EXERCISE 1

A square footing 3 m long is located 1.5 m below the ground surface. This foundation rests on a 10-m stratum of sand, which lies over a gravel stratum.

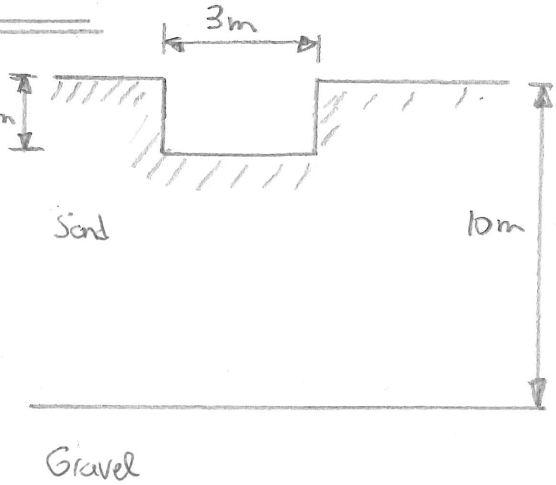
The bulk unit weight of sand is 18.3 kN/m^3 and the water table is well below the depth of influence of the foundation.

The average number of blows in the SPT along the sand stratum was 15. Also, it has been estimated that the friction angle is 30°.

Taking into account that the allowable settlement is 25 mm, it has been determined the maximum load the soil will carry: 219 kN/m^2.

Determine the allowable bearing capacity of soil and interpret the result.

Answer: q_{allow} = 169.40 kN/m^2.



Sand : $\gamma = 18.3$ kN/m^3 , $N_{AVG} = 15$

$\phi = 30°$

$S_t = 25$ mm , $q = 219$ kN/m^2

According to data, the maximum load is 219 kN/m^2 taking into account, only, the allowable settlement, S_t.

Now, it is neccesary to determine the maximum load, q_{allow}, taking into consideration the bearing capacity of soil (sand).

In this case (sand), two expressions can be used to calculate q_{allow} :

1) Analytical expression (slide 10 of the lecture material)

$$q'_{ult} = c' \cdot N_c \cdot f_c + \sigma'_{v0} \cdot N_q \cdot f_q + \frac{1}{2} \gamma \cdot B^* \cdot N_\gamma \cdot f_\gamma$$

2) Alternative expression depending on N_{AVG} (slide 13)

$$q_{allow}(kPa) = 8 \cdot N_{AVG} \cdot \left(1 + \frac{D}{3 \cdot B^*}\right) \cdot \left(\frac{S_t}{25}\right) \cdot \left(\frac{B^* + 0.3}{B^*}\right)^2$$

1) Analytical expression (to be used in granular soils as sand).

- $c' = 0$, because granular soils do not present cohesion (slide 5) $\Rightarrow c' \cdot N_c \cdot f_c = 0$
- σ'_{v_0} is the effective vertical stress due to the self weight of soil at the supporting plane of the foundation (slide 5). From lesson 4,

  $$\sigma'_{v_0} = \sigma_{v_0} - u_0 = \gamma \cdot H_{exc} - 0 = 18.3 \cdot 1.5 = 27.45 \ kN/m^2$$

- γ (slide 10) is depending on the distance to the water table. In this case, the water table is well below the depth of influence of the foundation $\Rightarrow \gamma = 18.3 \ kN/m^3$
- $B^* = B = 3m$, assuming that a vertical load is applied
- N_q, N_γ are the bearing capacity factors (slide 5) which depend on ϕ. Using the mathematical expressions in slide 5 or the auxiliary table provided with the course,

  $$\phi = 30° \Rightarrow N_q = 18.4011, \ N_\gamma = 15.0698$$

- f_q, f_γ are correction factors (slide 6)

  $$f_q = d_q \cdot i_q \cdot t_q \cdot s_q \quad ; \quad f_\gamma = d_\gamma \cdot i_\gamma \cdot t_\gamma \cdot s_\gamma$$

  d_q, d_γ take into account the shear strength of soil adjacent to and above the level of the foundation base (slides 6 and 7). These factors will not be considered when $H_{exc} < 2m$ as it is the case. $\Rightarrow d_q = d_\gamma = 1$

  i_q, i_γ take into account the inclination of the load. As, in this case, it is assumed a vertical load $\Rightarrow i_q = i_\gamma = 1$ (slide 8)

