Example JRC-02
Strip foundation
Verification of strength and settlement

Design situation

Consider a $B = 1.5\text{m}$ wide strip foundation that supports a concrete building, $L_x = 21.4\text{m}$ long by $L_y = 15.5\text{m}$ wide. The allowable settlement for this building is $s_{Cd} = 5\text{cm}$. The foundation carries the following permanent and variable vertical loads from columns C1-C6:

$$G_k = (460 \quad 687 \quad 627 \quad 624 \quad 685 \quad 417\,)\text{kN}$$

$$Q_k = (108 \quad 222 \quad 154 \quad 152 \quad 222 \quad 108\,)\text{kN}$$

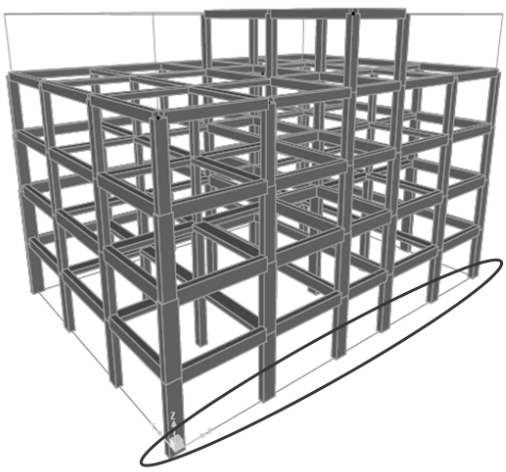
Shear forces and bending moments are negligible for static conditions. Ground conitions are:

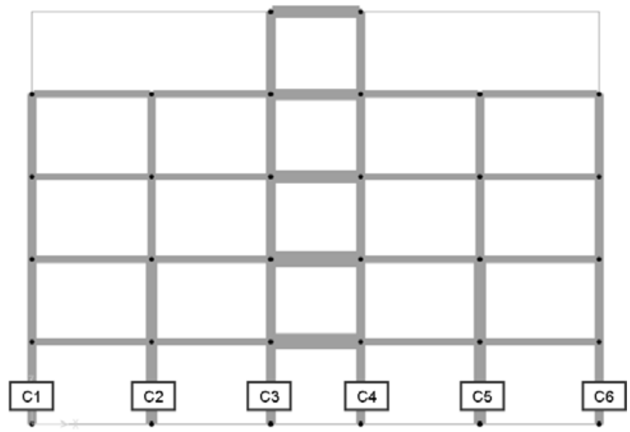
Soil 1 (medium dense clay): $\gamma_{k_1} = 18.5\frac{\text{kN}}{\text{m}^3}$, $\varphi_k = 38°$, $c'_k = 0\text{kPa}$, $E_{k_1} = 30\text{MPa}$), $\nu_{k_1} = 0.3$ (drained), $t_1 = 20\text{m}$ (thickness)

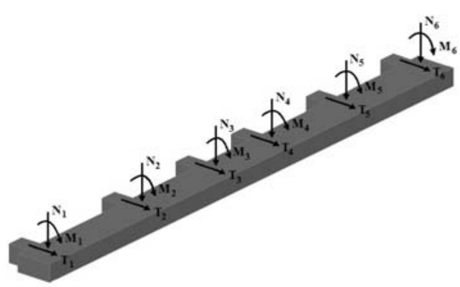
Soil 2 (clayey silt): $\gamma_{k_2} = 18.5\frac{\text{kN}}{\text{m}^3}$, $c_{u,k} = 80\text{kPa}$, $E_{k_2} = 32\text{MPa}$, $\nu_{k_2} = 0.5$ (undrained,) $OCR = 1$, $t_2 = 30\text{m}$

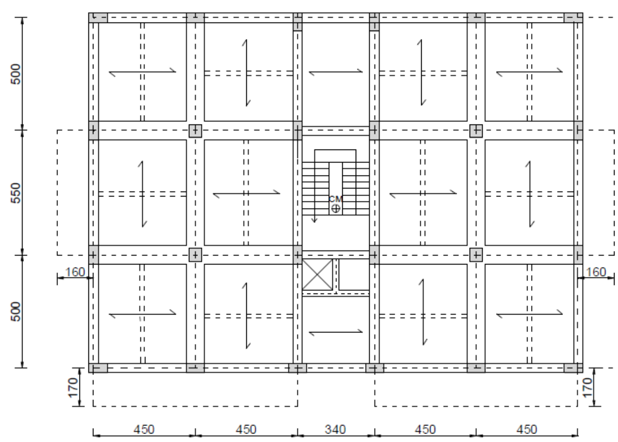
The foundation's embedment depth is $d_f = 1.5\text{m}$; groundwater is situated at $d_w = 2.5\text{m}$ below ground surface.

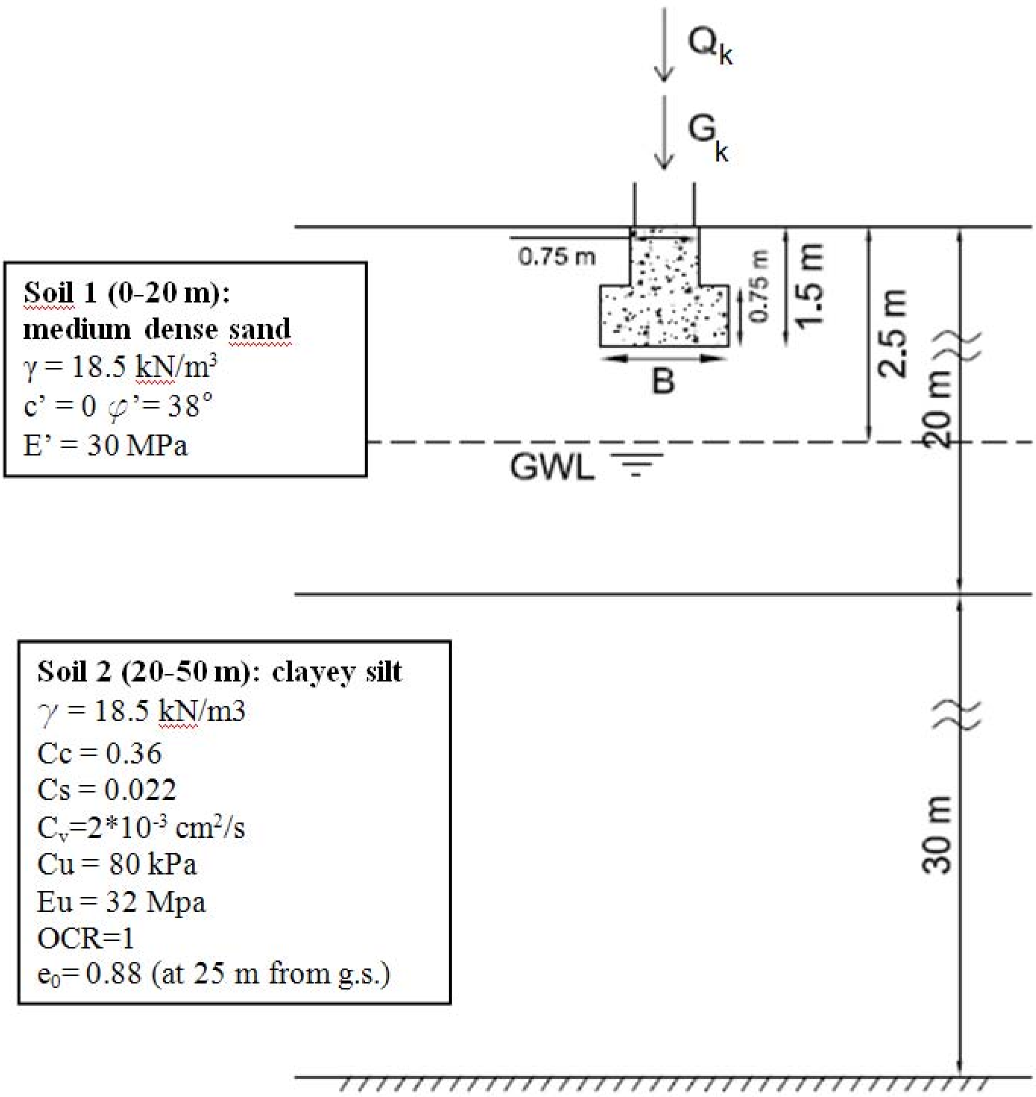
The characteristic weight density of reinforced concrete is $\gamma_{c,k} = 25\frac{\text{kN}}{\text{m}^3}$ and of groundwater $\gamma_{w,k} = 9.81\frac{\text{kN}}{\text{m}^3}$.











Geometry

Cross-sectional area of foundation is:

$$A = B \times 0.75\text{m} + 0.75\text{m}(1.5\text{m} - 0.75\text{m}) = 1.69\,\text{m}^2$$

Ultimate limit state

Actions

Self-weight of foundation:

$$W_{Gk} = \gamma_{c,k} \times L_x \times A = 902.8\,\text{kN}$$

Total characteristoic vertical actions:

$$\text{Permanent: } G_k = \sum G_k = 3500\,\text{kN}$$

$$\text{Variable: } Q_k = \sum Q_k = 966\,\text{kN}$$

Partial factors from Set A2: $\gamma_G = 1$ and $\gamma_Q = 1.3$

Design vertical force on foundation:

$$V_d = \gamma_G \times \left(G_k + W_{Gk}\right) + \gamma_Q \times Q_k = 5659\,\text{kN}$$

Material properties

Partial factors from Set M2: $\gamma_\varphi = 1.25$ and $\gamma_c = 1.25$

Design value of shearing resistance for Soil 1:

$$\varphi_d = \text{atan}\left(\frac{\tan(\varphi_k)}{\gamma_\varphi}\right) = 32°$$

Design value of effective cohesion for Soil 1:

$$c'_d = \frac{c'_k}{\gamma_c} = 0\,\text{kPa}$$

Bearing resistance

In this example, the lateral surcharge is not considered because the space between strip foundation is often used to create ventilated cavity to counteract rising humidity and create room for services and utilities.
Moreover, considering possible seasonal fluctuations. groundwater level is assumed at the base of foundation:

$$d_{w,d} = d_f = 1.5\,\text{m}$$

Design bearing capacity factors:

$$N_{q,d} = \overrightarrow{\left[e^{\pi\tan(\varphi_d)} \times \left(\tan\left(45° + \frac{\varphi_d}{2}\right)\right)^2\right]} = 23.2$$

$$N_{\gamma,d} = \overrightarrow{\left[2(N_{q,d} - 1) \times \tan(\varphi_d)\right]} = 27.7$$

Shape factors:

$$s_q = 1.0$$

$$s_\gamma = 1 - 0.3\frac{B}{L_x} = 0.979$$

Partial factor from Set R1: $\gamma_{Rv} = 1$

Design bearing resistance (in terms of pressure) is:

from overburden $q_{Rvq,d} = \overrightarrow{\left(\frac{\gamma_{k_1} \times d_f \times N_{q,d} \times s_q}{\gamma_{Rv}}\right)} = 643.7\,\text{kPa}$

from body-mass $q_{Rv\gamma,d} = \overrightarrow{\left[\frac{1}{2}\,\frac{B \times (\gamma_{k_1} - \gamma_{w,k}) \times N_{\gamma,d} \times s_\gamma}{\gamma_{Rv}}\right]} = 177\,\text{kPa}$

total $q_{Rv,d} = q_{Rvq,d} + q_{Rv\gamma,d} = 820.7\,\text{kPa}$

Giuseppe ignores q-term, so $q_{Rv,d} = q_{Rv\gamma,d} = 177\,\text{kPa}$

Characteristic bearing resistance (in terms of force) is:

$$R_d = q_{Rv,d} \times B \times L_x = 5682\,\text{kN}$$

Verifications

Verification of bearing resistance

'Degree of utilization' $\boxed{\Lambda = \frac{V_d}{R_d} = 100\,\%}$ or 'Overdesign factor' $\boxed{ODF = \frac{R_d}{V_d} = 1.0}$

The design is unacceptable if the degree of utilization is > 100% (or overdesign factor is < 1)

Serviceability limit state

Settlement calculation

A settlement calculation is required when the direct method is used. The SLS combinations of the actions require partial factors equal to 1 and design values of deformation parameters.

Partial factors on actions: $\gamma_G = \gamma_{G,SLS} = 1$ and $\gamma_Q = \gamma_{Q,SLS} = 1$

Partial factors on material parameters: $\gamma_\varphi = \gamma_{\varphi,SLS} = 1$ and $\gamma_c = \gamma_{c,SLS} = 1$

Immediate settlement

The immediate settlement can be calculated using elasticity theory. For the given soil stratigraphy, the first layer is characterised with drained deformation parameters whereas the second layer with undrained deformation parameters. There are $n = 4$ rows of strip foundation.

Bearing pressure underneath each foundation:

$$V_d = \gamma_G \times \left(G_k + W_{Gk}\right) + \gamma_Q \times Q_k = 5369\,\text{kN}$$

Total bearing pressure beneath building:

$$q_{Ed} = \frac{4V_d}{L_x \times L_y} = 64.7\,\text{kPa}$$

Distance to bottom of layer 1 is:

$$H_1 = t_1 = 20\,\text{m}$$

$$\frac{H_1}{L_y} = 1.29$$

Distance to bottom of layer 2 is:

$$H_2 = t_1 + t_2 = 50\,\text{m}$$

$$\frac{H_2}{L_y} = 3.23$$

Coefficients for elastic settlement calculations for each layer:

$$\mu_0 = \begin{pmatrix} 1.0 \\ 1.0 \end{pmatrix} \text{ and } \mu_1 = \begin{pmatrix} 0.5 \\ 0.7 \end{pmatrix}$$

Modulus of elasticity and Poisson's ratio for each layer:

$$E_k = \begin{pmatrix} 30 \\ 32 \end{pmatrix} \text{MPa and } \nu_k = \begin{pmatrix} 0.3 \\ 0.5 \end{pmatrix}$$

Immediate settlement is:

$$\text{Layer 1: } s_{0_1} = \mu_{0_1} \times \mu_{1_1} \times \left[\frac{1 - \left(\nu_{k_1}\right)^2}{E_{k_1}}\right] \times q_{Ed} \times L_y = 15.2\,\text{mm}$$

$$\text{Layer 2: } s_{0_2} = \mu_{0_2} \times \left(\mu_{1_2} - \mu_{1_1}\right) \times \left[\frac{1 - \left(\nu_{k_2}\right)^2}{E_{k_2}}\right] \times q_{Ed} \times L_y = 4.7\,\text{mm}$$

$$\text{Total: } s_0 = \sum s_0 = 19.9\,\text{mm}$$

Consolidation settlement

The consolidation settlement comes from delayed soil deformations in the second layer. It can be estimated as a fraction of the oedometric settlement. The calculation is carried out by dividing the second layer into sublayers. A stress increment and an initial void ratio is assigned to each layer. The stress increment induced by loads can be evaluated using the chart from Steinbrenner (which gives $\Delta\sigma z$ under the corner of a rectangular area with uniform pressure) beginning at a given depth D from the ground surface.