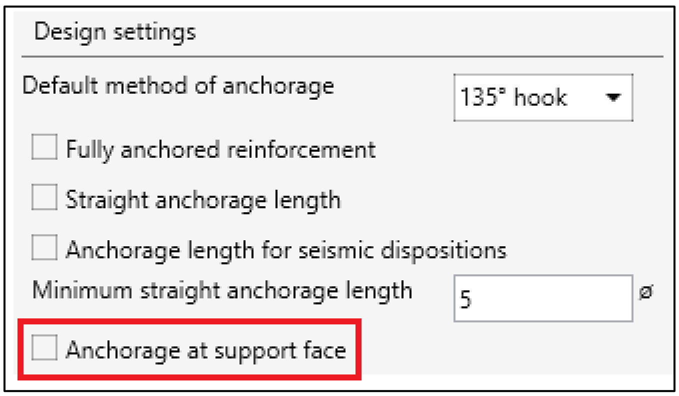
Anchorage length calculation

The Anchorage calculation is done according to §8.4 from EN 1992-1-1.

The assumptions considered in anchorage length calculation can be defined in Beam Reinforcement dialog, Anchorage tab.

To define the start point of the anchorage calculation over the end supports use option Anchorage at support face. If the option is checked the anchorage calculation start point will be the face of the support and if the option is unchecked the anchorage calculation start point will be at $s_0 \times \cot\theta$ from the face of the support.

In this example the option is unchecked the anchorage calculation start point will be at $s_0 \times \cot\theta$ from the face of the support.



Ultimate bond stress [§8.4.3 from EN 1992-1-1]

The design value of the ultimate bond stress, f_{bd}, for ribbed bars may be taken as §8.4.2(2) from EN 1992-1-1:

$$f_{bd} = 2.25 \times \eta_1 \times \eta_2 \times f_{ctd}$$

η_1 is a coefficient related to the quality of the bond condition and the position of the bar during concreting:

$\eta_1 = 1.0$ when 'good' conditions are obtained

$\eta_1 = 0.7$ for all other cases and for bars in structural elements built with slip-forms, unless it can be shown that 'good' bond conditions exist

η_2 is related to the bar diameter:

$$\eta_2 = 1.0 \text{ for } \phi \leq 32 \text{ mm}$$

$$\eta_2 = \frac{132 - \phi}{100} \text{ or } \phi > 32\,mm$$

f_{ctd} is the design value of concrete tensile strength according to 3.1.6 (2)P:

$$f_{ctd} = \alpha_{ct} \times \frac{f_{ctk,0.05}}{\gamma_c}$$

$$\gamma_c = 1.5$$

α_{ct} is a coefficient taking account of long term effects on the tensile strength and of unfavourable effects, resulting from the way the load is applied.

The value of α_{ct} for use in a Country may be found in its National Annex. The recommended value is 1,0. [§3.1.6 (2)P Note from EN 1992-1-1]

$f_{ctk,0.05} = 1.8\ \text{MPa}$ C25/30

$$f_{ctd} = \alpha_{ct} \times \frac{f_{ctk,0.05}}{\gamma_c} = 1.0 \times \frac{1.8}{1.5} = 1.2\ \text{MPa}$$

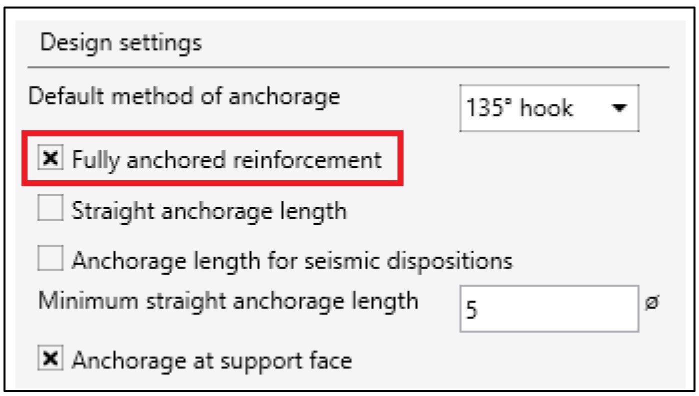
$$f_{bd} = 2.25 \times \eta_1 \times \eta_2 \times f_{ctd} = 2.25 \times 1.0 \times 1.0 \times 1.2 = 2.7\ \text{MPa}$$