t_q, t_γ take into account whether the ground surface is horizontal. In this case, it is, so

$$t_q = t_\gamma = 1 \quad \text{(slide 9)}$$

s_q, s_γ take into account the shape of the foundation (slide 9)

$$s_q = 1 + 1.5 \cdot \tan\phi \cdot \frac{B}{L} = 1 + 1.5 \cdot \tan 30 \cdot \frac{3}{3} = 1.8660$$

$$s_\gamma = 1 - 0.3\,\frac{3}{3} = 0.7$$

Substituting all these data, it leads to

$$q'_{ult} = 0 + 27.45 \cdot 18.4011 \cdot [1 \cdot 1 \cdot 1 \cdot 1.8660] + \frac{1}{2} 18.3 \cdot 3 \cdot 15.0698 \cdot [1 \cdot 1 \cdot 1 \cdot 0.7] =$$

$$= 1232.10 \text{ kN/m}^2$$

Taking into account that an excavation is done, and the partial safety factor, (slide 12)

$$q_{ult} = q'_{ult} + u = 1232.10 + 0 = 1232.10 \text{ kN/m}^2$$

$$q_{n_{ult}} = q_{ult} - \gamma \cdot H_{exc} = 1232.10 - 18.3 \cdot 1.5 = 1204.65 \text{ kN/m}^2$$

$$q_{allow} = \frac{q_{n_{ult}}}{\gamma_R} = \frac{1204.65}{3} = 401.55 \text{ kN/m}^2$$

2) Alternative expression

$N_{AVG} = 15$, $S_t = 25$ mm, $B^* = B = 3$ m

$D = H_{exc} = 1.5$ m (see slide 7)

In order to use this expression it is neccesary to verify that the complete set of requirements is verified:

slope of the ground surface < 10% ✓

horizontal load < 10% of vertical load ✓

$S_{allow} \leq 25$ mm ✓

$B = 3m < 5m$ ✓

In addition,

$$1 + \frac{D}{3 \cdot B^*} = 1 + \frac{1.5}{3 \cdot 3} = 1.17 < 1.30 \quad ✓$$

Then, as $B > 1.2$ m

$$q_{allow}(kPa) = 8 \cdot 15 \cdot \left(1 + \frac{1.5}{3 \cdot 3}\right) \cdot \left(\frac{25}{25}\right) \left(\frac{1.5 + 0.3}{1.5}\right)^2 = 169.40 \text{ kPa}$$

Values obtained using both expressions are valid, but the last one is the most unfavourable, and then, it will be selected.

$$\underline{\underline{q_{allow} = 169.40 \text{ kN/m}^2}}$$

[This q_{allow} is smaller than that obtained using the allowable settlement. That means that, in this case, soil strength is more restrictive that soil settlement.]

EXERCISE 9

At a planned construction site, which lies on a thick (30 m) deposit of overconsolidated clay, a foundation is to be constructed 3 m below the ground surface using a mat foundation (flexible type) 25 m by 50 m. These foundation will carry a vertical uniform load q = 116.2 kN/m^2. The water table has been found at 3 m depth.

During the geotechnical survey, several samples were taken and, after completing a series of tests, the following data were obtained:

a) Test to determine the density and unit weight of a soil.

Test result: bulk unit weight: 17.3 kN/m^3

b) Unconfined compression test.

Test result: unconfined compressive strength = 54.5 kPa.

c) CU triaxial compression test.

Test result: cohesion = 6.5 kPa

friction angle = 18°

Also, the undrained elastic modulus has been estimated to be 4.3 MN/m^2.

In addition, from a soil sample located above the water table, the bulk unit weight was obtained: 16.9 kN/m^3.

Finally, it has been found that the rock mass below the clay stratum is slightly weathered. Determine:

1. Total settlement of the soil under the foundation. Explain the results obtained.
2. Allowable bearing capacity of soil in a short-term and in a long-term. Also, verify whether that soil will fail. If it would fail, indicate whether it will be a short-term, medium-term or long-term failure.

Answers:

1) s_i = 314.16 mm; 2) q_{allow}(ST) = 51.36 kN/m^2; q_{allow}(LT) = 179.96 kN/m^2. ST failure.

