 Marks]

f) If the dump truck which is used to transport the soil from borrow pit to the construction site has a capacity of 15 $m^3$ and the truck loaded to the full capacity contains 20 tons of moist soil, determine number of truck loads required to construct the embankment.

[1.5 Marks]

Q2. It was proposed to construct a "A" class road on a low lying area consisted of 6.0 m thick soft soil layer. For the preliminary design, compressibility parameters were determined by obtaining an undisturbed soil samples from the soft soil layer and conducting laboratory oedometer tests. However, during the construction, it was realized that soft soil behavior in the field is quite different than the predicted consolidation behavior based on the labaoratory experimental data.

a) Why is it important to monitor soft soil behavior in the field? Briefly explain two factors.

[1.0 Marks]

b) Suggest four types of instruments with the relevant parameters to monitor soft soil behavior in the field in the above project.

[1.0 Marks]

c) The observed settlement in the field is shown in Table Q2.1. Using Asaoka's graphical method, determine the degree of consolidation of the soft layer.

[1.0 Marks]

d) A longitudinal crack has been observed on the embankment. What would be the possible reasons for this longitudinal crack? As you are a junior engineer in this project, suggest a suitable method/s to rectify this problem.

[1.0 Marks]

e) The contractor has proposed to adopt replacement method to construct the remaining area of the road in order to save the time and the cost of monitoring. As you are a junior engineer in this project, do you agree with this proposal? Justify your answer.

[1.0 Marks]

Q3. A bypass road is proposed to be constructed over a paddy field at Imaduwa along Galle-Deniyaya road to avoid heavy traffic jam in the town. Soil profile at the paddy field consists of 8.0 m thick soft peaty soil layer which is underlained by dense sand layer as shown in Figure 3.1. An impermeable bed rock is found under the dense sand layer. The water table is found to be at the existing ground level. Based on laboratory oedometer test results, compressibility characteristics of soft peaty soil such as coefficient of consolidation in vertical direction, coefficient of consolidation in horizontal direction, compression index and void ratio were found as 2.0 m²/year, 8.0 m²/year, 0.45 and 0.60, respectively. The bulk unit weight of peaty soil is 14.0 kN/m³.

As this area is frequently subjected to flooding, it was decided to raise the elevation of the road by 3.0 m, which is considered to be the sub grade level. The dead and live load of the road is found to be 25 kN/m². Preloading technique has been proposed to improve the soft soil and to compensate the dead and live load of the road, a soil fill of thickness 1.25 m will be placed over the sub grade level as shown in Figure 3.1. To shorten the preloading period, Prefabricated Vertical Drains (PVD) is proposed to install at 1.0 m spacing in square pattern up to a depth of 8.0 m before placing the soil fill. A gravel mat is placed over the soft peaty soil layer to facilitate the drainage. The bulk unit weight of fill material can be taken as 20 kN/m³.

The cross sectional dimensions of PVD and mandrel are 100 mm x 4 mm and 120 mm x 60 mm, respectively. The discharge capacity of the drain is given as 1000 m³/year by the manufacturer.

The unit weight of water is 9.81 kN/m³. You may use following equations with usual notations for calculations.

$$U_h = 1 - exp\left[\frac{-8T_h}{F}\right]$$

$$T_h = \frac{C_h t}{D_e^2}$$

$$F = F_{(n)} + F_s + F_r$$

$$F_{(n)} = ln\left[\frac{D_e}{d_w}\right] - \frac{3}{4}$$

$$F_s = \left[\left(\frac{k_h}{k_s}\right) - 1\right] ln\left(\frac{d_s}{d_w}\right)$$

$$F_r = \frac{2}{3}\pi L^2\left(\frac{k_h}{q_w}\right)$$

$D_e = 1.13S$ for square pattern

$d_s = 2d_m$

$$C_h = \left(\frac{k_h}{k_v}\right) C_v$$

$$U = 1 - (1 - U_h)(1 - U_v)$$

a) Assuming that soft peaty soil is normally consolidated, estimate the expected primary consolidation settlement of the soft peaty soil layer due to proposed design load.

