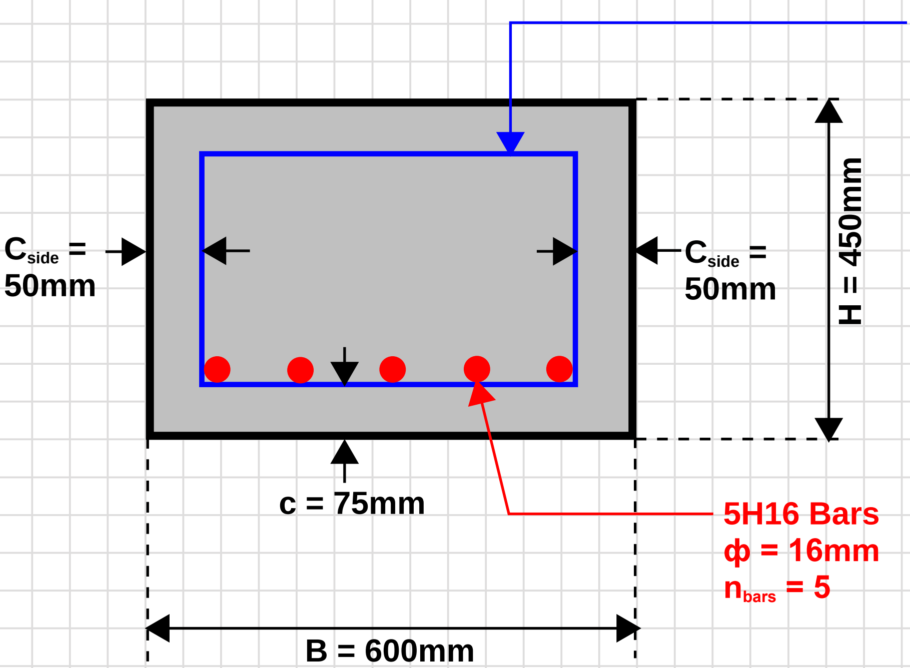
	Design Spreadsheet: **Concrete Anchorage and Mandrel Diameter**	**Date:13/11/2023**
	Subtitle: **Example 1**	**By: AL**
		Version: 1

Overview

RC Beam Cross Section



Concrete Grade C28/35

Characteristic Concrete Compressive Cylinder Strength
f_{ck} = 28N/mm^2

Aggregate Type: Limestone

Characteristic Yield Strength of Reinforcement
f_{yk} = 500N/mm^2 (typical)

Applied ULS Moment
M_{Ed} = 125kNm (sagging)

Tensile Design of RC Beam

Depth to Reinforcement d = H - c - ϕ_{links} - (ϕ/2)
Depth to Reinforcement d = 450mm - 75mm - 10mm - (16mm / 2)
Depth to Reinforcement d = 357mm

Design yield strength of reinforcement $f_{yd} = f_{yk} / \gamma_s$
Design yield strength of reinforcement f_{yd} = 500N/mm^2 / 1.15
Design yield strength of reinforcement f_{yd} = 435N/mm^2
Where γ_s is the material safety factor from BS EN1992-1-1 Section 2.4.2.4 Table 2.1N

Clear spacing between reinforcing bars S_{clear} = [B - (2 * c_{side}) - (2 * ϕ_{links}) - (n_{bars} * ϕ)] / [n_{bars} - 1]
Clear spacing between reinforcing bars S_{clear} = [600mm - (2 * 50mm) - (2 * 10mm) - (5 * 16mm)] / [5 - 1]
Clear spacing between reinforcing bars S_{clear} = 100mm

Centreline spacing between reinforcing bars S = S_{clear} + ϕ
Centreline spacing between reinforcing bars S = 100mm + 16mm
Centreline spacing between reinforcing bars S = 116mm

K Factor for Bending = M_{Ed} / (f_{ck} * B * d^2)
K Factor for Bending = 125x10^6 Nmm / (28N/mm^2 * 600mm * [357mm]^2)
K Factor for Bending = 0.05838

$$Z = min\left(0.95d\ ;\ d * \left[0.5 + \sqrt{0.25 - \frac{3K}{3.4}}\right]\right)$$

$$Z = min\left(0.95 * 357mm\ ;\ 357mm * \left[0.5 + \sqrt{0.25 - \frac{3 * 0.05838}{3.4}}\right]\right)$$

$$Z = min(339.15mm\ ;\ 337.551mm)$$

Lever Arm Z = 337.551mm

Tensile Design of RC Beam Continued

Area of Steel Required to resist moment $A_{s,req1}$

$$A_{s,req1} = \frac{M_{Ed}}{\frac{1}{\gamma_s} * f_{yk} * Z}$$

γ_s = 1.15 from BS EN1992-1-1 Section 2.4.2.4 Table 2.1N for persistent and transient loading conditions

$$A_{s,req1} = \frac{125x10^6 Nmm}{\frac{1}{1.15} * 500\frac{N}{mm^2} * 337.551mm}$$

$A_{s,req1} = 851.723mm^2$

Minimum Area of Steel Required $A_{s,min}$

$$A_{s,min} = max\left(0.26\frac{f_{ctm}}{f_{yk}} \; ; \; 0.0013\right) * B * d$$

$$A_{s,min} = max\left(0.26\frac{2.766\frac{N}{mm^2}}{500\frac{N}{mm^2}} \; ; \; 0.0013\right) * 600mm * 357mm$$

$A_{s,min} = 308.1mm^2$

UK National Annex to BS EN1992-1-1 Clause 9.2.1.1(1)

f_{ctm} from BS EN1992-1-1 Table 3.1 (Calculated later in this worked example as part of the concrete properties)

Area of Steel Required (final) $A_{s,req} = max(A_{s,req1} ; A_{s,min})$
Area of Steel Required (final) $A_{s,req} = max(851.724mm^2 ; 307.1mm^2)$
Area of Steel Required (final) $A_{s,req} = 851.724mm^2$

Maximum Area of Steel Allowed $A_{s,max}$ = 0.04 * B * H
Maximum Area of Steel Allowed $A_{s,max}$ = 0.04 * 600mm * 450mm
Maximum Area of Steel Allowed $A_{s,max} = 10800mm^2$

UK National Annex to BS EN1992-1-1 Clause 9.2.1.1(3)