Basic anchorage length [§8.4.3 from EN 1992-1-1]

$$l_{b,rqd} = \frac{\phi \times \sigma_{sd}}{4 \times f_{bd}}$$

Where σ_{sd} is the design stress of the bar at the position from where the anchorage is measured.

σ_{sd} is influenced by the option “Fully anchored reinforcement” in the ”Beam Reinforcement” dialog, ”Anchorage” tab.



If the option is checked the basic required anchorage length $l_{b,rqd}$ is determined considering design stress for the reinforcement in tension equal to f_{yd} or $k \times f_{yd}$ for an inclined stress-strain diagram.

If the option is unchecked the basic required anchorage length $l_{b,rqd}$ is determined considering the real anchorage effort.

In this example the option is checked so:

$$\sigma_{sd} = f_{yd} = 434.78\ \frac{\text{MN}}{\text{m}^2}$$

$$l_{b,rqd} = \frac{\phi \times \sigma_{sd}}{4 \times f_{bd}} = \frac{0.02 \times 434.78}{4 \times 2.7} = 0.805\ \text{m}$$

Design anchorage length[§8.4.4 from EN 1992-1-1]

$l_{bd} = \alpha_1 \times \alpha_2 \times \alpha_3 \times \alpha_4 \times \alpha_5 \times l_{b,rqd} \geq l_{b,min}$

α_1 is for the effect of the form of the bars assuming adequate cover

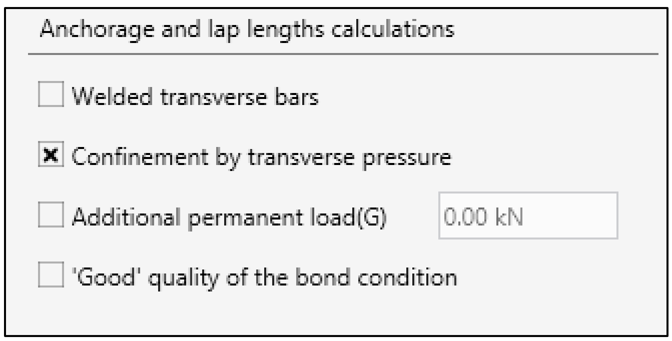
α_2 is for the effect of concrete minimum cover

α_3 is for the effect of confinement by transverse reinforcement

α_4 is for the influence of one or more welded transverse bars $\phi_t > 0.6 \times \phi$ along the design anchorage length l_{bd}

α_5 is for the effect of the pressure transverse to the plane of splitting along the design anchorage length

Assumptions that influence the values of these coefficients can be defined in the ”Anchorage and lap lengths calculations” section in the ”Beam Reinforcement” dialog, ”Anchorage” tab.



Using Welded transverse bars the user establish if the transverse reinforcement is welded or not, which will have an influence over α_4 coefficient.

Using Confinement by transverse pressure option the user is allowed to define the effect of transverse compression on bond, which will have an influence over bond length factor α_5 acording to the Table 8.2 from EN 1992-1-1.

$\alpha_5 = 1 - 0.04 \times p$

p transverse pressure [MPa] at ultimate limit state along l_{bd}.

By default, p = support reaction / support surface. But it is allowed to apply an additional charge in the edit-box of the option Additional permanent load(G) after checking it first.

