Spread foundation design - EN 1997

This document shows a design calculation to obtain the width of foundation based on EN 1997 - Eurocode 7. In the calculation, the minimum width of fundation is calculated in order to satisfy ULS with 3 design approaches.

References:

- Workshop : Towards the Eurocodes era
  - EN 1997 - Eurocode 7 : Geotechnical design, section 3 and section 6
- Eurocode 7: Geotechnical Design Worked examples
- EN 1997

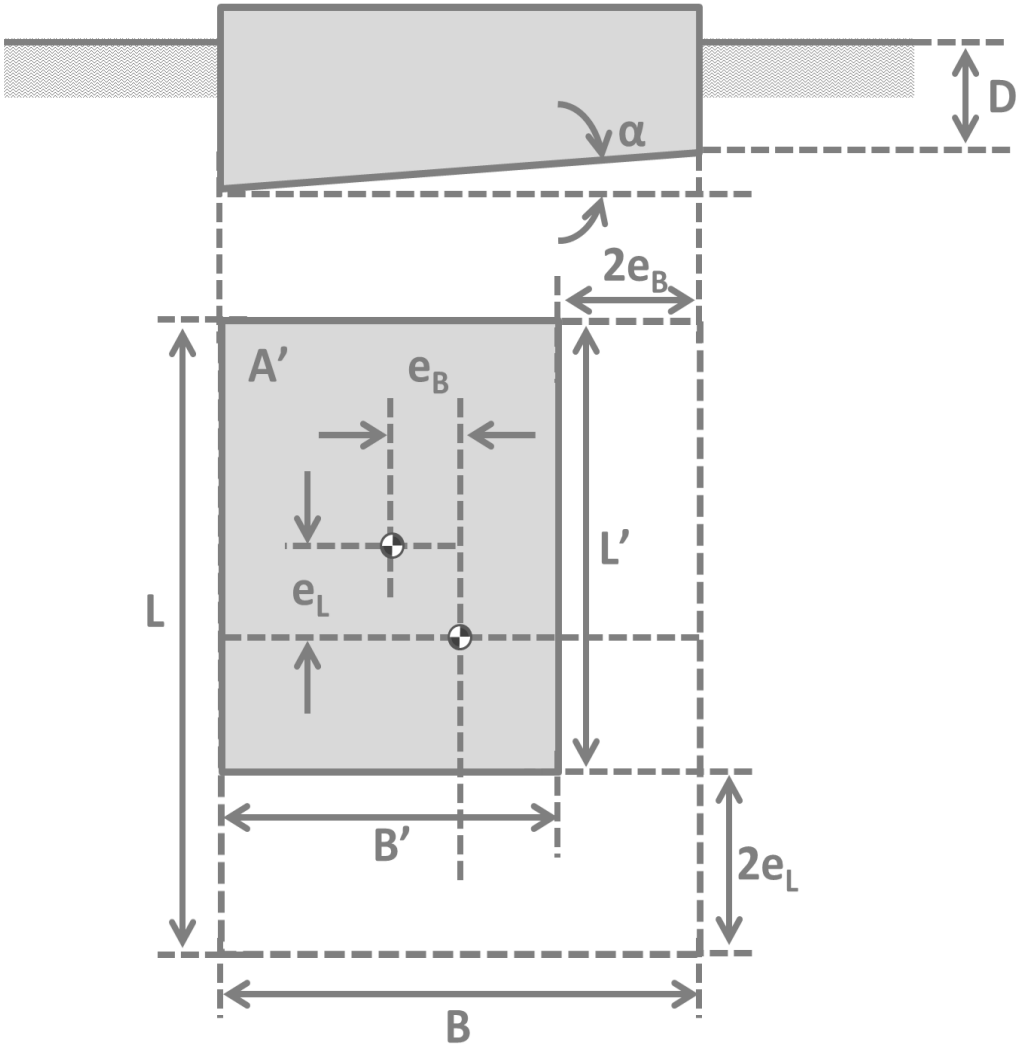

Figure 1 : Notation defined in EN 1997 Annex D

1. Design parameters and conditions

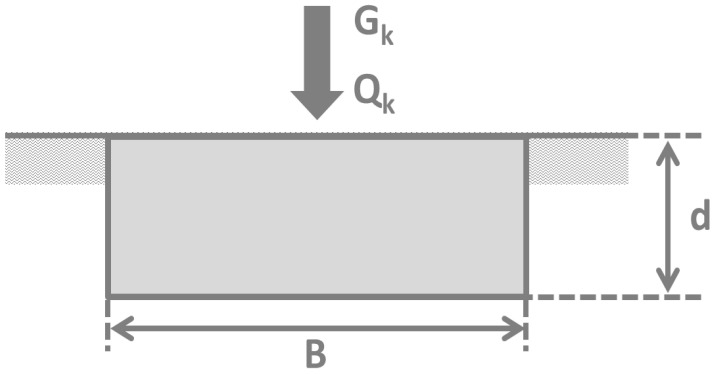

Figure 2 : Design situation / Square pad foundation

Value of actions

Permanent vertical load $G_k := 900\ \mathbf{kN}$

Variable vertical load $Q_k := 600\ \mathbf{kN}$

Concrete weight density $\gamma_c := 24\ \frac{\mathbf{kN}}{\mathbf{m^3}}$

Ground properties

Undrained shear strength $c_{u\_k} := 200\ \mathbf{kPa}$

Cohesion intersept $c_k := 0\ \mathbf{kPa}$

Angle of shearing resistance in terms of effective stress $\phi_k := 35\ \mathbf{deg}$

Soil weight density $\gamma_k := 22\ \frac{\mathbf{kN}}{\mathbf{m^3}}$

Horizontal load $H := 0$

Geometorical properties

Inclination of foundation base to the horizontal $\alpha := 0$

Height $d := 0.8\,\mathbf{m}$

Effective fundation area $A := (B \cdot \mathbf{m})^2$

2. ULS : Undrained conditions

2-0. Equation of undrained design bearing resistance

Reference : EN1997 Annex D

Equation to calculate Design bearing resistance

$$Eq_{undrained} := \frac{R_{u\_d}}{A} = \frac{(\pi + 2) \cdot c_{u\_d} \cdot b_c \cdot s_c \cdot i_c + q_{u\_d}}{\gamma_R}$$

Inclination of Foundation base

$$b_c := 1 - \frac{2 \cdot \alpha}{\pi + 2}$$

Shape of foundation

$$s_c := 1 + 0.2 \cdot \frac{B}{B} = 1.200$$