Area of Steel Provided $A_{s,prov} = \pi * \phi^2 * 0.25 * n_{bars}$
Area of Steel Provided $A_{s,prov} = \pi * (16mm)^2 * 0.25 * 5$ bars
Area of Steel Provided $A_{s,prov} = 1005mm^2$

Utility = max($A_{s,req} / A_{s,prov}$; $A_{s,prov} / A_{s,max}$)
Utility = max($851.724mm^2 / 1005mm^2$; $1005mm^2 / 10800mm^2$)
Utility = max(84.7% ; 9.3%)
Utility = 84.7% --> OK

ULS Tensile Stress in Reinforcement $\sigma_{sd} = (A_{s,req1} / A_{s,prov}) * f_{yk} * (1/\gamma_s)$
ULS Tensile Stress in Reinforcement $\sigma_{sd} = (851.724mm^2 / 1005mm^2) * 500N/mm^2 * (1 / 1.15)$
ULS Tensile Stress in Reinforcement $\sigma_{sd} = 368.5N/mm^2$

Area of a single reinforcing bar $A_s = \pi * \phi^2 * 0.25$
Area of a single reinforcing bar $A_s = \pi * (16mm)^2 * 0.25$
Area of a single reinforcing bar $A_s = 201mm^2$

ULS Force in a single bar $F_{bt} = \sigma_{sd} * A_s$
ULS Force in a single bar $F_{bt} = 368.5N/mm^2 * 201mm^2$
ULS Force in a single bar F_{bt} = 74068.5N = 74.06kN

	Design Spreadsheet: Concrete Anchorage and Mandrel Diameter	Date: 13/11/2023
	Subtitle: Example 1	By: AL
		Version: 1

Calculating Concrete Properties

Concrete grade: C28/35
Characteristic Concrete Cylinder Strength f_{ck} = 28N/mm^2
Characteristic Concrete Cube Strength $f_{ck,cube}$ = 35N/mm^2

BS EN1992-1-1 Table 3.1

Mean Compressive Stress $f_{cm} = f_{ck}$ + 8N/mm^2
Mean Compressive Stress f_{cm} = 28N/mm^2 + 8N/mm^2
Mean Compressive Stress f_{cm} = 36N/mm^2

BS EN1992-1-1 Table 3.1

Mean Tensile Strength
$f_{ctm} = 0.3f_{ck}^{(2/3)}$ for concrete grades ≤ C50/60
$f_{ctm} = 2.12\ln[\ 1 + (f_{cm}/10)]$ for concrete grades > C50/60

Mean Tensile Strength
f_{ctm} = 0.3 * (28N/mm^2)$^{2/3}$
f_{ctm} = 2.766N/mm^2

BS EN1992-1-1 Table 3.1

5% Fractile Tensile Strength $f_{ctk,0.05} = 0.7 * f_{ctm}$
5% Fractile Tensile Strength $f_{ctk,0.05}$ = 0.7 * 2.766N/mm^2
5% Fractile Tensile Strength $f_{ctk,0.05}$ = 1.936N/mm^2

Mean Modulus of Elasticity $E_{cm} = 22[f_{cm}/10]^{0.3}$
Mean Modulus of Elasticity E_{cm} = 22[36N/mm^2 / 10]$^{0.3}$
Mean Modulus of Elasticity E_{cm} = 32.3082GPa = 32308.2N/mm^2

BS EN1992-1-1 Table 3.1

However there is also a reduction based on the aggregate used
Quartzite Aggregate = Use 100% of previous value
Limestone Aggregate = Use 90% of previous value
Sandstone Aggregate = Use 70% of previous value
Basalt Aggregate = Use 120% of previous value

We have a limestone aggregate so the final Mean Modulus of Elasticity is:
E_{cm} = 90% of 32308.2N/mm^2 = 29077.4N/mm^2

BS EN1992-1-1 Section 3.1.3(2)

Coefficient Taking into account long terms effects on compressive strength α_{cc} = 0.85
(0.85 for compression in flexure i.e. a beam)

UK National Annex to BS EN1992-1-1 Table NA.1 Clause 3.1.6(1)P

Coefficient Taking into account long terms effects on Tensile strength α_{ct} = 1.00

UK National Annex to BS EN1992-1-1 Table NA.1 Clause 3.1.6(2)P

Material Safety Factor for Concrete γ_c = 1.5

BS EN1992-1-1 Section 2.4.2.4 Table 2.1N for persistent and transient loading conditions

---

Design Concrete Compressive Stress $f_{cd} = \alpha_{cc} * f_{ck} / \gamma_c$
Design Concrete Compressive Stress f_{cd} = 0.85 * 28N/mm^2 / 1.5
Design Concrete Compressive Stress f_{cd} = 15.86N/mm^2

BS EN1992-1-1 Section 3.1.6 Equation 3.15

Calculating Concrete Properties (Continued)

Design Concrete Tensile Stress $f_{ctd} = \alpha_{ct} * f_{ctk,0.05} / \gamma_c$
Design Concrete Tensile Stress f_{ctd} = 1.0 * 1.936N/mm^2 / 1.5
Design Concrete Tensile Stress f_{ctd} = 1.291N/mm^2

BS EN1992-1-1 Section 3.1.6 Equation 3.16

Ultimate Bond Stress

Type of Loading on the reinforcing bars = Tension

This is because we're looking at the bottom of a beam in bending i.e. the tensile zone
The type of loading affects 2 main things in the anchorage calculation:
- The equation for the minimum anchorage which is more onerous for a bar in compression
- Influence factors α_1, α_2, α_3, α_4 & α_5 which are more onerous for a bar in compression

---

ULS Force on a single bar F_{bt} = 74.06kN (calculated previously as part of beam assessment)

Ultimate Stress on the bar σ_{sd} = 368.5N/mm^2 (calculated previously as part of beam assessment)

Bond condition between the rebar and the concrete = Good
The bond condition has a detrimental impact on the ultimate bond stress if a poor bond is adopted. A good bond condition can be obtained by avoiding slip forms and by ensuring concrete is poured in one hit for slabs and beams and not in layers. Refer to Figure 8.2 and BS EN1992-1-1 for more information.

