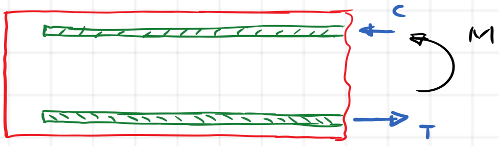
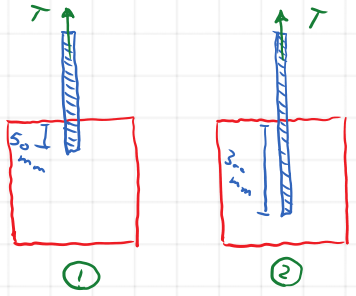
This video will teach us how to determine the anchorage length of the reinforced concrete element according to Eurocode 1992-1-1. The factors affecting the anchorage length and the concept behind it are reviewed. In the end, a straightforward example is provided to determine the required bar length.

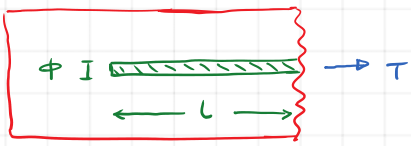
The example of the video:

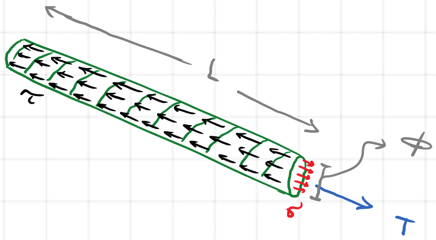
A simple beam with a length of 5 meters is with the class of C30/37 reinforced by 4T25 of class AH500. What is the minimum required length of the reinforcement?

Anchorage length :









$$\sigma = \frac{F}{A} = \frac{T}{\pi \times \phi^2/4}$$

$$\tau = \frac{F}{A} = \frac{T}{\pi \phi \cdot L}$$

If allowable axial stress in a rod is 300 Mpa & the allowable shear stress is 3 Mpa, determine the maximum tension that the rod can withstand?

$d_{bar} = 20mm$, $L = 600mm$

$$\sigma = 300 \text{ Mpa} = \frac{T}{\frac{\pi \times (20mm)^2}{4}} \rightarrow T \cong 94 \text{ kN}$$

$$\tau = 3 \text{ Mpa} = \frac{T}{\pi \times 20mm \times 600 mm} \rightarrow T \cong 113 \text{ kN}$$

$$T_{max} = \min\{T_{axial}, T_{shear}\} = \boxed{94 \text{ kN}}$$

$$\sigma = \frac{F}{A} = \frac{T}{\pi \times \phi^2/4} \longrightarrow T_{axial} = \sigma \cdot \frac{\pi \times \phi^2}{4}$$

$$\tau = \frac{F}{A} = \frac{T}{\pi \phi \cdot L} \longrightarrow T_{shear} = \tau \cdot \pi \times \phi \cdot L$$

To secure bond connection between concrete & reinforcement is valid,

$$T_{shear} \geq T_{axial} \Rightarrow$$

$$\tau \cdot \pi \times \phi \cdot L \geq \sigma \cdot \frac{\pi \times \phi^2}{4} \rightarrow \boxed{L \geq \frac{\sigma \cdot \phi}{4 \cdot \tau}}$$

$\sigma \rightarrow f_s \Rightarrow$ stress in reinforcement

$\tau \rightarrow f_{bd} \Rightarrow$ shear stress resistance (between concrete & reinforcement)