Inclination of the load by holizontal load

$$i_c := 0.5 \cdot \left(1 + \sqrt{1 - \frac{H}{A \cdot c_u}}\right)$$

Overburden pressure at the level of fundation base

$$q_{u\_d} := \gamma_k \cdot d$$

Design shear strength

$$c_{u\_d} := \frac{c_{u\_k}}{\gamma_{cu}}$$

2-1. Design Approach 1 - Combination 1 (A1 + M1 + R1)

A1 of partial factors on actions

Permanent action (unfavourable) $\gamma_G := 1.35$

Variable action (unfavourable) $\gamma_Q := 1.5$

M1 of partial factors for soil parameters

Undraied shear strength $\gamma_{cu} := 1.0$

R1 of partial resistance factors for spread foundations

Bearing $\gamma_R := 1.0$

Based on ULS design requirement

Design value of vertical action $V_{u\_d} := \gamma_G \cdot \left(G_k + G_{pad\_k} \right) + \gamma_Q \cdot Q_k$

Characteristic weight of concrete pad $G_{pad\_k} := A \cdot \gamma_c \cdot d$

Equation to calculate Design bearing resistance $Eq_{undrained} := \frac{R_{u\_d}}{A} = \frac{(\pi + 2) \cdot c_{u\_d} \cdot b_c \cdot s_c \cdot i_c + q_{u\_d}}{\gamma_R}$

Design value of bearing resistance $R_{u\_d\_sol} := \text{solve}\left(Eq_{undrained}, R_{u\_d} \right)$

Solve $V_d \leq R_d$, to get the mimum value of pad length $B_{u\_DA1\_1} := fsolve\left(R_{u\_d\_sol} = V_{u\_d}, B = 0..10 \right)$ m

$B_{u\_DA1\_1} = 1.314$ m

2-2. Design Approach 1 - Combination 2 (A2 + M2 + R1)

A1 of partial factors on actions

Permanent action (unfavourable) $\gamma_G := 1.0$

Variable action (unfavourable) $\gamma_Q := 1.3$

M2 of partial factors for soil parameters

Undraied shear strength $\gamma_{cu} := 1.4$

R1 of partial resistance factors for spread foundations

Bearing $\gamma_R := 1.0$

Based on ULS design requirement

Design value of vertical action $V_{u\_d} := \gamma_G \cdot \left(G_k + G_{pad\_k} \right) + \gamma_Q \cdot Q_k$