$l_{b,min}$ is the minimum anchorage length if no other limitation is applied:

- for anchorages in tension: $l_{b,min} > \max\{0.3 \times l_{b,rqd}; 10 \times \phi; 100\text{ mm}\}$

- for anchorages in compression: : $l_{b,min} > \max\{0.6 \times l_{b,rqd}; 10 \times \phi; 100\text{ mm}\}$

$$l_{b,min} > \max\{0.3 \times l_{b,rqd}; 10 \times \phi; 100\text{ mm}\}$$
$$= \max\{0.3 \times 805; 10 \times 20; 100\text{ mm}\} = \max\{241.5; 200; 100\text{ mm}\} = 241.5\text{ mm}$$

Values of $\alpha_1, \alpha_2, \alpha_3, \alpha_4$ and $\alpha_5$coefficients

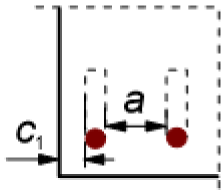
Table 8.2: Values of $\alpha_1, \alpha_2, \alpha_3, \alpha_4$ and α_5 coefficients

Influencing factor	Type of anchorage	Reinforcement bar	
		In tension	In compression
Shape of bars	Straight	$\alpha_1 = 1$	$\alpha_1 = 1$
	Other than straight see Figure 8.1 (b), (c) and (d)	$\alpha_1 = 0.7$ if Cd >3φ otherwise $\alpha_1 = 1$ (see Figure 8.3 for values of Cd)	$\alpha_1 = 1$
Concrete cover	Straight	α_2 = 1-0.15 (Cd - φ)/ φ ≥ 0.7 and ≤ 1.0	$\alpha_2 = 1$
	Other than straight see Figure 8.1 (b), (c) and (d)	α_2 = 1-0, 15 (Cd - 3φ)/ φ ≥ 0.7 and ≤ 1.0 (see Figure 8.3 for values of Cd)	$\alpha_2 = 1$
Confinement by transverse reinforcement not welded to main reinforcement	All types	α_3 = 1 - Kλ ≥ 0.7 and ≤ 1.0	$\alpha_3 = 1$
Confinement by welded transverse reinforcement*	All types, position and size as specified in Figure 8.1 (e)	$\alpha_4 = 0.7$	$\alpha_4 = 0.7$
Confinement by transverse pressure	All types	α_5 = 1 - 0.04p ≥ 0.7 and ≤ 1.0	--

where:

- $\lambda = (\sum A_{st} - \sum A_{st,min}) / A_s$
- $\sum A_{st}$: cross-sectional area of the transverse reinforcement along the design anchorage length l_{bd}
- $\sum A_{st,min}$: cross-sectional area of the minimum transverse reinforcement
  = 0,25 As for beams and 0 for slabs.
- A_s: area of a single anchored bar with maximum bar diameter
- K: values shown in Figure 8.4
- p: transverse pressure [MPa] at ultimate limit state along lbd

* See also 8.6: For direct supports, l_{bd} mai be taken less than $l_{b,min}$ provided that there is at least one transverse wire welded within the support. This should be at least 15 mm from the face of the support.



b) Bent or hooked bars

$c_d = \min(a/2, c_1)$

$$c_d = \min\left(\frac{a}{2}, c_1\right) = \min\left(\frac{86}{2}, 31\right) = 31 \text{ mm}$$

$$c_d < 3 \times \phi = 60\ mm \Rightarrow \alpha_1 = 1$$

$$0.7 \leq \alpha_2 = 1 - 0.15 \times \frac{c_d - 3 \times \phi}{\phi} \leq 1.0$$

$$0.7 \leq \alpha_2 = 1 - 0.15 \times \frac{31 - 60}{31} = 1.14 \leq 1.0 \Rightarrow \alpha_2 = 1.0$$