[1.0 Marks]

b) By considering only the horizontal drainage, what would be the expected time period to achieve 95% degree of consolidation?

[3.0 Marks]

c) In order to accelerate consolidation or reduce preloading period, a junior engineer has proposed to install PVD at 0.75 m spacing in square pattern. Do you agree with this proposal? Justify your answer.

[0.5 Marks]

d) Why is it important to do "Depth check" before installation of PVD in the field?

[0.5 Marks]

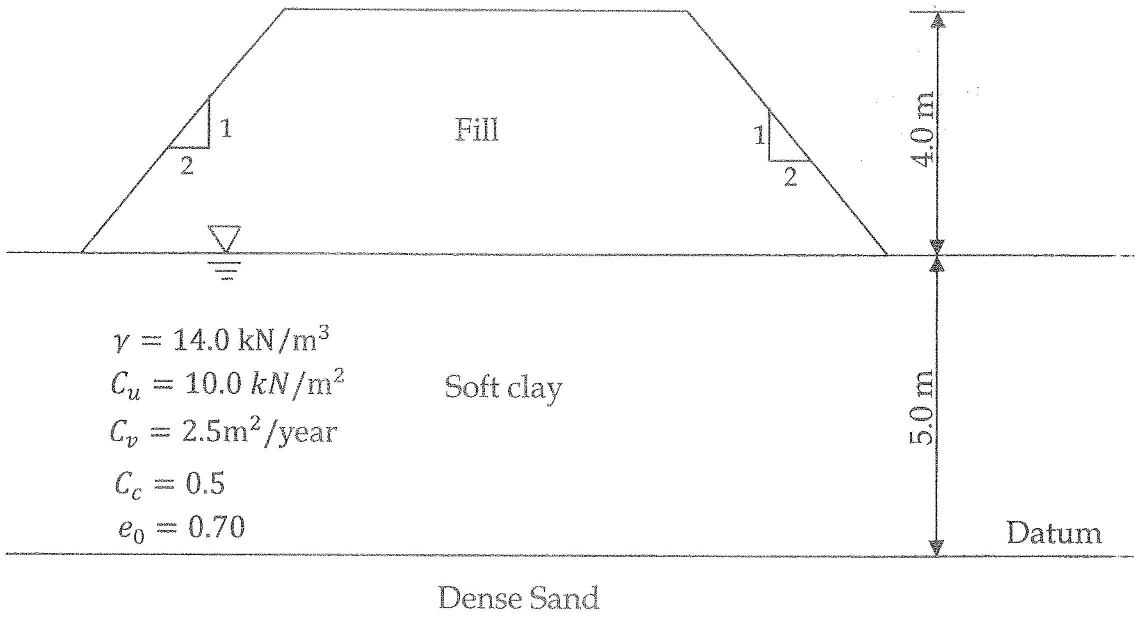


Figure Q1.1 – Sub surface soil profile

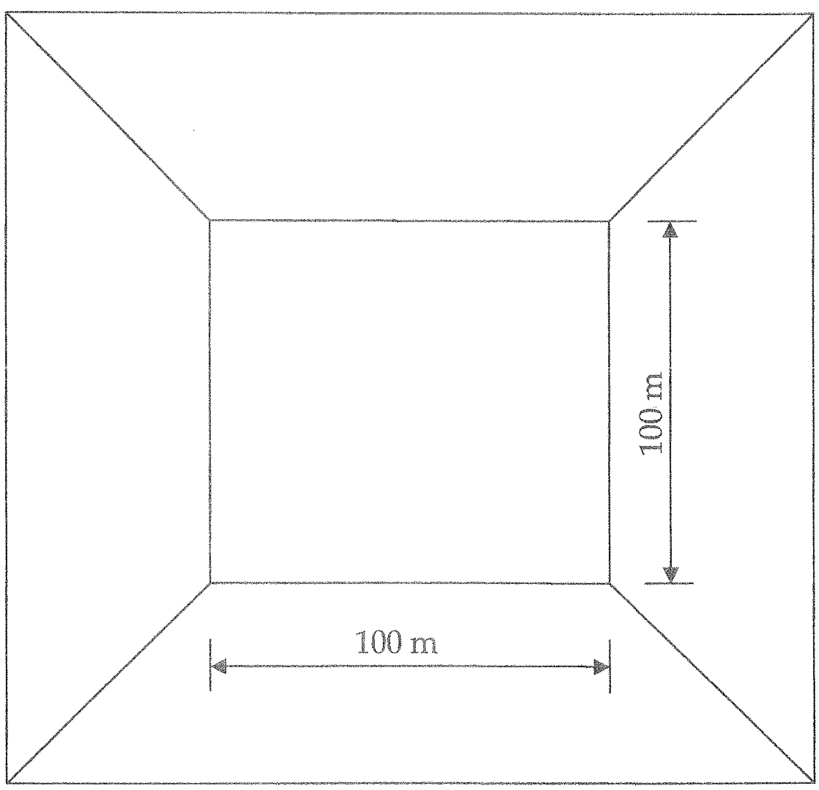


Figure Q1.2 – Plan view of play ground

Table Q1.1 – Maximum possible height of fill

| Shear strength $C_u$(kN/m²) | 10.0 | 14.5 | 16.3 | 20.1 | 24.8 | 35.2 |
|---|---|---|---|---|---|---|
| Safe fill height (m) | 2.0 | 3.2 | 4.5 | 5.0 | 6.0 | 8.6 |

Table Q1.2 – Variation of $T_v$ with $U$

| $U$(%) | $T_v$ | $U$(%) | $T_v$ |
|---|---|---|---|
| 0 | 0 | 51 | 0.204 |
| 1 | 0.00008 | 52 | 0.212 |
| 2 | 0.0003 | 53 | 0.221 |
| 3 | 0.00071 | 54 | 0.230 |
| 4 | 0.00126 | 55 | 0.239 |
| 5 | 0.00196 | 56 | 0.248 |
| 6 | 0.00283 | 57 | 0.257 |
| 7 | 0.00385 | 58 | 0.267 |
| 8 | 0.00502 | 59 | 0.276 |
