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Sample CPD Notes – by Professor Ian Smith

Geotechnical Design to Eurocode 7 – Worked examples

These are some of the completed examples from the above CPD course offered by Ian Smith.

Example 6.1: Bearing resistance: undrained

A continuous footing is 1.8 m wide by 0.5 m deep and is founded at a depth of 0.75 m in a clay soil of unit weight 20 kN/m^3 and c_u = 30 kPa. The foundation is to carry a vertical line load of magnitude 50 kN/m run, which will act at a distance of 0.4 m from the centre-line. Take the weight density of concrete as 24 kN/m^3.

Check the Eurocode 7 GEO limit state (Design Approach 1) by establishing the magnitude of the over-design factor.

Solution

Self-weight of foundation, $W_f = 0.5 \times 24 \times 1.8 = 21.6$ kN/m run

Weight of soil on top of foundation, $W_s = 0.25 \times 20 \times 1.8 = 9.0$ kN/m run

Total weight of foundation + soil, $W = 21.6 + 9.0 = 30.6$ kN/m run

From Table 9.1, for $\phi_u = 0°$, $N_c = 5.14$, $N_q = 1.0$, $N_\gamma = 0$.

Footing is continuous, i.e. $L \rightarrow \infty$; $s_c = 1.0$.

1. Combination 1 (partial factor sets A1 + M1 + R1)

From Table 5.1: $\gamma_{G;\,unfav} = 1.35$; $\gamma_Q = 1.5$; $\gamma_{cu} = 1.0$; $\gamma_{Rv} = 1.0$.

Design material property: $c_{u;d} = \frac{c_u}{\gamma_{cu}} = \frac{30}{1} = 30$ kPa

Design actions:

Weight of foundation, $W_d = W \times \gamma_{G;unfav} = 30.6 \times 1.35 = 41.3$ kN/m run

Applied line load, $P_d = P \times \gamma_{G;\,unfav} = 50 \times 1.35 = 67.5$ kN/m run

Effect of design actions:

Total vertical force, $F_d = 41.3 + 67.5 = 108.8$ kN/m run

Eccentricity, $e = \frac{P_d \times e_P}{P_d + W_d} = \frac{67.5 \times 0.4}{67.5 + 41.3} = 0.248$ m

Since $e \leq \frac{B}{6}$, the total force acts within the middle-third of the foundation.
Effective width of footing, $B' = 1.8 - 2 \times 0.248 = 1.3$ m

Design resistance:

Ultimate bearing capacity, $q_u = c_{u;d}N_cs_c + \gamma zN_q$

$= 30 \times 5.14 \times 1 + 20 \times 0.75 \times 1.0$

$= 169.2$ kPa

Ultimate bearing capacity per metre run, $Q_u = 169.2 \times 1.3 = 220$ kN/m run

Bearing resistance, $R_d = \frac{Q_u}{\gamma_{Rv}} = \frac{220}{1} = 220$ kN/m run

Over-design factor, $\Gamma = \frac{R_d}{F_d} = \frac{220}{108.8} = 2.03$

Since $\Gamma > 1$, the GEO limit state requirement is satisfied.

2. Combination 2 (partial factor sets A2 + M2 + R1)

The calculations are the same as for Combination 1 except that this time the following partial factors (from Table 5.1) are used: $\gamma_{G;\,unfav} = 1.0$; $\gamma_Q = 1.3$; $\gamma_{cu} = 1.40$; $\gamma_{Rv} = 1.0$.