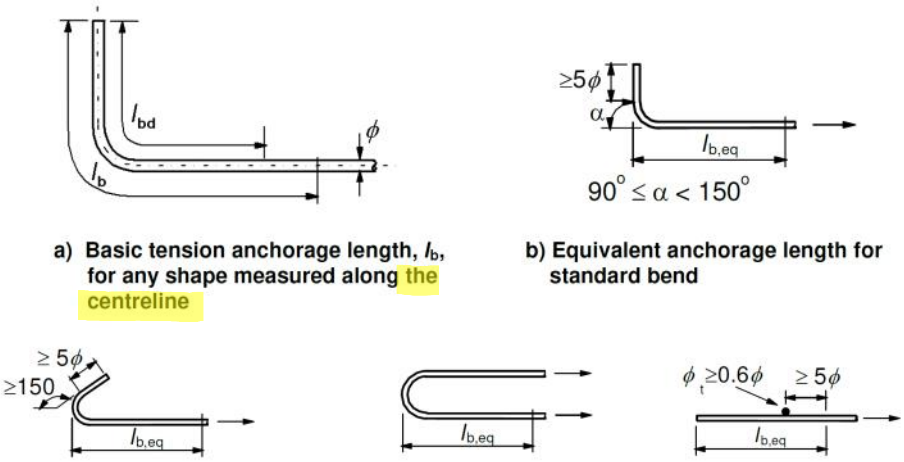
$$\boxed{L \geq \frac{f_s \cdot \phi}{4 f_{bd}}}$$

8.4 Anchorage of longitudinal reinforcement

8.4.1 General

(1)P Reinforcing bars, wires or welded mesh fabrics shall be so anchored that the bond forces are safely transmitted to the concrete avoiding longitudinal cracking or spalling. Transverse reinforcement shall be provided if necessary.

(2) Methods of anchorage are shown in Figure 8.1 (see also 8.8 (3)).



a) Basic tension anchorage length, l_b, for any shape measured along the centreline

b) Equivalent anchorage length for standard bend

c) Equivalent anchorage length for standard hook

d) Equivalent anchorage length for standard loop

e) Equivalent anchorage length for welded transverse bar

Figure 8.1: Methods of anchorage other than by a straight bar

8.4.2 Ultimate bond stress

(1)P The ultimate bond strength shall be sufficient to prevent bond failure.

(2) The design value of the ultimate bond stress, f_{bd}, for ribbed bars may be taken as:

$$f_{bd} = 2{,}25\ \eta_1\ \eta_2\ f_{ctd} \tag{8.2}$$

where:

f_{ctd} is the design value of concrete tensile strength according to 3.1.6 (2)P. Due to the increasing brittleness of higher strength concrete, $f_{ctk,0,05}$ should be limited here to the value for C60/75, unless it can be verified that the average bond strength increases above this limit

η_1 is a coefficient related to the quality of the bond condition and the position of the bar during concreting (see Figure 8.2):

$\eta_1 = 1{,}0$ when 'good' conditions are obtained and

$\eta_1 = 0{,}7$ 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:

$\eta_2 = 1{,}0$ for $\phi \leq 32$ mm

$\eta_2 = (132 - \phi)/100$ for $\phi > 32$ mm

3.1.6 Design compressive and tensile strengths

(2)P The value of the design tensile strength, f_{ctd}, is defined as

$$f_{ctd} = \alpha_{ct}\ f_{ctk,0,05} / \gamma_C \tag{3.16}$$

where:

γ_C is the partial safety factor for concrete, see 2.4.2.4, and

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.

Note: The value of α_{ct} for use in a Country may be found in its National Annex. The recommended value is 1,0.

Table 3.1 Strength and defo

Strength classes for concrete														Analytical relation / Explanation
f_{ck} (MPa)	12	16	20	25	30	35	40	45	50	55	60	70	80	90	
$f_{ck,cube}$ (MPa)	15	20	25	30	37	45	50	55	60	67	75	85	95	105	
f_{cm} (MPa)	20	24	28	33	38	43	48	53	58	63	68	78	88	98	$f_{cm} = f_{ck}+8$(MPa)
f_{ctm} (MPa)	1,6	1,9	2,2	2,6	2,9	3,2	3,5	3,8	4,1	4,2	4,4	4,6	4,8	5,0	$f_{ctm}=0,30\times f_{ck}^{(2/3)} \le$ C50/60 $f_{ctm}=2,12\cdot\ln(1+(f_{cm}/10))$ > C50/60
$f_{ctk,\,0,05}$ (MPa)	1,1	1,3	1,5	1,8	2,0	2,2	2,5	2,7	2,9	3,0	3,1	3,2	3,4	3,5	$f_{ctk;0,05} = 0,7\times f_{ctm}$ 5% fractile