| 9 | 0.00636 | 60 | 0.286 |
| 10 | 0.00785 | 61 | 0.297 |
| 11 | 0.0095 | 62 | 0.307 |
| 12 | 0.0113 | 63 | 0.318 |
| 13 | 0.0133 | 64 | 0.329 |
| 14 | 0.0154 | 65 | 0.304 |
| 15 | 0.0177 | 66 | 0.352 |
| 16 | 0.0201 | 67 | 0.364 |
| 17 | 0.0227 | 68 | 0.377 |
| 18 | 0.0254 | 69 | 0.390 |
| 19 | 0.0283 | 70 | 0.403 |
| 20 | 0.0314 | 71 | 0.417 |
| 21 | 0.0346 | 72 | 0.431 |
| 22 | 0.0380 | 73 | 0.446 |
| 23 | 0.0415 | 74 | 0.461 |
| 24 | 0.0452 | 75 | 0.477 |
| 25 | 0.0491 | 76 | 0.493 |
| 26 | 0.0531 | 77 | 0.511 |
| 27 | 0.0572 | 78 | 0.529 |
| 28 | 0.0615 | 79 | 0.547 |
| 29 | 0.0660 | 80 | 0.567 |
| 30 | 0.0707 | 81 | 0.588 |
| 31 | 0.0754 | 82 | 0.610 |
| 32 | 0.0803 | 83 | 0.633 |
| 33 | 0.0855 | 84 | 0.658 |
| 34 | 0.0907 | 85 | 0.684 |
| 35 | 0.0962 | 86 | 0.712 |
| 36 | 0.102 | 87 | 0.742 |
| 37 | 0.107 | 88 | 0.774 |
| 38 | 0.113 | 89 | 0.809 |
| 39 | 0.119 | 90 | 0.848 |
| 40 | 0.126 | 91 | 0.891 |
| 41 | 0.132 | 92 | 0.938 |
| 42 | 0.138 | 93 | 0.993 |
| 43 | 0.145 | 94 | 1.055 |
| 44 | 0.152 | 95 | 1.129 |
| 45 | 0.159 | 96 | 1.219 |
| 46 | 0.166 | 97 | 1.336 |
| 47 | 0.173 | 98 | 1.500 |
| 48 | 0.181 | 99 | 1.781 |
| 49 | 0.188 | 100 | ∞ |
| 50 | 0.197 | | |