Coefficient Accounting for Bond Condition:
η_1 = 1.0 for good bond and 0.7 for poor bond
η_1 = 1.0 in this example as we have a good bond condition

BS EN1992-1-1 Section 8.4.2(2)

Coefficient Accounting for Bar Diameter:
η_2 = 1.0 for $\phi \leq$ 32mm
η_2 = (132 - ϕ) / 100 for ϕ > 32mm

Our bar diameter is 16mm (ϕ = 16mm)
η_2 = 1.0

BS EN1992-1-1 Section 8.4.2(2)

Ultimate Bond Stress $f_{bd} = 2.25 * \eta_1 * \eta_2 * f_{ctd}$
Ultimate Bond Stress f_{bd} = 2.25 * 1.0 * 1.0 * 1.291N/mm^2
Ultimate Bond Stress f_{bd} = 2.904N/mm^2

BS EN1992-1-1 Section 8.4.2(2) Equation 8.2

Basic Anchorage Length

Basic Anchorage Length $L_{b,rqd} = (ф / 4) * (σ_{sd} / f_{bd})$
Basic Anchorage Length $L_{b,rqd}$ = (16mm / 4) * (368.5N/mm^2 / 2.904N/mm^2)
Basic Anchorage Length $L_{b,rqd}$ = 507.57mm = 508mm

BS EN1992-1-1 Section 8.4.3(2) Eq - 8.3

Minimum Anchorage Length

$L_{b,min}$ = max{ 0.3$L_{b,rqd}$; 10ф ; 100mm} for bars in tension
$L_{b,min}$ = max{ 0.6$L_{b,rqd}$; 10ф ; 100mm} for bars in compression (more onerous)

Our reinforcement is in tension
$L_{b,min}$ = max{ 0.3 * 508mm ; 10 * 16mm ; 100mm}
$L_{b,min}$ = max{ 152.4mm ; 160mm ; 100mm}
$L_{b,min}$ = 160mm

BS EN1992-1-1 Section 8.4.4(1) Eq - 8.6 & 8.7

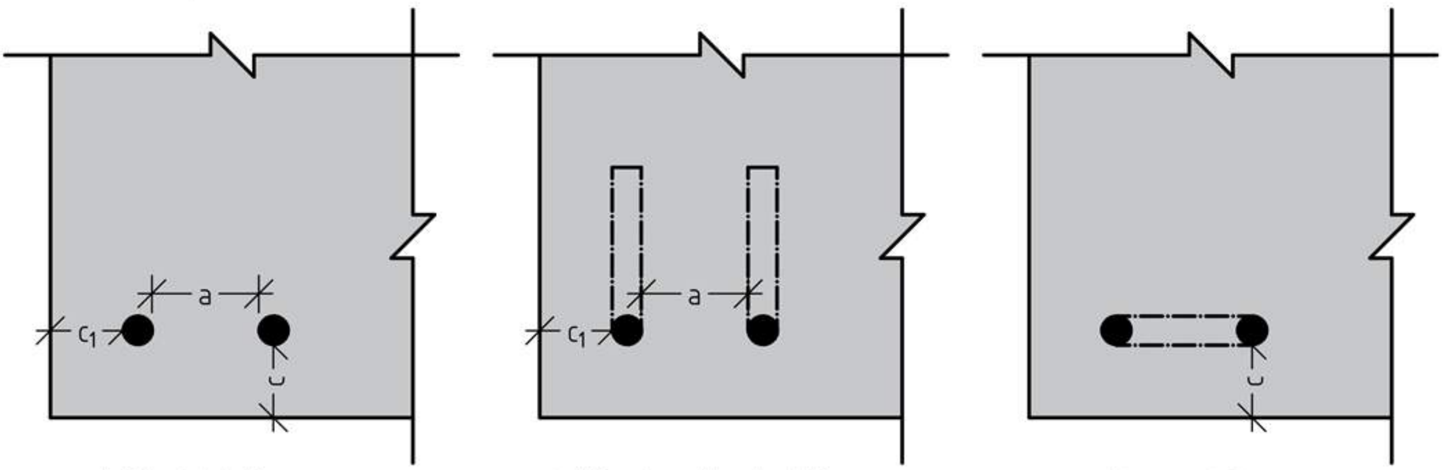
Design Anchorage Length

To run through a full design let's calculate all of the alpha factors assuming they all contribute. For most cases all alpha factors should be set equal to 1.0 to produce a conservative design

---

Minimum Concrete Cover C_d

BS EN1992-1-1 Figure 8.3
Values of C_d for beams and slabs



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: $C_d = c$

We have straight bars in a beam which is the case on the far left of the diagram above

$C_d = \min(a/2, c_1, c)$ **BS EN1992-1-1 Figure 8.3 (reproduced above)**

using the labelling previous adopted for the RC beam assessment

$C_d = \min(S_{clear} / 2, c_{side}, c)$
C_d = min(100mm / 2 , 50mm , 75mm)
C_d = 50mm

	Design Spreadsheet: Concrete Anchorage and Mandrel Diameter	Date: 13/11/2023
		By: AL
	Subtitle: Example 1	Version: 1

Influence Factor - Shape of Bars α_1

α_1 = 1.0 (straight bars in tension)
α_1 = 1.0 (straight bars in compression)
α_1 = 1.0 (bent bars in compression)

for bent bars in tension
α_1 = 0.7 if $C_d > 3\phi$ otherwise α_1 = 1.0

We have straight bars in tension so α_1 = 1.0

BS EN1992-1-1
Section 8.4.4
Table 8.2

Influence Factor - Concrete Cover α_2

α_2 = 1.0 (straight bars in compression)
α_2 = 1.0 (bent bars in compression)

for straight bars in tension
$\alpha_2 = 1 - 0.15(C_d - \phi)/\phi$ but $0.7 \le \alpha_2 \le 1.0$

for bent bars in tension
$\alpha_2 = 1 - 0.15(C_d - 3\phi)/\phi$ but $0.7 \le \alpha_2 \le 1.0$