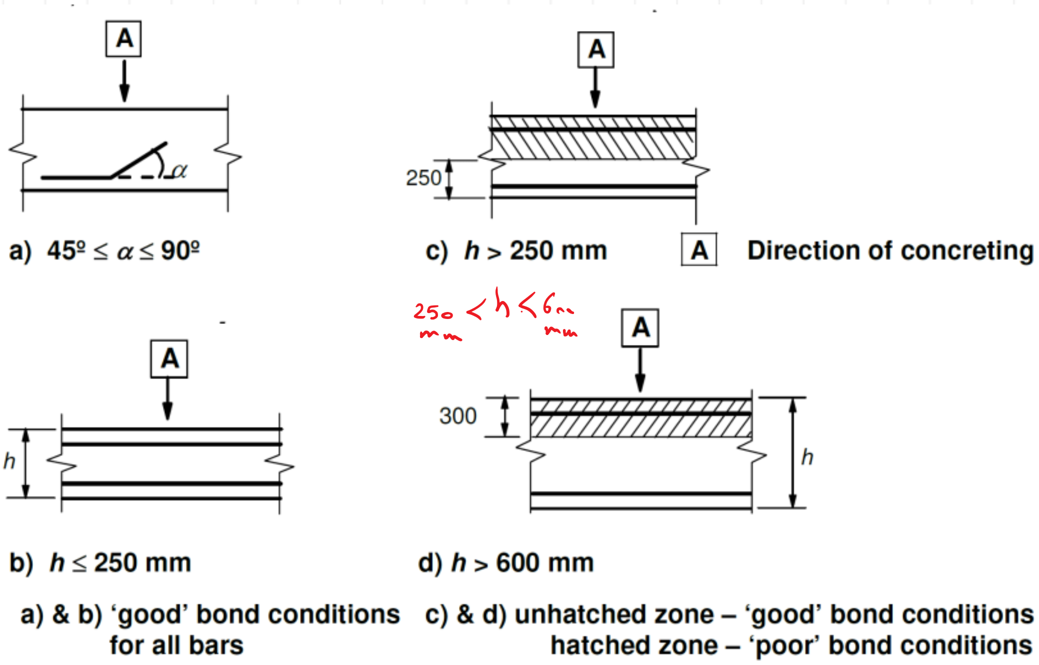


Figure 8.2: Description of bond conditions

8.4.3 Basic anchorage length

(1)P The calculation of the required anchorage length shall take into consideration the type of steel and bond properties of the bars.

(2) The basic required anchorage length, $l_{b,rqd}$, for anchoring the force $A_s\,\sigma_{sd}$ in a straight bar assuming constant bond stress equal to f_{bd} follows from:

$$l_{b,rqd} = (\phi / 4)\,(\sigma_{sd} / f_{bd}) \qquad (8.3)$$

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

Values for f_{bd} are given in 8.4.2.

(3) For bent bars the basic anchorage length, l_b, and the design length, l_{bd}, should be measured along the centre-line of the bar (see Figure 8.1a).

8.4.4 Design anchorage length

(1) The design anchorage length, l_{bd}, is:

$$l_{bd} = \alpha_1 \alpha_2 \alpha_3 \alpha_4 \alpha_5 \; l_{b,rqd} \geq l_{b,min} \quad (8.4)$$

where α_1 , α_2 , α_3, α_4 and α_5 are coefficients given in Table 8.2:

α_1 is for the effect of the form of the bars assuming adequate cover (see Figure 8.1).