Table Q2.1 – Variation of settlement with time

| Day after end of embankment construction | Settlement (m) |
|---|---|
| 0 | 1.868 |
| 10 | 1.925 |
| 20 | 1.958 |
| 30 | 1.980 |
| 40 | 1.992 |
| 50 | 2.006 |
| 60 | 2.019 |
| 70 | 2.026 |
| 80 | 2.036 |
| 90 | 2.040 |

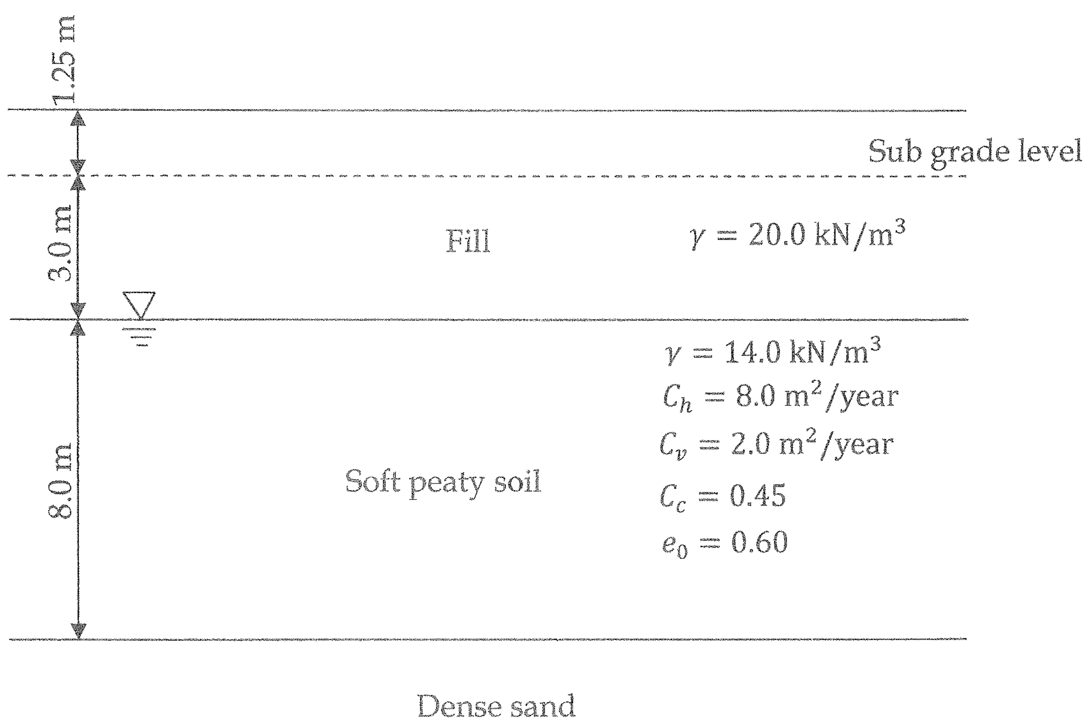


Figure Q3.1 – Sub surface soil profile