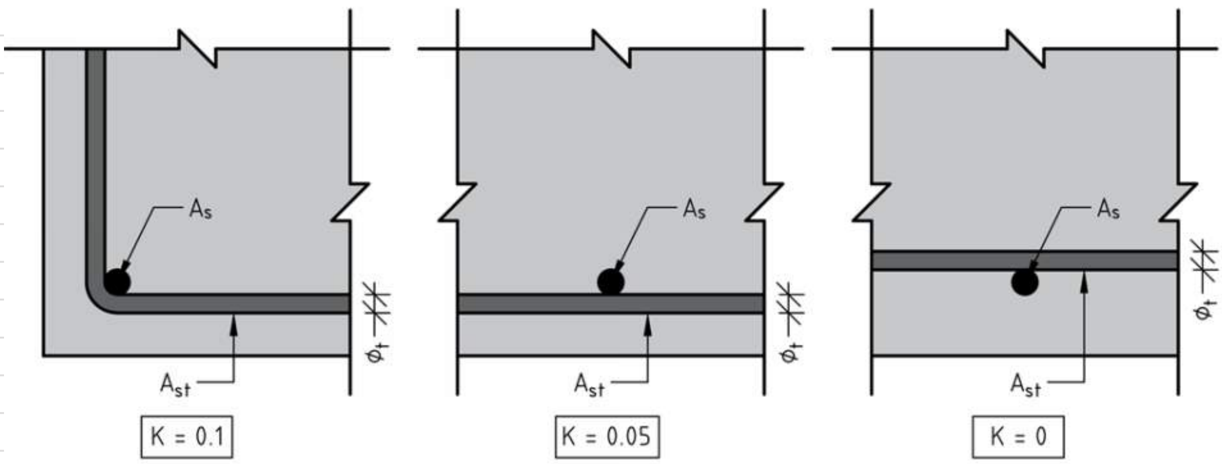
we have straight bars in tension so
$\alpha_2 = 1 - 0.15(C_d - \phi)/\phi$
$\alpha_2 = 1 - 0.15(50mm - 16mm)/16mm$
$\alpha_2 = 0.68125$

however α_2 must be between 0.7 and 1.0 and our calculated value is less than 0.7
therefore α_2 defaults to the minimum value of 0.7
$\alpha_2 = 0.7$

Influence Factor - Transverse Reinforcement α_3

K Factor = 0.1 as we have a beam with shear links (see diagram below)

BS EN1992-1-1
Figure 8.4: Values of K for Beams and Slabs



A_s = The reinforcement we're trying to anchor (i.e. applied tension/compression force is in and out of the page)
A_{st} = the transverse reinforcement providing additional restraint

Find the cross sectional area of the transverse reinforcement along the design anchorage length.
In our example this is the area of the shear links along the anchorage length

As we don't know the design anchorage length we'll use the basic anchorage length to work out the number of shear link transverse bars which contribute to this influence factor

Basic Anchorage Length = 508mm
Spacing of Shear Links = 150mm c/c
Diameter of Shear Links ϕ_{link} = 10mm
Number of Shear Links along anchorage length = 508mm / 150mm = 3.38 bars = 3 bars

$\Sigma A_{st} = \pi * (10mm)^2 * 0.25 * 3$ bars
$\Sigma A_{st} = 235mm^2$

BS EN1992-1-1
Section 8.4.4
Table 8.2

Find the minimum area of transverse reinforcement

$\Sigma A_{st,min} = 0$ for slabs
$\Sigma A_{st,min} = 0.25A_s$ for beams

we have a beam so
$\Sigma A_{st,min} = 0.25 * A_s$
$\Sigma A_{st,min} = 0.25 * 201mm^2$
$\Sigma A_{st,min} = 50.25mm^2$

BS EN1992-1-1
Section 8.4.4
Table 8.2

$\lambda = (\Sigma A_{st} - \Sigma A_{st,min}) / A_s$
$\lambda = (235mm^2 - 50.25mm^2) / 201mm^2$
$\lambda = 0.919$

BS EN1992-1-1
Section 8.4.4
Table 8.2

$\alpha_3 = 1 - K\lambda$ but $0.7 \leq \alpha_3 \leq 1.0$
$\alpha_3 = 1 - (0.1 * 0.919)$
$\alpha_3 = 0.9081$
α_3 is between 0.7 and 1.0 so no need to modify further

BS EN1992-1-1
Section 8.4.4
Table 8.2

Influence Factor - Transverse Reinforcement (Welded) α_4

If there is transverse reinforcement which is welded to the bars we're looking to anchor then there is an additional benefit with this factor

If there is a transverse bar welded to our bar we're trying to anchor
AND
the diameter of this bar is greater than 0.6ϕ
THEN
$\alpha_4 = 0.7$

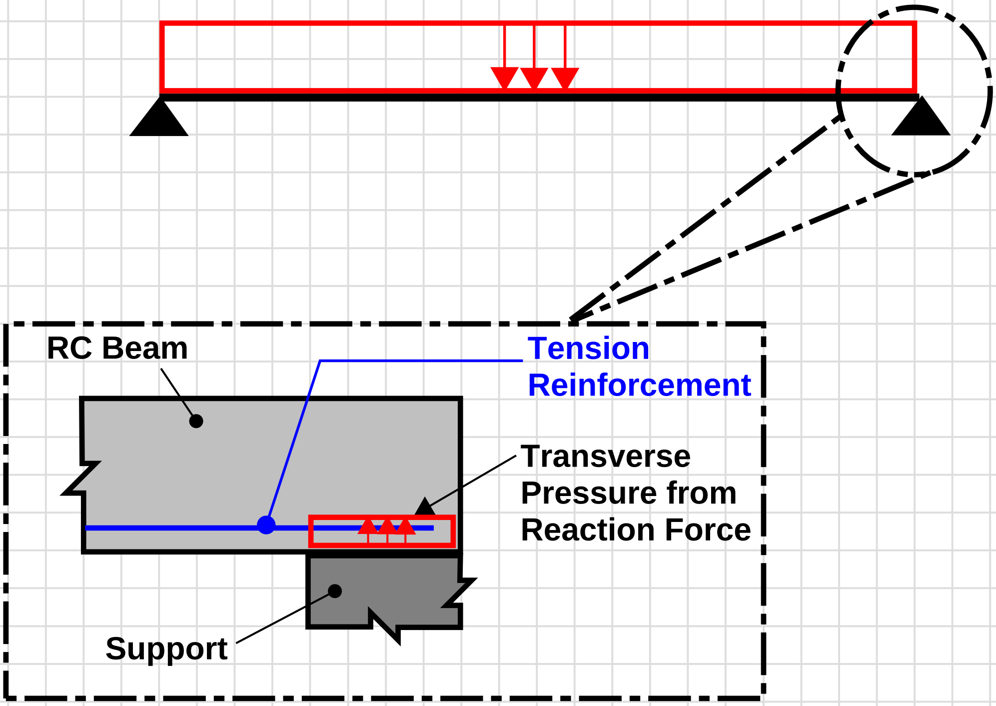
Otherwise $\alpha_4 = 1.0$

We don't have a welded bar in this example so $\alpha_4 = 1.0$

Influence Factor - Transverse Pressure α_5

If at the position where we're trying to provide anchorage to our reinforcement there is a transverse stress (pressure) applied to the concrete this can provide additional anchorage capacity.