Characteristic weight of concrete pad $G_{pad\_k} := A \cdot \gamma_c \cdot d$

Equation to calculate Design bearing resistance $Eq_{undrained} := \dfrac{R_{u\_d}}{A} = \dfrac{(\pi + 2) \cdot c_{u\_d} \cdot b_c \cdot s_c \cdot i_c + q_{u\_d}}{\gamma_R}$

Design value of bearing resistance $R_{u\_d\_sol} := \text{solve}\left(Eq_{undrained}, R_{u\_d} \right)$

Solve $V_d \leq R_d$, to get the mimum value of pad length $B_{u\_DA1\_2} := \text{fsolve}\left(R_{u\_d\_sol} = V_{u\_d}, B = 0 \ldots 10 \right)$ m

$B_{u\_DA1\_2} = 1.382$ m

2-3. Design Approach 2 (A1 + M1 + R2)

A1 of partial factors on actions

Permanent action (unfavourable) $\gamma_G := 1.35$

Variable action (unfavourable) $\gamma_Q := 1.5$

M1 of partial factors for soil parameters

Undraied shear strength $\gamma_{cu} := 1.0$

R2 of partial resistance factors for spread foundations

Bearing $\gamma_R := 1.4$

Based on ULS design requirement

Design value of vertical action $V_{u\_d} := \gamma_G \cdot \left(G_k + G_{pad\_k} \right) + \gamma_Q \cdot Q_k$

Characteristic weight of concrete pad $G_{pad\_k} := A \cdot \gamma_c \cdot d$

Equation to calculate Design bearing resistance $Eq_{undrained} := \frac{R_{u\_d}}{A} = \frac{(\pi + 2) \cdot c_{u\_d} \cdot b_c \cdot s_c \cdot i_c + q_{u\_d}}{\gamma_R}$

Design value of bearing resistance $R_{u\_d\_sol} := \text{solve}\left(Eq_{undrained}, R_{u\_d} \right)$

Solve $V_d \leq R_d$, to get the mimum value of pad length $B_{u\_DA2} := \text{fsolve}\left(R_{u\_d\_sol} = V_{u\_d}, B = 0 \ldots 10 \right)$ **m**

$B_{u\_DA2} = 1.561$ **m**

2-4. Design Approach 3 (A1 + M2 + R3)

A1 of partial factors on actions

Permanent action (unfavourable) $\gamma_G := 1.35$

Variable action (unfavourable) $\gamma_Q := 1.5$

M2 of partial factors for soil parameters

Undraied shear strength $\gamma_{cu} := 1.4$

R3 of partial resistance factors for spread foundations

Bearing $\gamma_R := 1.0$

Based on ULS design requirement

Design value of vertical action $V_{u\_d} := \gamma_G \cdot \left(G_k + G_{pad\_k} \right) + \gamma_Q \cdot Q_k$

Characteristic weight of concrete pad $G_{pad\_k} := A \cdot \gamma_c \cdot d$

Equation to calculate Design bearing resistance $Eq_{undrained} := \dfrac{R_{u\_d}}{A} = \dfrac{(\pi + 2) \cdot c_{u\_d} \cdot b_c \cdot s_c \cdot i_c + q_{u\_d}}{\gamma_R}$

Design value of bearing resistance $R_{u\_d\_sol} := \text{solve}\left(Eq_{undrained}, R_{u\_d} \right)$

Solve $V_d \leq R_d$, to get the mimum value of pad length $B_{u\_DA3} := \text{fsolve}\left(R_{u\_d\_sol} = V_{u\_d}, B = 0 \ldots 10 \right)$ **m**

$B_{u\_DA3} = 1.556$ **m**

3. ULS : Drained conditions

3-0. Equation of drained design bearing resistance

Reference : EN1997 Annex D

Equation to calculate
Design bearing resistance

$$Eq_{drained} := \frac{R_{d\_d}}{A} = \frac{\left(c_d \cdot N_{c\_d} \cdot b_{c\_d} \cdot s_{c\_d} \cdot i_{c\_d} + q_{d\_d} \cdot N_{q\_d} \cdot s_{q\_d} \cdot i_{q\_d} + 0.5 \cdot \gamma_d \cdot (B \cdot \mathbf{m}) \cdot N_\gamma \cdot b_\gamma \cdot s_\gamma \cdot i_\gamma\right)}{\gamma_R}$$