$c_{u;d} = 21.4$ kPa

$W_d = 30.6 \times \gamma_{G;\,unfav} = 30.6$ kN/m run

$P_d = 50.0 \times \gamma_{G;\,unfav} = 50.0$ kN/m run

$F_d = 30.6 + 50.0 = 80.6$ kN/m run

$e = 0.248$ m; $B' = 1.3$ m

$Q_u = (c_{u;d} N_c s_c + \gamma z N_q) \times B' = 125.1 \times 1.3 = 163.1$ kN/m run

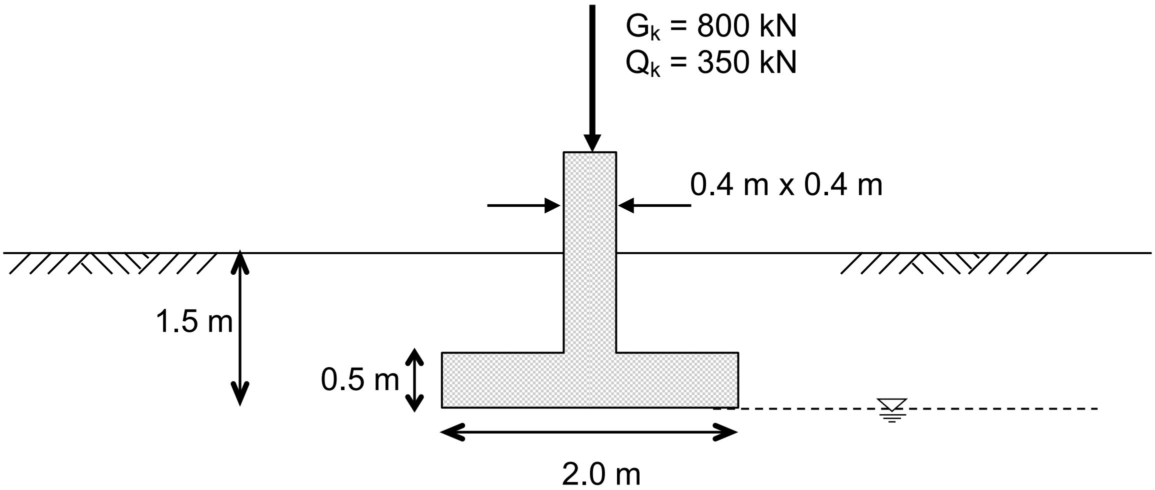
$$R_d = \frac{Q_u}{\gamma_{Rv}} = \frac{163.1}{1} = 163.1 \text{ kN/m run}$$

$$\Gamma = \frac{R_d}{F_d} = \frac{163.1}{80.6} = 2.02$$

Since $\Gamma > 1$, the GEO limit state requirement is satisfied.

Example 6.2: Bearing resistance: undrained and drained

It is proposed to place a 2 m × 2 m square footing at a depth of 1.5 m in a glacial clay soil as shown below. The 0.5 m thick footing is to support a 0.4 m × 0.4 m centrally located square column which will carry a vertical characteristic permanent load of 800 kN and a vertical characteristic transient load of 350 kN. Take the unit weight of reinforced concrete, $\gamma_{concrete}$ as 25 kN/m^3.



The soil has the following properties:

undrained shear strength, c_u = 200 kPa
effective cohesion, c' = 0 kPa
angle of shearing resistance, ϕ' = 28°
weight density, γ = 20 kN/m^3

The ground water table is coincident with the base of the foundation.

Check compliance of the bearing resistance limit state using Design Approach 1 for:

i. the *short-term* state;
ii. the *long-term* state;

Solution:

(i)Representative actions:

Self weight of concrete:

$$W_{concrete} = \left(B \times L \times t + B_{col} \times L_{col} \times \left(z - t\right)\right) \times \gamma_{concrete}$$

= [(2.0 × 2.0 × 0.5) + (0.4 × 0.4 × 1.0)] × 25

= 54.0 kN

Self weight of soil:

$$W_{soil} = (B \times L - B_{col} \times L_{col}) \times (z - t) \times \gamma_{soil}$$

= (2.0 × 2.0 – 0.4 × 0.4) × (1.5 – 0.5) × 20

= 76.8 kN

i/ short-term state

1. Combination 1 (partial factor sets A1 + M1 + R1)

From Table 5.1: $\gamma_{G,\,unfav}$ = 1.35; $\gamma_{G,\,fav}$ = 1.0; γ_Q = 1.5; γ_{cu} = 1.0; γ_γ = 1.0; γ_{Rv} = 1.0.