α_2 is for the effect of concrete minimum cover (see Figure 8.3)

α_3 is for the effect of confinement by transverse reinforcement
α_4 is for the influence of one or more welded transverse bars ($\phi_t > 0,6\phi$) along the design anchorage length l_{bd} (see also 8.6)
α_5 is for the effect of the pressure transverse to the plane of splitting along the design anchorage length

The product $(\alpha_2\alpha_3\alpha_5) \geq 0,7$ (8.5)

$l_{b,rqd}$ is taken from Expression (8.3)
$l_{b,min}$ is the minimum anchorage length if no other limitation is applied:

- for anchorages in tension: $l_{b,min} > \max\{0,3 l_{b,rqd}; 10\phi; 100 \text{ mm}\}$ (8.6)
- for anchorages in compression: $l_{b,min} > \max\{0,6 l_{b,rqd}; 10\phi; 100 \text{ mm}\}$ (8.7)

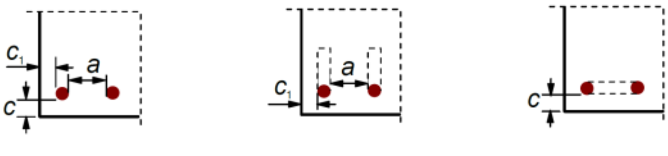
(2) As a simplified alternative to 8.4.4 (1) the tension anchorage of certain shapes shown in Figure 8.1 may be provided as an equivalent anchorage length, $l_{b,eq}$. $l_{b,eq}$ is defined in this figure and may be taken as:

- $\alpha_1 l_{b,rqd}$ for shapes shown in Figure 8.1b to 8.1d (see Table 8.2 for values of α_1)
- $\alpha_4 l_{b,rqd}$ for shapes shown in Figure 8.1e (see Table 8.2 for values of α_4).

where
α_1 and α_4 are defined in (1)
$l_{b,rqd}$ is calculated from Expression (8.3)

Table 8.2: Values of α_1, α_2, α_3, α_4 and α_5 coefficients

Influencing factor	Type of anchorage	Reinforcement bar: In tension	Reinforcement bar: In compression
Shape of bars	Straight	$\alpha_1 = 1,0$	$\alpha_1 = 1,0$
	Other than straight (see Figure 8.1 (b), (c) and (d)	$\alpha_1 = 0,7$ if $c_d > 3\phi$ otherwise $\alpha_1 = 1,0$ (see Figure 8.3 for values of c_d)	$\alpha_1 = 1,0$
Concrete cover	Straight	$\alpha_2 = 1 - 0,15 (c_d - \phi)/\phi$ $\geq 0,7$ $\leq 1,0$	$\alpha_2 = 1,0$
	Other than straight (see Figure 8.1 (b), (c) and (d))	$\alpha_2 = 1 - 0,15 (c_d - 3\phi)/\phi$ $\geq 0,7$ $\leq 1,0$ (see Figure 8.3 for values of c_d)	$\alpha_2 = 1,0$
Confinement by transverse reinforcement not welded to main reinforcement	All types	$\alpha_3 = 1 - K\lambda$ $\geq 0,7$ $\leq 1,0$	$\alpha_3 = 1,0$
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	$\alpha_5 = 1 - 0,04p$ $\geq 0,7$ $\leq 1,0$	-

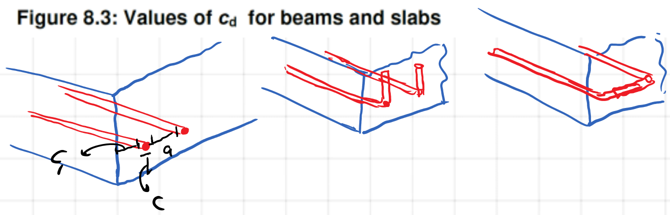


a) Straight bars $c_d = \min (a/2, c_1, c)$

b) Bent or hooked bars $c_d = \min (a/2, c_1)$

c) Looped bars $c_d = c$

Figure 8.3: Values of c_d for beams and slabs



where:

λ = $(\Sigma A_{st} - \Sigma A_{st,min})/ A_s$

ΣA_{st} cross-sectional area of the transverse reinforcement along the design anchorage length l_{bd}

$\Sigma A_{st,min}$ cross-sectional area of the minimum transverse reinforcement = 0,25 A_s 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 l_{bd}

* See also 8.6: For direct supports l_{bd} may 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.