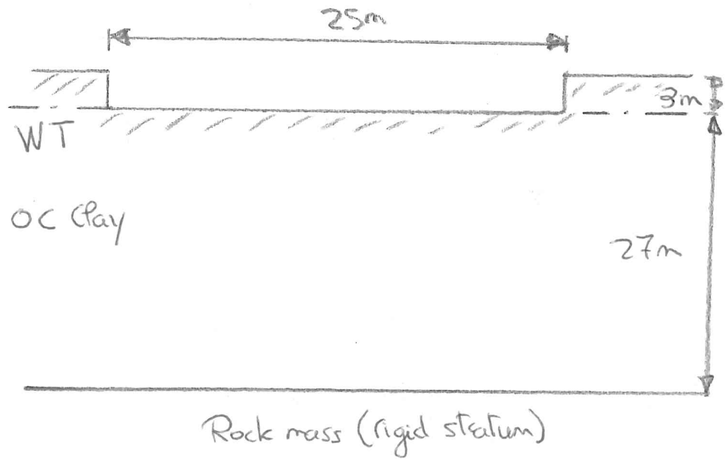
$B = 25\,m,\ L = 50\,m,\ q = 116.2\ kN/m^2$

$\gamma_{sat} = 17.3\ kN/m^3,\ E_u = 4.3\ MN/m^2,\ \gamma = 16.9\ \frac{kN}{m^3}$

$q_u = 54.5\ kPa \Rightarrow C_u = \frac{q_u}{2} = 27.25\ \frac{kN}{m^2}$

CU Triaxial compression test

- $c' = 6.5\ kPa$
- $\phi' = 18°$

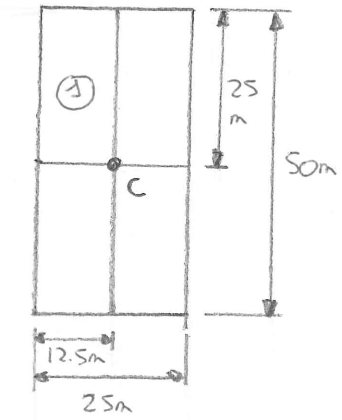


① Total settlement

Soil settlement is determined in lesson 5. Several exercises have already been done.

$$S_i = 4 \cdot S_{i①} = 4\left[C_{s①} \cdot q \cdot B_1 \cdot \frac{1-\nu^2}{E_u}\right]$$

where $\nu = 0.5$ and $B_1 = 12.5\ m$



$C_{s①}$ (slide 11 of lesson 5) is determined in the corresponding expression (limited depth) with $B = 12.5\,m$, $L = 25\,m$, $H = 27\,m$

$$C_{s①} = 0.31$$

Substituting

$$S_i = 4\left[0.31 \cdot 116.2 \cdot 12.5 \cdot \frac{1-0.5^2}{4.3 \cdot 10^3}\right] = 314.16 \cdot 10^{-3}\,m = 314.16\,mm$$

From this result, it can be seen that immediate settlement is larger than allowable settlements (slide 5, lesson 5) for mat foundations: 50 mm.

Then, the load $q = 116.2\ kN/m^2$ should not be applied.

(2) Allowable bearing capacity.

In this case (overconsolidated clay), two expressions must be used: the first one to determine the long-term bearing capacity (slide 10)

$$q'_{ult} = c' \cdot N_c \cdot f_c + \sigma'_{v0} \cdot N_q \cdot f_q + \frac{1}{2} \gamma \cdot B^* \cdot N_\gamma \cdot f_\gamma$$

Expression also used in the complete resolution of exercise 1.

The second one will be used to determine the short-term bearing capacity (slide 11)

$$q_{ult} = c_u \cdot N_c \cdot f_c + \sigma_{v0} \cdot N_q \cdot f_q$$

Long-term allowable bearing capacity

$c' = 6.5 \frac{kN}{m^2}$

$\sigma'_{v0} = \sigma_{v0} - u_0 = \gamma \cdot H_{exc} - 0 = 16.9 \cdot 3 = 50.7\ kN/m^2$

$\gamma \rightarrow$ when water table coincides or is above the supporting plane of the foundation $\gamma \rightarrow \gamma'$ (slide 10)

$$\gamma' = \gamma_{sat} - \gamma_w = 17.3 - 9.8 = 7.5\ kN/m^3$$

$B^* \equiv B = 25\ m$, assuming that a vertical load is applied

N_c, N_q, N_γ: $\phi' = 18° \rightarrow$ auxiliary table $\rightarrow N_c = 13.1037, N_q = 5.2576, N_\gamma = 2.0751$

f_c, f_q, f_γ:

As in exercise 1, $i_c = i_q = i_\gamma = 1$, $t_c = t_q = t_\gamma = 1$

Also, $d_c = d_q = d_\gamma = 1$ (slide 7) assuming that it is not possible to assure that soil remain over the lifespan of the structure.

$$s_c = 1 + 0.2 \frac{B}{L} = 1 + 0.2 \cdot \frac{25}{50} = 1.1$$

$$s_q = 1 + 1.5 \cdot \tan\phi' \cdot \frac{B}{L} = 1 + 1.5 \cdot \tan 18 \cdot \frac{25}{50} = 1.2437$$

$$s_\gamma = 1 - 0.3 \cdot \frac{B}{L} = 1 - 0.3 \cdot \frac{25}{50} = 0.85$$

Substituting all these data, it leads to

$$q'_{ult} = 6.5 \cdot 13.1037 \cdot [1 \cdot 1 \cdot 1 \cdot 1.1] + 50.7 \cdot 5.2576 \cdot [1 \cdot 1 \cdot 1 \cdot 1.2437] +$$
$$+ \frac{1}{2} \cdot 7.5 \cdot 25 \cdot 2.0751 \cdot [1 \cdot 1 \cdot 1 \cdot 0.85] = 590.57 \text{ kN/m}^2$$

$$q_{ult} = q'_{ult} + u = 590.57 + 0 = 590.57 \text{ kN/m}^2$$

$$q_{n_{ult}} = q_{ult} - \gamma \cdot H_{exc} = 590.57 - 16.9 \cdot 3 = 539.87 \text{ kN/m}^2$$

$$\underline{q_{allow}} = \frac{q_{n_{ult}}}{\gamma_R} = \frac{539.87}{3} = \underline{179.96 \text{ kN/m}^2 \quad \text{(LONG-TERM)}}$$

<u>Short-term allowable bearing capacity</u>

$c_u = 27.25 \text{ kN/m}^2$, $N_c = 5.14$, $N_q = 1$ (see slide 11)

$$\sigma_{v_0} = \gamma \cdot H_{exc} = 16.9 \cdot 3 = 50.7 \text{ kN/m}^2$$

$$f_c = d_c \cdot i_c \cdot t_c \cdot s_c \quad ; \quad f_q = d_q \cdot i_q \cdot t_q \cdot s_q$$

Using the same arguments that those in long-term

$$d_c = d_q = 1 \; ; \; i_c = i_q = 1 \; ; \; t_c = t_q = 1$$

In addition

$$s_c = 1 + 0.2 \frac{B}{L} = 1 + 0.2 \cdot \frac{25}{50} = 1.1$$

$$s_q = 1 + 1.5 \cdot \tan\phi_u \cdot \frac{B}{L} = 1 + 1.5 \cdot \tan 0 \cdot \frac{25}{50} = 1.0$$

where $\phi_u = 0$ (slide 11) because under short-term conditions (undrained conditions) the only strength parameter in clays is c_u (see lesson 6).

Substituting

$$q_{ult} = 27.25 \cdot 5.14 \cdot [1 \cdot 1 \cdot 1 \cdot 1.1] + 50.7 \cdot 1 \cdot 1 = 204.77 \ kN/m^2$$

$$q_{nult} = q_{ult} - \gamma \cdot H_{exc} = 204.77 - 16.9 \cdot 3 = 154.07 \ kN/m^2$$

$$\underline{\underline{q_{allow}}} = \frac{q_{nult}}{\gamma_R} = \frac{154.07}{3} = \underline{\underline{51.36 \ kN/m^2 \quad (\text{SHORT-TERM})}}$$

Net load applied by the foundation is:

$$q_{NET} = q - \gamma \cdot H_{exc} = 116.2 - 16.9 \cdot 3 = 65.5 \ kN/m^2 > q_{allow}(\text{short-term}) = 51.36 \ \frac{kN}{m^2}$$

Then, a <u>short-term failure will occur</u> if the load $q = 116.2 \ \frac{kN}{m^2}$ is applied.