Bearing resistance

$$N_{q\_d} := e^{\pi \cdot \tan\left(\phi_d\right)} \cdot \tan^2\left(45 \cdot \mathbf{deg} + \frac{\phi_d}{2}\right)$$

$$N_{c\_d} := \left(N_{q\_d} - 1\right) \cdot \cot\left(\phi_d\right)$$

$$N_\gamma := 2 \cdot \left(N_{q\_d} - 1\right) \cdot \tan\left(\phi_d\right)$$

Inclination of foundation base

$$b_{c\_d} := b_q - \frac{\left(1 - b_q\right)}{N_{c\_d} \cdot \tan\left(\phi_d\right)}$$

$$b_{q\_d} := \left(1 - \alpha \cdot \tan\left(\phi_d\right)\right)^2$$

$$b_\gamma := b_{q\_d}$$

Shape of foundation

$$s_{q\_d} := 1 + \left(\frac{B}{B}\right) \cdot \sin\left(\phi_d\right)$$

$$s_\gamma := 1 - 0.3 \cdot \left(\frac{B}{B}\right)$$

$$s_{c\_d} := \frac{s_{q\_d} \cdot N_{q\_d} - 1}{N_{q\_d} - 1}$$

Inclination of the load by holizontal load

$$i_{c\_d} := i_{q\_d} - \frac{\left(1 - i_{q\_d}\right)}{N_{c\_d} \cdot \tan\left(\phi_k\right)}$$

$$i_{q\_d} := \left(1 - \frac{H}{V + A \cdot c \cdot \cos\left(\phi_k\right)}\right)^{m_d}$$

$$i_{\gamma} := \left(1 - \frac{H}{V + A \cdot c \cdot \cos\left(\phi_k\right)}\right)^{m_d + 1}$$

$$m_d := \frac{2 + \left(\frac{B}{B}\right)}{1 + \left(\frac{B}{B}\right)}$$

Effective weight density of the soil

$$\gamma_d := \gamma_k - \gamma_w$$

$$\gamma_w := 9.81 \ \frac{\mathbf{kN}}{\mathbf{m^3}}$$

Effective oerburden pressure at the level of fundation base

$$q_{d\_d} := \gamma_d \cdot d = 9.752 \ \mathbf{kPa}$$

Design value of angle of shearing resistance

$$\phi_d := \arctan\left(\frac{\tan\left(\phi_k\right)}{\gamma_M}\right) = \arctan\left(\frac{0.700}{\gamma_M}\right)$$

Design value of cohision interseot

$$c_d := c_k$$

3-1. Design Approach 1 - Combination 1 (A1 + M1 + R1)

A1 of partial factors on actions

Permanent action (unfavourable) $\gamma_G := 1.35$

Variable action (unfavourable) $\gamma_Q := 1.5$

M1 of partial factors for soil parameters

Shearing resistance $\gamma_M := 1.0$

R1 of partial resistance factors for spread foundations

Bearing $\gamma_R := 1.0$

Based on ULS design requirement

Characteristic weight of concrete pad $G_{pad\_k} := A \cdot \left(\gamma_c - \gamma_w\right) \cdot d$

Design value of vertical action $V_{d\_d} := \gamma_G \cdot \left(G_k + G_{pad\_k}\right) + \gamma_Q \cdot Q_k$

Equation to calculate Design bearing resistance

$$Eq_{drained} := \frac{R_{d\_d}}{A} = \frac{\left(c_d \cdot N_{c\_d} \cdot b_{c\_d} \cdot s_{c\_d} \cdot i_{c\_d} + q_{d\_d} \cdot N_{q\_d} \cdot s_{q\_d} \cdot i_{q\_d} + 0.5 \cdot \gamma_d \cdot (B \cdot \mathbf{m}) \cdot N_\gamma \cdot b_\gamma \cdot s_\gamma \cdot i_\gamma\right)}{\gamma_R}$$

Design value of bearing resistance $R_{d\_d\_sol} := \text{solve}\left(Eq_{drained}, R_{d\_d}\right)$

Solve $V_d \leq R_d$, to get the mimum value of pad length $B_{d\_DA1\_1} := fsolve\left(R_{d\_d\_sol} = V_{d\_d}, B = 0..10\right)$ **m**

$B_{d\_DA1\_1} = 1.618$ **m**

3-2. Design Approach 1 - Combination 2 (A2 + M2 + R1)

A1 of partial factors on actions

Permanent action (unfavourable) $\gamma_G := 1.0$

Variable action (unfavourable) $\gamma_Q := 1.3$

M2 of partial factors for soil parameters

Shearing resistance $\gamma_M := 1.25$

R1 of partial resistance factors for spread foundations

Bearing $\gamma_R := 1.0$

Based on ULS design requirement

Characteristic weight of concrete pad $G_{pad\_k} := A \cdot (\gamma_c - \gamma_w) \cdot d$

Design value of vertical action $V_{d\_d} := \gamma_G \cdot (G_k + G_{pad\_k}) + \gamma_Q \cdot Q_k$

Equation to calculate Design bearing resistance

$$Eq_{drained} := \frac{R_{d\_d}}{A} = \frac{(c_d \cdot N_{c\_d} \cdot b_{c\_d} \cdot s_{c\_d} \cdot i_{c\_d} + q_{d\_d} \cdot N_{q\_d} \cdot s_{q\_d} \cdot i_{q\_d} + 0.5 \cdot \gamma_d \cdot (B \cdot \mathbf{m}) \cdot N_\gamma \cdot b_\gamma \cdot s_\gamma \cdot i_\gamma)}{\gamma_R}$$

Design value of bearing resistance $R_{d\_d\_sol} := \text{solve}(Eq_{drained}, R_{d\_d})$

Solve $V_d \leq R_d$, to get the mimum value of pad length $B_{d\_DA1\_2} := \text{fsolve}(R_{d\_d\_sol} = V_{d\_d}, B = 0..10)\ \mathbf{m}$

$B_{d\_DA1\_2} = 2.071\ \mathbf{m}$

3-3. Design Approach 2 (A1 + M1 + R2)

A1 of partial factors on actions

Permanent action (unfavourable) $\gamma_G := 1.35$

Variable action (unfavourable) $\gamma_Q := 1.5$

M1 of partial factors for soil parameters

Shearing resistance $\gamma_M := 1.0$

R2 of partial resistance factors for spread foundations

Bearing $\gamma_R := 1.4$

Based on ULS design requirement

Characteristic weight of concrete pad $G_{pad\_k} := A \cdot \left(\gamma_c - \gamma_w\right) \cdot d$

Design value of vertical action $V_{d\_d} := \gamma_G \cdot \left(G_k + G_{pad\_k}\right) + \gamma_Q \cdot Q_k$

Equation to calculate Design bearing resistance

$$Eq_{drained} := \frac{R_{d\_d}}{A} = \frac{\left(c_d \cdot N_{c\_d} \cdot b_{c\_d} \cdot s_{c\_d} \cdot i_{c\_d} + q_{d\_d} \cdot N_{q\_d} \cdot s_{q\_d} \cdot i_{q\_d} + 0.5 \cdot \gamma_d \cdot (B \cdot \mathbf{m}) \cdot N_\gamma \cdot b_\gamma \cdot s_\gamma \cdot i_\gamma\right)}{\gamma_R}$$

Design value of bearing resistance $R_{d\_d\_sol} := \text{solve}\left(Eq_{drained}, R_{d\_d}\right)$

Solve $V_d \leq R_d$, to get the mimum value of pad length $B_{d\_DA2} := \text{fsolve}\left(R_{d\_d\_sol} = V_{d\_d}, B = 0 \ldots 10\right) \mathbf{m}$

$B_{d\_DA2} = 1.867\ \mathbf{m}$

3-4. Design Approach 3 (A1 + M2 + R3)

A1 of partial factors on actions

Permanent action (unfavourable) $\gamma_G := 1.35$

Variable action (unfavourable) $\gamma_Q := 1.5$

M2 of partial factors for soil parameters

Shearing resistance $\gamma_M := 1.25$

R3 of partial resistance factors for spread foundations

Bearing $\gamma_R := 1.0$

Based on ULS design requirement

Characteristic weight of concrete pad $G_{pad\_k} := A \cdot (\gamma_c - \gamma_w) \cdot d$

Design value of vertical action $V_{d\_d} := \gamma_G \cdot (G_k + G_{pad\_k}) + \gamma_Q \cdot Q_k$

Equation to calculate Design bearing resistance

$$Eq_{drained} := \frac{R_{d\_d}}{A} = \frac{(c_d \cdot N_{c\_d} \cdot b_{c\_d} \cdot s_{c\_d} \cdot i_{c\_d} + q_{d\_d} \cdot N_{q\_d} \cdot s_{q\_d} \cdot i_{q\_d} + 0.5 \cdot \gamma_d \cdot (B \cdot \mathbf{m}) \cdot N_\gamma \cdot b_\gamma \cdot s_\gamma \cdot i_\gamma)}{\gamma_R}$$

Design value of bearing resistance $R_{d\_d\_sol} := \text{solve}(Eq_{drained}, R_{d\_d})$

Solve $V_d \leq R_d$, to get the mimum value of pad length $B_{d\_DA3} := \text{fsolve}(R_{d\_d\_sol} = V_{d\_d}, B = 0..10)\ \mathbf{m}$

$B_{d\_DA3} = 2.287\ \mathbf{m}$