(ii)Design actions:

Design value of self weight of concrete and soil (unfavourable, permanent action):

$$W_d = (W_{concrete} + W_{soil}) \times \gamma_{G,unfav}$$

= (54.0 + 76.8) × 1.35 = 176.6 kN

Design value of the vertical structural (unfavourable) actions:

$V_d = V_G \times \gamma_{G,unfav} + V_Q \times \gamma_{Q,unfav}$ = (800 × 1.35) + (350 × 1.5) = 1605 kN

Design effect of actions (i.e. sum of vertical forces):

$F_d = W_d + V_d$ = 176.6 + 1605 = 1781.6 kN

Overburden pressure: $q = \gamma_{soil} z$ = 20 × 1.5 = 30 kPa

(iii) Design material properties:

Design cohesion: $c_{u;d} = \left(\dfrac{c_{u;k}}{\gamma_{cu}}\right) = \dfrac{200}{1}$ = 200 kPa

Design weight density of soil: $\gamma_d = \left(\dfrac{\gamma_k}{\gamma_\gamma}\right) = \dfrac{20}{1}$ = 20 kN/m^3

(iv) Design geometry:

No eccentric loading, ⇒ A' = B × L = 2.0 × 2.0 = 4.0 m^2
No inclined loading, ⇒ i_c = 1.0
Foundation base horizontal, ⇒ b_c = 1.0
s_c = 1.2 (EN 1997-1: 2004, Annex D)

(v) Bearing resistance:

$R / A' = (\pi+2)\ c_u\ b_c\ s_c\ i_c + q$

$R_k = 4.0 \times [(5.14 \times 200 \times 1.0 \times 1.2 \times 1.0) + 30] = 5054.4$ kN

$$R_d = \frac{R_k}{\gamma_{Rv}} = \frac{5054.4}{1.0} = 5054.4 \text{ kN}$$

From the results it is seen that the GEO limit state requirement is satisfied since the design bearing resistance (5054.4 kN) is greater than the design effects of actions (1781.6 KN).

Over-design factor, $\Gamma = \frac{R_d}{F_d} = \frac{5054.4}{1781.6} = 2.84$

2. Combination 2 (partial factor sets A2 + M2 + R1)

From Table 5.1: $\gamma_{G,\ unfav} = 1.0$; $\gamma_{G,\ fav} = 1.0$; $\gamma_Q = 1.3$; $\gamma_{cu} = 1.4$; $\gamma_\gamma = 1.0$; $\gamma_{Rv} = 1.0$.

(ii) Design actions:

Design value of self weight of concrete and soil (unfavourable, permanent action):

$$W_d = (W_{concrete} + W_{soil}) \times \gamma_{G,unfav}$$

$$= (54.0 + 76.8) \times 1.0 = 130.8 \text{ kN}$$

Design value of the vertical structural (unfavourable) actions:

$$V_d = V_G \times \gamma_{G,unfav} + V_Q \times \gamma_{Q,unfav} = (800 \times 1.0) + (350 \times 1.3) = 1255 \text{ kN}$$

Design effect of actions (i.e. sum of vertical forces):

$$F_d = W_d + V_d = 130.8 + 1255 = \underline{1385.8 \text{ kN}}$$

(iii) Design material properties:

Design cohesion: $c_{u;d} = \left(\frac{c_{u;k}}{\gamma_{cu}}\right) = \frac{200}{1.4} = 142.9$ kPa

Design weight density of soil: $\gamma_d = \left(\frac{\gamma_k}{\gamma_\gamma}\right) = \frac{20}{1} = 20$ kN/m^3

(iv) Design geometry:

No eccentric loading, $\Rightarrow$ A' = B $\times$ L = 2.0 $\times$ 2.0 = 4.0 m^2

No inclined loading, $\Rightarrow$ $i_c = 1.0$

Foundation base horizontal, $\Rightarrow$ $b_c = 1.0$

$s_c = 1.2$ (EN 1997-1: 2004, Annex D)

(v) Bearing resistance:

$$R / A' = (\pi+2)\, c_u\, b_c\, s_c\, i_c + q$$

$$R_k = 4.0 \times [(5.14 \times 142.9 \times 1.0 \times 1.2 \times 1.0) + 30] = 3645.6 \text{ kN}$$

$$R_d = \frac{R_k}{\gamma_{Rv}} = \frac{3645.6}{1.0} = 3645.6 \text{ kN}$$

GEO limit state requirement satisfied since design bearing resistance (3645.6 kN) > design effects of actions (1385.8 KN).

Over-design factor, $\Gamma = \dfrac{R_d}{F_d} = \dfrac{3645.6}{1385.8} = 2.63$

ii/ long-term state

The ground water level is taken as coincident with the ground surface (see Section 9.5.2 and EN 1997-1:2004 §2.4.6.1(11)).

(11) Unless the adequacy of the drainage system can be demonstrated and its maintenance ensured, the design ground-water table should be taken as the maximum possible level, which may be the ground surface.

EN 1997-1:2004 §2.4.6.1(11)

1. Combination 1 (partial factor sets A1 + M1 + R1)

From Table 5.1: $\gamma_{G,\,unfav} = 1.35$; $\gamma_{G,\,fav} = 1.0$; $\gamma_Q = 1.5$; $\gamma_{\phi'} = 1.0$; $\gamma_\gamma = 1.0$; $\gamma_{Rv} = 1.0$.

(ii) Design actions:

To consider the effects of the buoyant uplift, we can either use the submerged weight of the whole footing, or use the total weight and subtract the uplift force due to water pressure under foundation.

Design value of self weight of concrete and soil (unfavourable, permanent action):

$$W_d = (W_{concrete} + W_{soil}) \times \gamma_{G,unfav}$$

= (54.0 + 76.8) × 1.35 = 176.6 kN

Design value of the vertical structural (unfavourable) actions:

$V_d = V_G \times \gamma_{G,unfav} + V_Q \times \gamma_{Q,unfav}$ = (800 × 1.35) + (350 × 1.5) = 1605 kN

Design value of water pressure under the base (unfavourable (negative) action – from Single Source Principal):

$U_d = U \times \gamma_{G,unfav}$ = (-1.5 × 2.0 × 2.0 × 9.81) × 1.35 = -79.5 kN

Design effect of actions (i.e. sum of vertical forces):

$F_d = W_d + V_d + U_d$ = 176.6 + 1605 – 79.5 = 1702.1 kN

Overburden pressure: $q = \gamma_{soil} z$ = (20 – 9.81) × 1.5 = 15.29 kPa

(iii) Design material properties:

Design angle of shearing resistance: $\phi'_d = \tan^{-1}\left(\frac{\tan\phi'}{\gamma_{\phi'}}\right) = \tan^{-1}\left(\frac{\tan 28°}{1.0}\right)$ = 28°

Design weight density of soil: $\gamma_d = \left(\frac{\gamma_k}{\gamma_\gamma}\right) = \frac{20}{1}$ = 20 kN/m^3

(iv) Design geometry:

No eccentric loading, ⇒ A' = B × L = 2.0 × 2.0 = 4.0 m^2
No inclined loading, ⇒ i_c = 1.0
Foundation base horizontal, ⇒ b_c = 1.0

From EN 1997-1: 2004, Annex D:

$N_q = e^{\pi \cdot \tan\varphi'} \tan^2\left(45 + \frac{\varphi'}{2}\right)$ = 14.72

$N_\gamma = 2\,(N_q - 1)\tan\varphi'_d$ = 14.59

$s_q = 1 + \sin\varphi'$ = 1.47

$s_\gamma = 0.7$

(v) Bearing resistance:

$$R/A' = c'\,N_c\,b_c\,s_c\,i_c + q'\,N_q\,b_q\,s_q\,i_q + 0.5\,\gamma\,B'\,N_\gamma\,b_\gamma\,s_\gamma\,i_\gamma$$

R_k = 4.0 × [0 + (15.29 × 14.72 × 1.0 × 1.47 × 1.0) + (0.5 × (20 – 9.81) × 2.0 × 14.59 × 1.0 × 0.7 × 1.0)]

= 1738.8 kN

$$R_d = \frac{R_k}{\gamma_{Rv}} = \frac{1738.8}{1.0} = 1738.8 \text{ kN}$$

GEO limit state requirement satisfied since design bearing resistance (1738.8 kN) > design effects of actions (1702.1 KN).

Over-design factor, $\Gamma = \frac{R_d}{F_d} = \frac{1738.8}{1702.1} = 1.02$

2. Combination 2 (partial factor sets A2 + M2 + R1)

From Table 5.1: $\gamma_{G,\,unfav}$ = 1.0; $\gamma_{G,\,fav}$ = 1.0; γ_Q = 1.3; $\gamma_{\phi'}$ = 1.25; γ_γ = 1.0; γ_{Rv} = 1.0.

(ii) Design actions:

Again we use the total weight of the foundation and subtract the uplift force due to water pressure under foundation.

Design value of self weight of concrete and soil (unfavourable, permanent action):

$$W_d = \left(W_{concrete} + W_{soil}\right) \times \gamma_{G,unfav}$$

= (54.0 + 76.8) × 1.0 = 130.8 kN

Design value of the vertical structural (unfavourable) actions:

$V_d = V_G \times \gamma_{G,unfav} + V_Q \times \gamma_{Q,unfav}$ = (800 × 1.0) + (350 × 1.3) = 1255 kN

Design value of water pressure under the base (unfavourable (negative) action – from Single Source Principal):

$U_d = U \times \gamma_{G,unfav}$ = (-1.5 × 2.0 × 2.0 × 9.81) × 1.0 = -58.9 kN

Design effect of actions (i.e. sum of vertical forces):

$F_d = W_d + V_d + U_d$ = 130.8 + 1255 – 58.9 = 1326.9 kN

Overburden pressure: $q = \gamma_{soil} z$ = (20 – 9.81) × 1.5 = 15.29 kPa

(iii) Design material properties:

Design angle of shearing resistance: $\phi'_d = \tan^{-1}\left(\frac{\tan\phi'}{\gamma_{\phi'}}\right) = \tan^{-1}\left(\frac{\tan 28°}{1.25}\right)$ = 23°

Design weight density of soil: $\gamma_d = \left(\frac{\gamma_k}{\gamma_\gamma}\right) = \frac{20}{1}$ = 20 kN/m^3

(iv) Design geometry:

No eccentric loading, ⇒ A' = B × L = 2.0 × 2.0 = 4.0 m^2
No inclined loading, ⇒ i_c = 1.0
Foundation base horizontal, ⇒ b_c = 1.0

From EN 1997-1: 2004, Annex D:

$$N_q = e^{\pi \cdot \tan\varphi'} \tan^2\left(45 + \frac{\varphi'}{2}\right) = 8.7$$
$$N_\gamma = 2\,(N_q - 1)\tan\varphi'_d = 6.55$$

$$s_q = 1 + \sin\varphi' = 1.39$$
$$s_\gamma = 0.7$$

(v) Bearing resistance:

$$R / A' = c'\,N_c\,b_c\,s_c\,i_c + q'\,N_q\,b_q\,s_q\,i_q + 0.5\,\gamma\,B'\,N_\gamma\,b_\gamma\,s_\gamma\,i_\gamma$$

R_k = 4.0 × [0 + (15.29 × 8.7 × 1.0 × 1.39 × 1.0) + (0.5 × (20 – 9.81) × 2.0 × 6.55 × 1.0 × 0.7 × 1.0)]

= 926.5 kN

$$R_d = \frac{R_k}{\gamma_{Rv}} = \frac{926.5}{1.0} = 926.5 \text{ kN}$$

GEO limit state requirement NOT satisfied since design bearing resistance (926.5 kN) < design effects of actions (1326.9 KN).

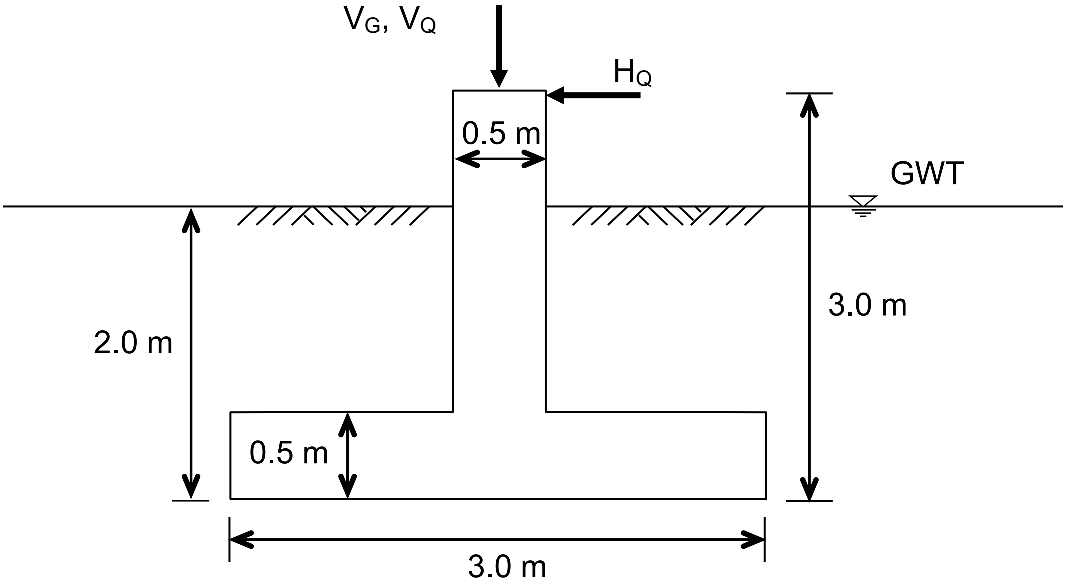
Over-design factor, $\Gamma = \frac{R_d}{F_d} = \frac{926.5}{1326.9} = 0.70$

This example illustrates the need to check the limit state requirements for both combinations and for both the undrained and the drained states. In this case, the footing is inadequately designed and the dimensions of the footing would have to be increased to ensure the requirements are met in all cases.

Example 6.3: Bearing resistance – vertical and horizontal loading

In accordance with Eurocode 7, Design Approach 2, check compliance of the bearing resistance limit state under drained conditions of the square pad foundation shown below.

The footing is supporting a concentric square column which is carrying both permanent and variable vertical loading, together with a transient horizontal load applied as shown.



The ground water table is coincident with the ground surface, and the following data is provided:

Characteristic vertical permanent load, $V_{G;k}$ =	800 kN
Characteristic vertical transient load, $V_{Q;k}$ =	400 kN
Weight density of soil, γ_{soil} =	19.0 kN/m^3
Effective cohesion, c' =	0 kPa
Angle of shearing resistance, ϕ' =	30°
Characteristic horizontal transient load, H_Q =	100 kN
Weight density of concrete, $\gamma_{concrete}$ =	24 kN/m^3

Solution:

- - end of free sample - -