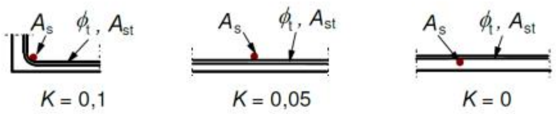
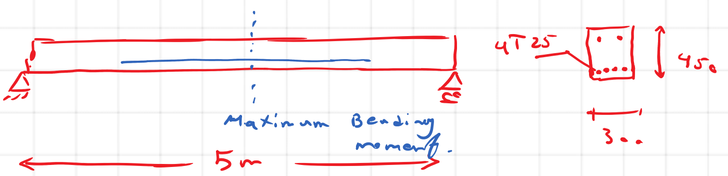


Figure 8.4: Values of K for beams and slabs

Assume the beam shown in the figure is made of concrete C30/37 and is designed with 4T25. Determine the required minimum reinforcement length?

C30/37, 4T25



$$L_{b,rqd} = \frac{\phi}{4} \cdot \frac{\sigma_{sd}}{f_{bd}}$$

$$f_{bd} = 2.25\, \eta_1 \cdot \eta_2 \cdot f_{ctd}$$

Good bond condition → $\eta_1 = 1$

$\phi = 20\,mm \leq 32\,mm$ → $\eta_2 = 1$

$\sigma_{sd} = f_{yd}$

AH500, B500

$f_y = 500\,Mpa$

$$f_{yd} = \frac{f_y}{\gamma_s} = \frac{500\,Mpa}{1.15} = 435\,Mpa$$

$\phi = 20\,mm$ $\quad f_{bd} = ?$

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

α_{ct} → 1, $f_{ctk,0.05}$ → 2 Mpa, γ_c → 1.5

$f_{ctd} = 1.33\,Mpa$

$$f_{bd} = 2.25\, \eta_1 \cdot \eta_2 \cdot f_{ctd} = 3\,Mpa$$

$$L_{b,rqd} = \frac{\phi}{4} \times \frac{f_{yd}}{f_{bd}} = \frac{20\,mm}{4} \times \frac{435\,Mpa}{3\,Mpa} = 725\,mm$$

Straight bar → $\alpha_1 = 1$

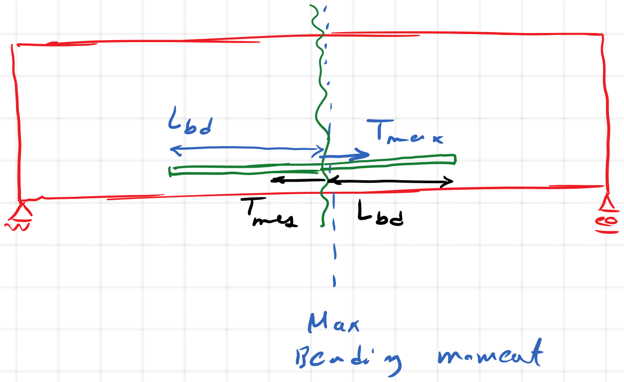
$\alpha_2 = 1$

$\alpha_3, \alpha_4, \alpha_5 = 1$

$$l_{b,d} = \alpha_1 \alpha_2 \alpha_3 \alpha_4 \alpha_5 \, l_{b,rqd} \geq l_{b,min} = \max\{0.3\, l_{b,rqd},\ 10\phi,\ 100\,mm\}$$

(217.5 mm, 200 mm)

$L_{bd} = 725\,mm \geq 217.5\,mm$ (OK)



$\min L = 2 \times l_{bd} = 2 \times 725 = 1450\,mm$