An example of a transverse pressure would be the bearing pressure which occurs at the support location of an RC beam. If you have a simple RC beam resting on a dead bearing support then there will be a bearing pressure at the support location. This bearing pressure acts in a perpendicular direction to the tensile reinforcement in the bottom of the beam i.e.



In our example lets assume a dead bearing support similar to that shown in the diagram above. Lets take an applied transverse ULS pressure of $p = 5N/mm^2$

$\alpha_5 = 1 - (0.04 * p)$ but $0.7 \leq \alpha_5 \leq 1.0$
$\alpha_5 = 1 - (0.04 * 5N/mm^2)$
$\alpha_5 = 0.8$
0.8 is already between 0.7 and 1.0 so no need for further amendments

---

Design Anchorage Length

First we must check to ensure the product of $\alpha_2 * \alpha_3 * \alpha_5 \leq 0.7$
(i.e. 0.7 is the minimum value)

$0.7 * 0.9081 * 0.8 \leq 0.7$
$0.5085 \leq 0.7$ --> we're lower than the minimum value of 0.7 so we must limit this product to 0.7

$\alpha_2 * \alpha_3 * \alpha_5 = 0.7$

BS EN1992-1-1 Section 8.4.4 Eq 8.5

Design Anchorage Length $L_{bd} = \max\{ \alpha_1 * \alpha_2 * \alpha_3 * \alpha_4 * \alpha_5 * L_{b,rdq} ; L_{b,min} \}$
Design Anchorage Length $L_{bd} = \max\{ 1.0 * \alpha_2 * \alpha_3 * 1.0 * \alpha_5 * L_{b,rdq} ; L_{b,min} \}$
Design Anchorage Length $L_{bd} = \max\{ 1.0 * 1.0 * 0.7 * 508mm ; 160mm \}$
Design Anchorage Length $L_{bd} = \max\{ 356mm ; 160mm \}$
Design Anchorage Length L_{bd} = 356mm = 360mm rounded to nearest 5mm

BS EN1992-1-1 Section 8.4.4 Eq 8.4

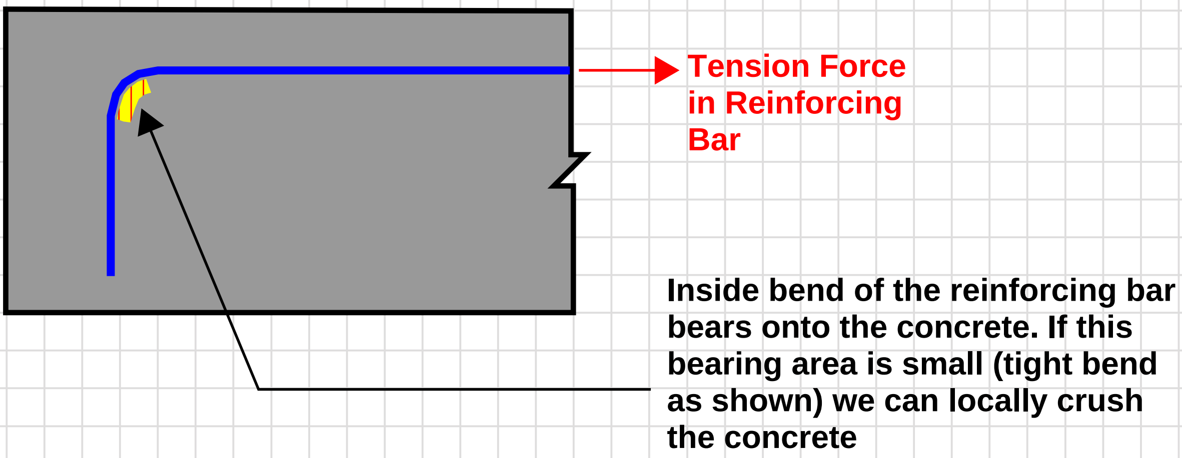
Provided Anchorage Length

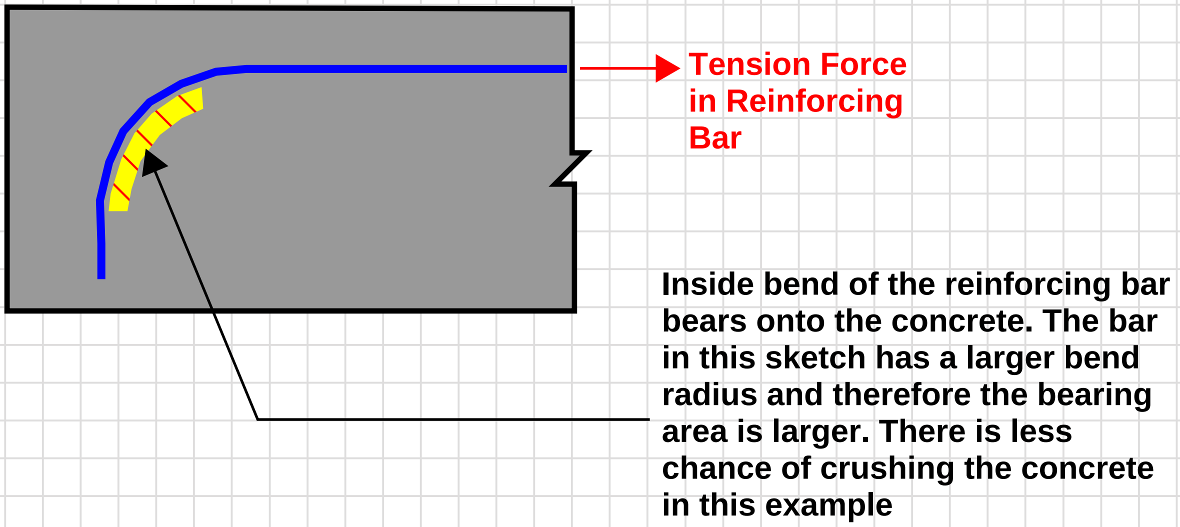
In this example we'll provide an actual anchorage length of 450mm along the straight bar. Refer to Figure 8.1 in BS EN 1992-1-1 for how the anchorage length is measured.

$L_{b,actual}$ = 450mm (provided anchorage length)
Utility = L_{bd} / $L_{b,actual}$ = 360mm / 450mm = 80% --> OK

Minimum Mandrel Diameter

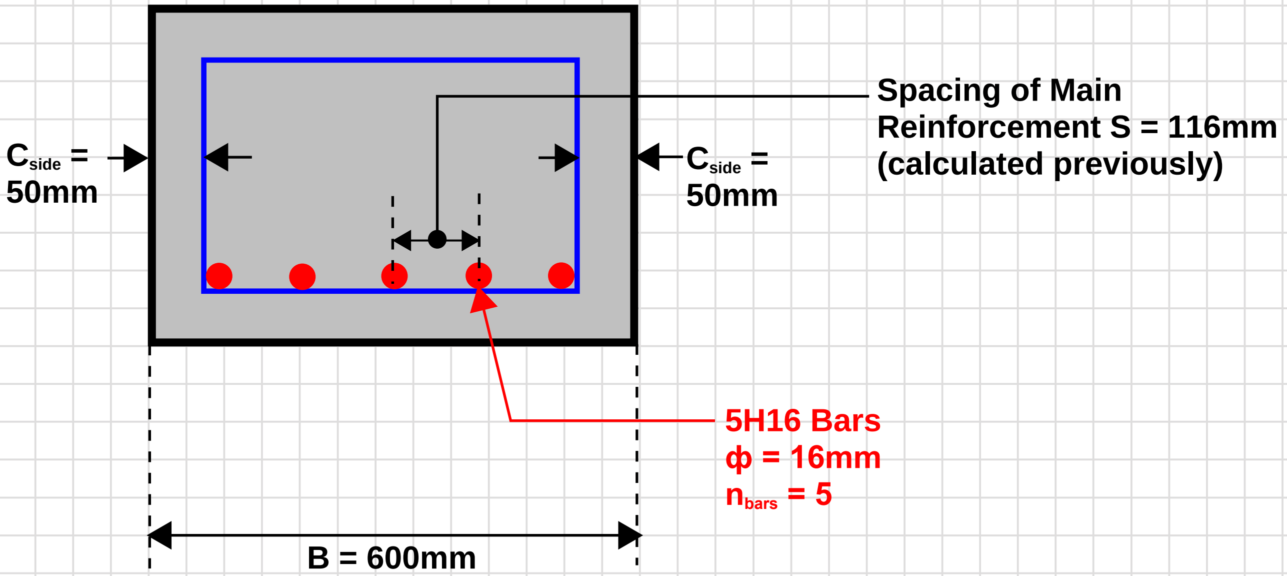
The minimum mandrel diameter relates to when we're trying to anchor a bar with a bend/hook on it. The inside portion of the bend will bear onto the concrete when we apply tension to the reinforcing bar. If we don't provide enough of a bearing surface (i.e. the radius of the curve is too sharp) then we'll cause crushing of the concrete locally i.e:





The following calculations consider the minimum bend we need to achieve in order to avoid crushing of the concrete. This is expressed as the "mandrel diameter" i.e. the bend diameter of the bar

Spacing of Reinforcement



Half the Centre-to-Centre Distance between Bars

Half the centre-to-centre distance can be thought of as the bearing width that we're looking at for the bent bar in this instance it is equal to:

a_b = S / 2
a_b = 116mm / 2
a_b = 58mm

BS EN1992-1-1 Section 8.3 Equation 8.1

ULS Tension Force in the Bar
This was calculated previously F_{bt} = 74.1kN (74100N)

Design Concrete Compressive Stress $f_{cd} = \alpha_{cc} * f_{ck} / \gamma_c$
Design Concrete Compressive Stress f_{cd} = 0.85 * 28N/mm² / 1.5
Design Concrete Compressive Stress f_{cd} = 15.86N/mm²

BS EN1992-1-1 Section 3.1.6 Equation 3.15

Minimum Mandrel Diameter

$$\phi_{m,min} = F_{bt}\left[\frac{1}{a_b} + \frac{1}{2\phi}\right]\frac{1}{f_{cd}}$$

$$\phi_{m,min} = 74100N\left[\frac{1}{58mm} + \frac{1}{2*16mm}\right]\frac{1}{15.86\frac{N}{mm^2}}$$

BS EN1992-1-1 Section 8.3 Equation 8.1

Minimum Mandrel Diameter $\phi_{m,min}$ = 226.55mm = 230mm rounded to nearest 5mm

The minimum mandrel diameter should also be checked to ensure it is greater than the minimum bend radius for the bar as per BS 8666:2020 Table 2. For a H16 bar this diameter is 64mm so we're OK in this instance

Provided Mandrel Diameter

For this example lets provide an L-bar at the ends of the RC beam with a bend diameter of 250mm

D_{prov} = 250mm
Utility = $\phi_{m,min}$ / D_{prov} = 230mm / 250mm = 92% --> OK

Project	N/A	BS EN1992-1-1 & UK National Annex	
Client	N/A	Made by / Date / Job No	
Description	Worked Example 1	AL / 13-11-23 / N/A	
Concrete Anchorage and Mandrel Diameter v1.0		Checked / Revision	
		N/A / N/A	

1.0 - CONCRETE PROPERTIES @ 28 DAYS (BS EN1992-1-1 Table 3.1)

Concrete Grade	C28/35	
Aggregate Type	Limestone	
Characteristic Cylinder Strength (N/mm^2) f_{ck}	28	User input
Mean Compressive Strength (N/mm^2) f_{cm}	36	$f_{cm} = f_{ck} + 8N/mm^2$
Mean Tensile Strength (N/mm^2) f_{ctm}	2.766	$f_{ctm} = 0.3 * f_{ck}^{2/3} \leq C50/60$ $f_{ctm} = 2.12ln(1+f_{cm}/10) > C50/60$
5% Fractile Tensile Strength (N/mm^2) $f_{ctk,0.05}$	1.936	$f_{ctk,0.05} = 0.7 * f_{ctm}$
Mean Modulus of Elasticity (N/mm^2) E_{cm}	29077	$E_{cm} = 22[f_{cm}/10]^{0.3}$ (with allowance for aggregate type)
Coefficent Taking into Account Long Term Effects on the Compressive Strength α_{cc}	0.85	NA Table NA.1 Clause 3.1.6 (1)P
Coefficent Taking into Account Long Term Effects on the Tensile Strength α_{ct}	1.00	NA Table NA.1 Clause 3.1.6 (2)P
Material Safety Factor for Concrete γ_c	1.50	Section 2.4.2.4 Table 2.1N (persistant & transient loads at ULS)
Design Concrete Tensile Stress (N/mm^2) f_{ctd}	1.29	$f_{ctd} = \alpha_{ct} * f_{ctk,0.05} * (1/\gamma_c)$ Section 3.1.6 Eq - 3.16

2.0 - ULTIMATE BOND STRESS (BS EN1992-1-1 Section 8.4.2)

Type of Loading on the Reinforcing Bar	Tension	
ULS Force in a Single Reinforcing Bar F_{bt} (kN)	74.10	
Diametre of Reinforcing Bar ϕ (mm)	16	
Cross Sectional Area of Reinforcing Bar A_s (mm^2)	201	$A_s = \pi * \phi^2 * 0.25$
Ultimate Stress in the Reinforcing Bar σ_{sd} (N/mm^2)	368.5	$\sigma_{sd} = F_{bt} / A_s$
Bond Condition Between Reinforcing Bar and Concrete	Good	Section 8.4.2(2)
Coefficient Accounting for Bond Condition η_1	1.0	Section 8.4.2(2)
Coefficient Accounting for Bar Diameter η_2	1.00	$\eta_2 = 1.0$ for $\phi \leq 32mm$ $\eta_2 = (132-\phi)/100$ for $\phi > 32mm$ Section 8.4.2(2)
Ultimate Bond Stress f_{bd} (N/mm^2)	2.905	$f_{bd} = 2.25 * \eta_1 * \eta_2 * f_{ctd}$ Section 8.4.2(2) Eq - 8.2

3.0 - BASIC ANCHORAGE LENGTH (BS EN1992-1-1 Section 8.4.3 & 8.4.4)

Basic Required Anchorage Length $L_{b,rqd}$ (mm)	508	$L_{b,rqd} = (\phi/4) * (\sigma_{sd}/f_{bd})$ Section 8.4.3(2) Eq - 8.3
Minimum Anchorage Length $L_{b,min}$ (mm)	160	$L_{b,min} = max\{0.3L_{b,rqd} ; 10\phi ; 100mm\}$ for Tension Section 8.4.4(1) Eq - 8.6 $L_{b,min} = max\{0.6L_{b,rqd} ; 10\phi ; 100mm\}$ for Compression Section 8.4.4(1) Eq - 8.7

4.0 - INFLUENCE FACTORS (BS EN1992-1-1 Section 8.4.4 Table 8.2)

Design Type	Detailed	Simple design sets all α factors equal to 1
Type of Anchorage	Straight Bars	
Include Detailed Calculation of α_1 Factor	INCLUDE	If omitted $\alpha_1 = 1$
Include Detailed Calculation of α_2 Factor	INCLUDE	If omitted $\alpha_2 = 1$
Include Detailed Calculation of α_3 Factor	INCLUDE	If omitted $\alpha_3 = 1$
Include Detailed Calculation of α_4 Factor	INCLUDE	If omitted $\alpha_4 = 1$
Include Detailed Calculation of α_5 Factor	INCLUDE	If omitted $\alpha_5 = 1$

4.1 - INFLUENCE FACTORS α_1 & α_2 - BAR SHAPE AND COVER

Minimum Concrete Cover c_d (mm)	50	Refer to BS EN1992-1-1 Figure 8.3
Influence Factor - Shape of Bars α_1	1.0	$\alpha_1 = 1.0$ for Straight Bars in tension and all bars in compression $\alpha_1 = 0.7$ for $c_d > 3\phi$ for Non-Straight Bars in Tension otherwise $\alpha_1 = 1.0$
Influence Factor - Concrete Cover α_2	0.70	$\alpha_2 = 1.0$ for bars in compression $\alpha_2 = 1 - 0.15(c_d-\phi)/\phi$ with $0.7 \leq \alpha_2 \leq 1.0$ for straight bars in tension $\alpha_2 = 1 - 0.15(c_d-3\phi)/\phi$ with $0.7 \leq \alpha_2 \leq 1.0$ for non-straight bars in tension

4.2 - INFLUENCE FACTOR α_3 - TRANSVERSE REINFORCEMENT

K Factor for Beams and Slabs	0.1	BS EN1992-1-1 Section 8.4.4 Figure 8.4
Cross Sectional Area of the Transverse Reinforcement Along the Design Anchorage Length ΣA_{st} (mm^2)	235	BS EN1992-1-1 Section 8.4.4 Figure 8.4
Cross Sectional Area of the Minimum Transverse Reinforcement $\Sigma A_{st,min}$ (mm^2)	Beam 50.27	$\Sigma A_{st,min} = 0.25A_s$ for beams $\Sigma A_{st,min} = 0$ for slabs
λ Factor	0.919	$\lambda = (\Sigma A_{st} - \Sigma A_{st,min}) / A_s$ Table 8.2
Influence Factor - Transverse Reinforcement α_3	0.908	$\alpha_3 = 1 - K\lambda$ but $0.7 \leq \alpha_3 \leq 1.0$ Table 8.2

4.3 - INFLUENCE FACTOR α_4 - TRANSVERSE REINFORCEMENT (WELDED)

Is Additional Anchorage Provided By a Transverse Bar Welded to the Main Bar? And Does $\phi_{transverse} \geq 0.6\phi$?	NO	BS EN1992-1-1 Section 8.4.1 Figure 8.1 & Table 8.2
Influence Factor - Welded Transverse Reinforcement α_4	1.0	$\alpha_4 = 0.7$ with welded transverse bar $\alpha_4 = 1.0$ with no welded transverse bar

4.4 - INFLUENCE FACTOR α_5 - TRANSVERSE CONFINEMENT PRESSURE

Transverse Confining Pressure at Ultimate Limit State along Design Anchorage Length p (N/mm^2)	5	BS EN1992-1-1 Section 8.4.4 Table 8.2
Influence Factor - Transverse Confinement Pressure α_5	0.80	$\alpha_5 = 1 - (0.04p)$ but $0.7 \leq \alpha_5 \leq 1.0$ Table 8.2

5.0 - DESIGN ANCHORAGE LENGTH (BS EN1992-1-1 Section 8.4.4)

Design Anchorage Length L_{bd} (mm)	360	$L_{bd} = max\{\alpha_1*\alpha_2*\alpha_3*\alpha_4*\alpha_5*L_{b,rqd} ; L_{b,min}\}$ with $(\alpha_2*\alpha_3*\alpha_5) \geq 0.7$ Eq - 8.4 & 8.5
Anchorage Length Provided $L_{b,actual}$ (mm)	450	User Defined
Utilisation %	80%	$L_{bd} / L_{b,actual}$

6.0 - MINIMUM MANDREL DIAMETER (BS EN1992-1-1 Section 8.3)

Spacing of Main Reinforcement S (mm)	116.0	i.e. centreline spacing between the anchored bar and the next anchored bar adjacent
Half the centre-to-centre distance between bars a_b (mm)	58	$a_b = S / 2$
ULS Force in a Single Reinforcing Bar F_{bt} (kN)	74.1	User input defined previously (only relevant for bar in tension)
Design Concrete Compressive Stress f_{cd} (N/mm^2)	15.87	$f_{cd} = \alpha_{cc} * f_{ck} * (1/\gamma_c)$ (and limited to no greater than C55/67) Eq 3.15 & Section 8.3
Minimum Mandrel Diameter $\phi_{m,min}$ (mm)	230.00	$\phi_{m,min} = F_{bt} * [(1/a_b) + (1/2\phi)] * (1/f_{cd})$ Section 8.3(3) Eq - 8.1
Minimum Bend Radius for Reinforceing Bar $r_{m,min}$ (mm)	115.00	$r_{m,min} = \phi_{m,min} / 2$
Perform Check on Provided Bar:	Diameter	User can enter either a radius or diameter
Provided Bar Diameter Dprov (mm)	250.0	User Input
Utilisation %	**92%**	

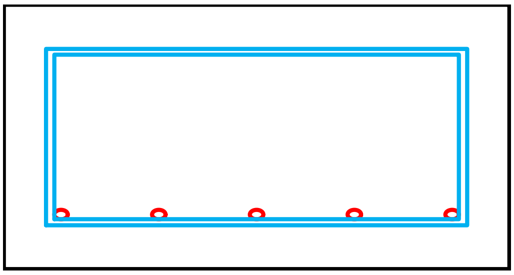
7.0 - CALCULATE TENSION FORCE IN REINFORCEMENT

7.1 - CONCRETE BEAM/SLAB GEOMETRY & COVER

Type of Concrete Element (Beam or Slab)	BEAM	User input
Width of Concrete Beam B (mm)	600	User Input
Depth of Concrete Beam H (mm)	450	User input
Main Concrete Cover to Beam c (mm)	75	User input
Concrete Cover to Sides c_{side} (mm)	50	User input

7.2 - REINFORCEMENT

Diametre of Main Reinforcing Bars ϕ (mm)	16	User input
Number of Reinforcing Bars n_{bars}	5	User Input
Centreline Spacing Between Reinforcing Bars S (mm)		Section 7.1 Below
Diametre of Shear Links ϕ_{links} (mm)	10	User input



7.3 - APPLIED ULS BENDING MOMENT

ULS Applied Bending Moment M_{Ed} (kNm)	125	User input

7.4 - BENDING CALCULATIONS

Characteristic Yield Strength of Rebar f_{yk} (N/mm^2)	500	Typically f_{yk} = 500N/mm^2
Material Safety Factor for Rebar γ_s	1.15	Section 2.4.2.4 Table 2.1N
Design Yield Strength of Rebar f_{yd} (N/mm^2)	435	$f_{yd} = f_{yk} / \gamma_s$ Typically f_{yd} = 435N/mm^2
Depth to Reinforcement d (mm)	357	$d = H - c - \phi links - \phi/2$
Clear Spacing Between Reinforcing Bars s_{clear} (mm)	100	$s_{clear} = [B - (2 * c_{side}) - (2 * \phi_{link}) - (n_{bars} * \phi)] / (n_{bars} - 1)$ for $n_{bars} > 1$
Centreline Spacing Between Reinforcing Bars S (mm)	116	$S = s_{clear} + \phi$
K Factor for Bending	0.058	$K = M_{Ed} / (f_{ck} * B * d^2)$
Lever Arm Z (mm)	338	$Z = \min(0.95d ; d *[0.5 + \sqrt{0.25 - 3K/3.4}])$
Minimum Area of Reinforcement $A_{s,min}$ (mm^2)	308.1	$A_{s,min} = \max(0.26f_{ctm}/f_{yk} ; 0.0013) * B * d$ UK NA to BS EN1992-1-1 Clause 9.2.1.1(1)
Maximum Area of Reinforcement $A_{s,max}$ (mm^2)	10800	$A_{s,max} = 0.04 * B * h$ UK NA to BS EN1992-1-1 Clause 9.2.1.1(3)
Required Area of Reinforcement for Moment $A_{s,req1}$ (mm^2)	852	$A_{s,req1} = M_{Ed} / [(1/\gamma_s) * f_{yk} * Z]$
Required Area of Reinforcement Overall $A_{s,req}$ (mm^2)	852	$A_{s,req} = \max(A_{s,req1} ; A_{s,min})$
Area of Reinforcement Provided $A_{s,prov}$ (mm^2)	1005	$A_{s,prov} = n_{bars} * \pi * \phi^2 * 0.25$
Utilisation %	**85%**	$\max(A_{s,req} / A_{s,prov} ; A_{s,prov} / A_{s,max})$
ULS Tensile Stress in the Reinforcement σ_{sd} (N/mm^2)	368.4	$\sigma_{sd} = (A_{s,req1} / A_{s,prov}) * f_{yk} * (1/\gamma_s)$
Area of a Single Reinforcing Bar A_s (mm^2)	201	$A_s = \pi * \phi^2 * 0.25$
ULS Tension Force in a Single Reinforcing Bar F_{bt} (kN)	74.1	$F_{bt} = \sigma_{sd} * A_s$