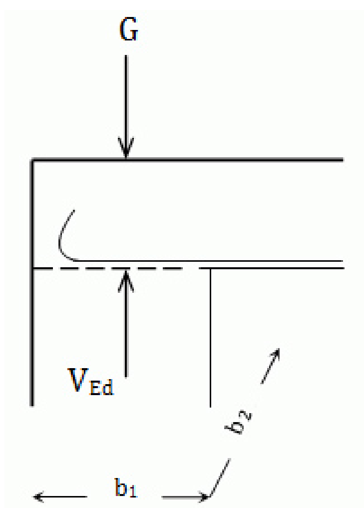
$\alpha_3 = 1$ considering no confinement by transverse reinforcement

$$\alpha_4 = 1$$

$$\alpha_5 = 1 - 0.04 \times p$$

$$p = \frac{V_{Ed}}{b_1^2} = \frac{478.79 \times 10^{-3}}{0.3^2} = 5.32 \frac{MN}{m^2}$$

where b_1 is the support width.



$$\alpha_5 = 1 - 0.04 \times p = 1 - 0.04 \times 5.32 = 0.8$$

$$l_{bd} = \alpha_1 \times \alpha_2 \times \alpha_3 \times \alpha_4 \times \alpha_5 \times l_{b,rqd} \geq l_{b,min}$$

$$l_{bd} = 1 \times 1 \times 1 \times 1 \times 0.8 \times 805 \geq 241.5$$

$$l_{bd} = 1 \times 1 \times 1 \times 1 \times 0.8 \times 805 \geq 241.5$$

$$l_{bd} = 644 \text{ mm}$$

Mandrel diameter calculation (§8.3 from EN 1992-1-1)

The minimum diameter to which a bar is bent shall be such as to avoid bending cracks in the bar, and to avoid failure of the concrete inside the bend of the bar. [§8.3.1(P) from EN 1992-1-1]

$$\phi_{m,min} \geq F_{bt} \times \frac{\frac{1}{a_b} + \frac{1}{2 \times \phi}}{f_{cd}}$$

where:

F_{bt} is the tensile force from ultimate loads in a bar or group of bars in contact at the start of a bend

a_b for a given bar (or group of bars in contact) is half of the centre-to-centre distance between bars (or groups of bars) perpendicular to the plane of the bend. For a bar or group of bars adjacent to the face of the member, ab should be taken as the cover plus ϕ / 2

$$F_{bt} = \pi \times \frac{\phi^2}{4} \times f_{yd} = \pi \times \frac{0.02^2}{4} \times 434.78 = 136.59 \text{ kN}$$

$$f_{cd} = 16.67 \frac{\text{MN}}{\text{m}^2}$$

- For a bar adjacent to the face of the beam: $a_b = 25 + 6 + \frac{20}{2} = 41 \text{ mm}$
- For an internal bar:

The spacing between the longitudinal bars is 69.3 mm

$$a_b = \frac{69.3}{2} = 34.7 \text{ mm}$$

For a bar adjacent to the face of the beam:

$$\phi_{m,min} \geq F_{bt} \times \frac{\frac{1}{a_b} + \frac{1}{2 \times \phi}}{f_{cd}} = 136.59 \times 10^{-3} \times \frac{\frac{1}{0.041} + \frac{1}{2 \times 20}}{16.67} = 0.200 \text{ m}$$

For an internal bar:

$$\phi_{m,min} \geq F_{bt} \times \frac{\frac{1}{a_b} + \frac{1}{2 \times \phi}}{f_{cd}} = 136.59 \times 10^{-3} \times \frac{\frac{1}{0.035} + \frac{1}{2 \times 20}}{16.67} = 0.234 \text{ m}$$

So the theoretical mandrel diameter will be considered $\phi_m = 25 \text{ cm}$.

The assumptions concerning the mandrel diameter can be defined in the ”Beam Reinforcement” dialog, ” Anchorage” tab.

This theoretical diameter will be used by the program when the user checks the option ”Calculated” and selects from the list ”Theoretical mandrel diameter”: