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ProtaStructure Design Guide

Column Design to EC 2

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Please contact us for your training and technical support queries

asiasupport@protasoftware.com

globalsupport@protasoftware.com

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Introduction

By default, ProtaStructure designs columns bent about a single axis, or bent about both axes using the code clauses given in **BS EN 1992-1-1:2004 Part 1.**

The following table summarises the various stages of the EC 2 column design process:

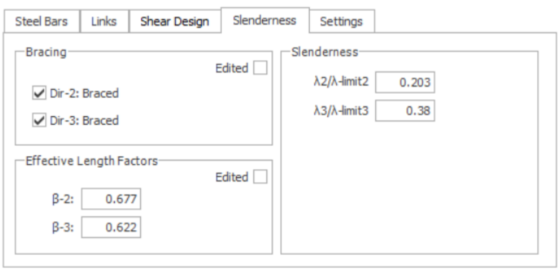
Step	Calculation	Clause
1	Braced or Unbraced	5.8.3.2 (3)
2	Calculate effective Length	5.8.3.2 (3)
3	Determine First Order Moment	5.2 (7a) & 5.8.8.2 (2)
4	Determine Minimum Moment	6.1 (4)
5	Check slenderness ratio	5.8.3.2 (2)
6	Check Slenderness limit and Classify as short or slender	5.8.3.1
7	Calculate Moments	
7a	If short - calculate design moments	5.8.8.2 (2)
7b	If slender - calculate Nominal Second Order Moment and design moments	5.8.8.2 (3) & 5.8.8.3

In ProtaStructure, the second order moments of slender columns will be determined using nominal curvature method (Cl. 5.8.8).

The EC 2 Column Design Process

1. Braced or unbraced - Cl 5.8.3.2 (3)

Individual columns can have their braced/unbraced status modified within the Column Interactive Design, via the Slenderness tab as shown below:



For walls, the braced/unbraced status is applied in the same way as it is for columns. However, it should be noted that walls can always be considered as braced along their major axis (i.e dir 1).

2. Calculate effective height - Cl 5.8.3.2 (3)

The effective height is determined from the equation:

$l_e = \beta l_o$

For Braced members:

$$\boldsymbol{\beta = 0.5 \times \sqrt{\left(1 + \frac{k_1}{0.45 + k_1}\right) \times \left(1 + \frac{k_2}{0.45 + k_2}\right)}}$$

For Unbraced members:

$$\boldsymbol{\beta = \sqrt{1 + 10 \times \left(\frac{k_1 \times k_2}{k_1 + k_2}\right)}}$$

Or

$$\boldsymbol{\beta = \left(1 + \frac{k_1}{1 + k_1}\right) \times \left(1 + \frac{k_2}{1 + k_2}\right)}$$

Whichever is greater.

In ProtaStructure, the lower limit and upper limit of k are 0.1 and 10 respectively.

k = 0.1 for fixed bases, k = 10 for hinged bases.

The beta value can be edited and replaced by the value from the tables if required.

3. Determine First Order Moment – Cl. 5.2 (7a) & 5.8.8.2 (2)

In ProtaStructure, the additional minimum imperfections moment from Cl. 5.2 (7) will always be added to the first order moments.

$$\boldsymbol{M_{01} = \min\{|M_{top}|, |M_{bottom}|\} + e_i N_{Ed}}$$

$$\boldsymbol{M_{02} = \max\{|M_{top}|, |M_{bottom}|\} + e_i N_{Ed}}$$

where

$e_i = \dfrac{l_o}{400}$

$N_{Ed} = Design\ Load\ in\ the\ column$

4. Determine Minimum Moment – Cl. 6.1 (4)

The minimum moment will be determined by design load applied with a minimum eccentricity, e_o.

$$e_o = \frac{h}{30} \geq 20\ mm, where\ h\ is\ the\ section\ depth.$$

$$\boldsymbol{Min. moment = N_{Ed} \times e_o}$$

5. Check Slenderness ratio – Cl. 5.8.3.2 (2)

The slenderness ratio is defined, λ, of the restrained length about each axis is calculated as follows:

$$\lambda = {}^{l_o}/_{i} \qquad equation\ 5.14$$

$$\lambda = 3.46\,{}^{l_o}/_{h} \qquad for\ rectangular\ sections$$

$$\lambda = 4.0\,{}^{l_o}/_{d} \qquad for\ circular\ sections$$

Where

- l_o is the effective length.
- i is the radius of gyration of the uncracked concrete section.
- h is the overall depth.
- d is the column diameter.

6. Check slenderness limit and Classify - Cl 5.8.3.1

The limiting slenderness ratio about each axis can be determined by:

$$\lambda_{lim} = 20 \times A \times B \times C/\sqrt{n}$$

Where:

- $\boldsymbol{A = {}^{1}/_{(1 + 0.2\varphi_{ef})}}$ (if φ_{ef} is not known, A= 0.7 maybe used)
- $\boldsymbol{B = \sqrt{1 + 2\varpi}}$ (if ϖ is not known, B =1.1 may be used)
  Where $\varpi = A_s f_{yd} / (A_c f_{cd})$; mechanical reinforcement ratio.
- $\boldsymbol{C = 0.7}$
  In ProtaStrutructure, the value of C is 0.7 regardless of braced or bracing columns. This is to produce the result which is more conservative. Using the value of M_{01} that gives the largest positive value for r_m and hence the smallest value for C.
- $\boldsymbol{n = {}^{N_{Ed}}/_{(A_c f_{cd})}}$

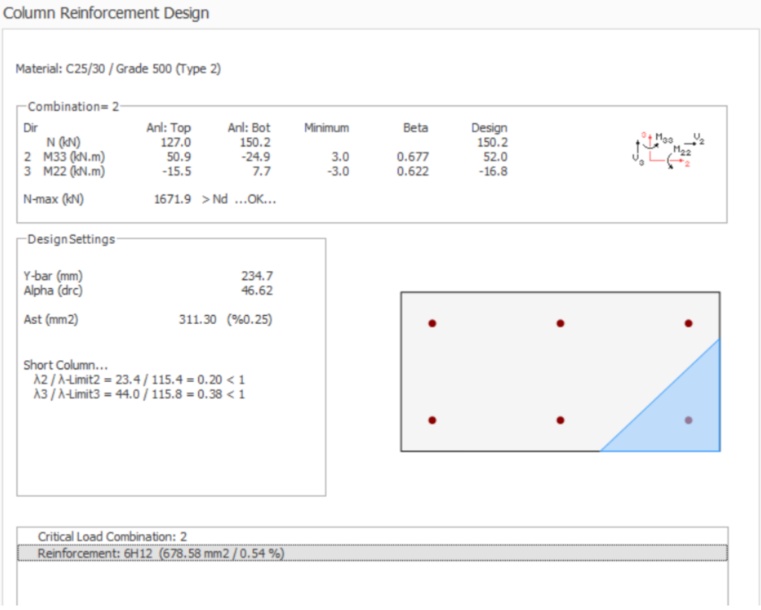
The value of φ_{ef} can be obtained from the design report after performing interactive design.

The column will be classified as short column if $\lambda \leq \lambda_{lim}$. Likewise, the column will be classified as slender column if $\lambda \geq \lambda_{lim}$.

7. Calculate Moment

a. If short (braced or unbraced) – Calculate Design Moments – Cl. 5.8.8.2 (2)

For the short columns (not slender column), the design moment, M_{Ed} is equal to M_{02}.



Where M_{Ed} is the design moment in directions - 2 and -3 and gets stated under the *"Design"* column in the dialogue shown above.

Also, note that ProtaStructure will continue the conservative practice where the design moment in each direction is determined separately, so in direction - 2 the critical case could be at the top of the member and in direction - 3 it could be at the bottom, but these moments are then considered as co-existent for the purposes of section analysis.

b. If slender – Calculate Nominal Second Order Moment and design moments – Cl. 5.8.8.2 (3) & 5.8.8.3

For slender symmetric columns, the additional nominal second order moment will be calculated using nominal curvature method, whereas Nominal stiffness method will be used to calculate additional nominal second order moment for slender asymmetrical columns.

In order to calculate the additional moment induced in the column it is required that factor K be determined. Although the code allows for K to be conservatively taken as 1.0, ProtaStructure calculates K using the equation 5.36 in the code:

$$K = \frac{n_u - n}{n_u - n_{bal}} \leq 1 \qquad \qquad equation\ 5.34$$

<u>Calculation of n, relative axial force – 5.8.8.3 (3):</u>

$$n = \frac{N_{Ed}}{A_c f_{cd}}$$

Where

- N_{Ed} is the design value of axial force.
- F_{cd} is the concrete compressive strength.

Calculation of n_{bal} – 5.8.8.3 (3):

The code indicates that N_{bal} is the value of n at maximum moment resistance.

The value of 0.4 is used in ProtaStructure.

Calculation of nu – 5.8.8.3 (3):

The value of n_u will be calculated by:

$$n_u = 1 + \omega$$

$$\omega = {A_s f_{yd}}/{A_c f_{cd}}$$

Where

As is the total area of reinforcement, whereas Ac is the area of concrete cross section.

Calculation of K_φ – 5.8.8.3 (3):

$$K_\varphi = 1 + \beta\, \varphi_{ef} \geq 1$$

Where

- φ_{ef} = The effective creep ratio
- β = 0.35 + f_{ck}/200 – λ/150
- λ = the slenderness ratio

Calculation of e_2 – Cl. 5.8.8.2 (3):

The deflection due to second order effect, e_2 can be calculated by

$$e_2 = 0.1\left(\frac{K_r K_\varphi f_{yd}}{0.45 d E_s}\right){l_o}^2$$

Where Es is the elastic modulus of reinforcing steel (200GPa).

Calculation of Additional Moment - Cl. 5.8.8.2 (3):

The additional nominal second order moment can be obtained by multiplying N_{Ed} and e_2.

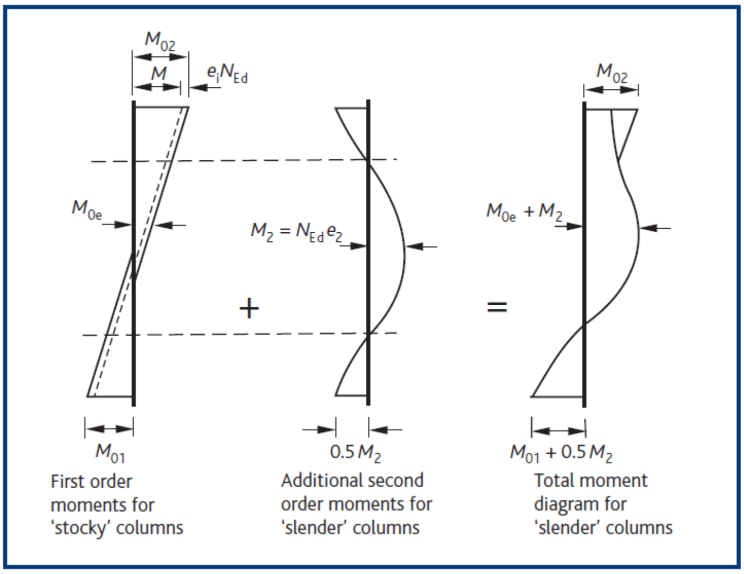
$$M_{add} = N_{Ed} \times e_2$$

Calculation of Design Moment - Cl. 5.8.8.2 (3):

EC2 does not explicitly deal with the fact that the end moments of a fixed end member would also be amplified as a result of the strut buckling P-delta effect. The UK design guidance makes this clear.

In the *"How to Design Concrete Structures using Eurocode 2: Column"*, the design moment of the slender column is whichever greatest of M_{02}, M_0e + M_{add} or M_{01} + $0.5M_{add}$. *(see Concrete Centre "How To Design Concrete Structures using Eurocode 2: Column" guide – diagram in figure 4 and equation in figure 3 flowchart).*

$$M_{Ed} = MAX(M_{02}\,, M_{0e} + \, M_2\,, M_{01} + 0.5\, M_2\,)$$



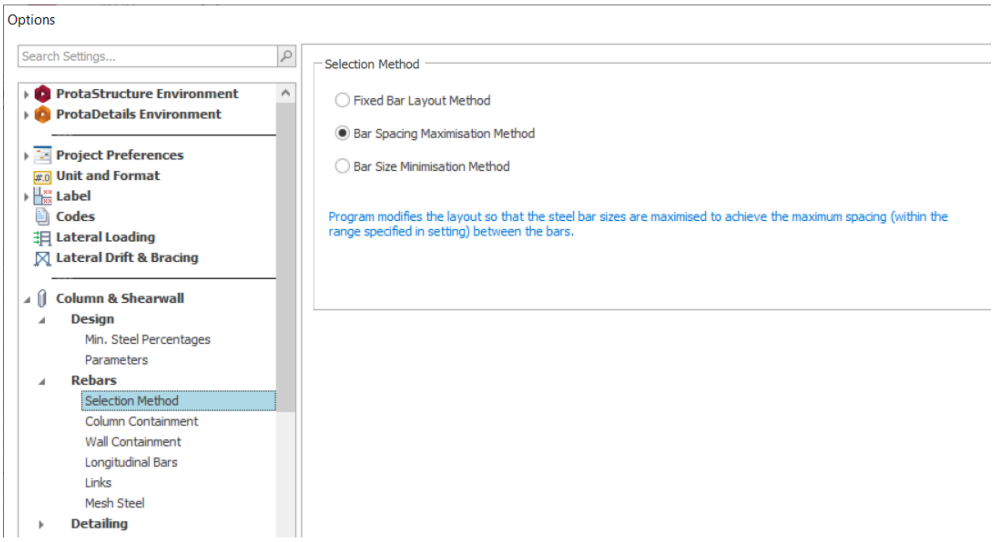
8. Member Design

With the design axial load and design moment established, the program determines the required steel area using the EC 2 stress block. The neutral axis of the cross section is determined and a bar size and spacing obtained to provide sufficient moment capacity.

Each design combination is considered and the one that results in the largest steel area requirement is selected as being critical.

If the minimum area of steel is satisfactory for every combination, the program will record combination 1 as being critical, irrespective of the relative magnitude of loads in each combination.

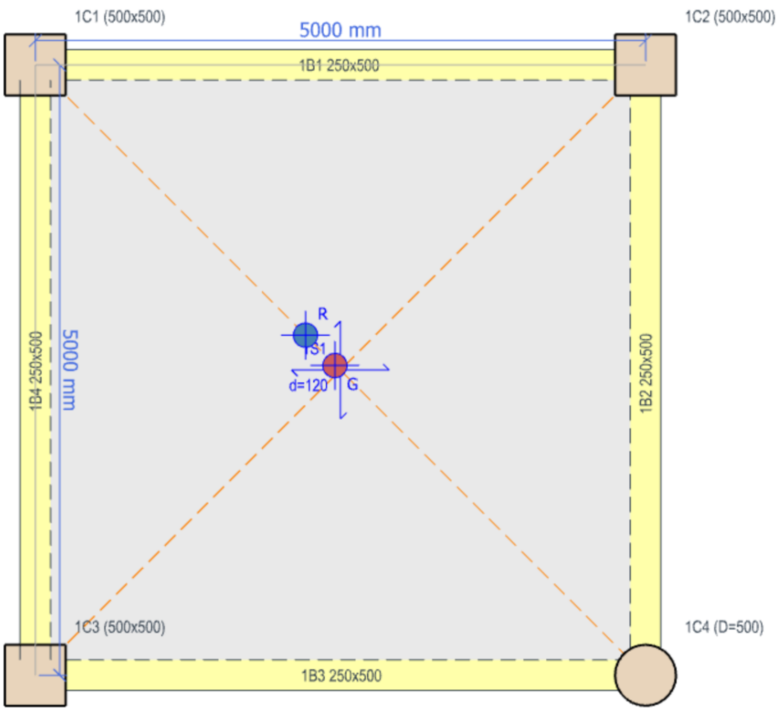
Three methods of bar selection are available:

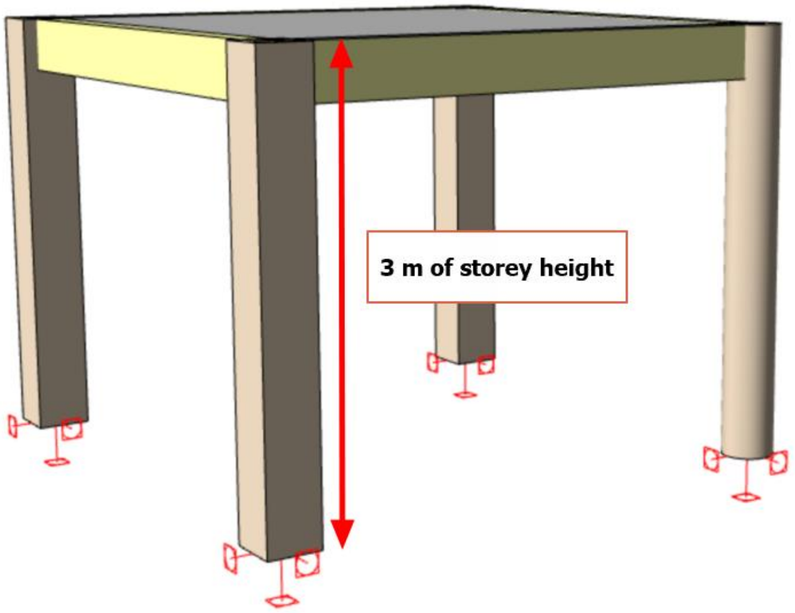


- Fixed bar layout — The bar locations are defined by the user and the program determines the bar size required.
- Bar Spacing Maximisation — The program determines the bar size and spacing with the aim to maximise the spacing. This is normally the preferred option.
- Bar Size Minimisation — The program determines the bar size and spacing with the aim to minimise the bar size.

Worked Examples

A simple structure is built as shown in the figure below to demonstrate the design process of a square column. In this model the steel grade is 500 and the steel material factor is 1.15. Bar diameters of 12 mm are used. The minimum link diameter is set to 8 mm.

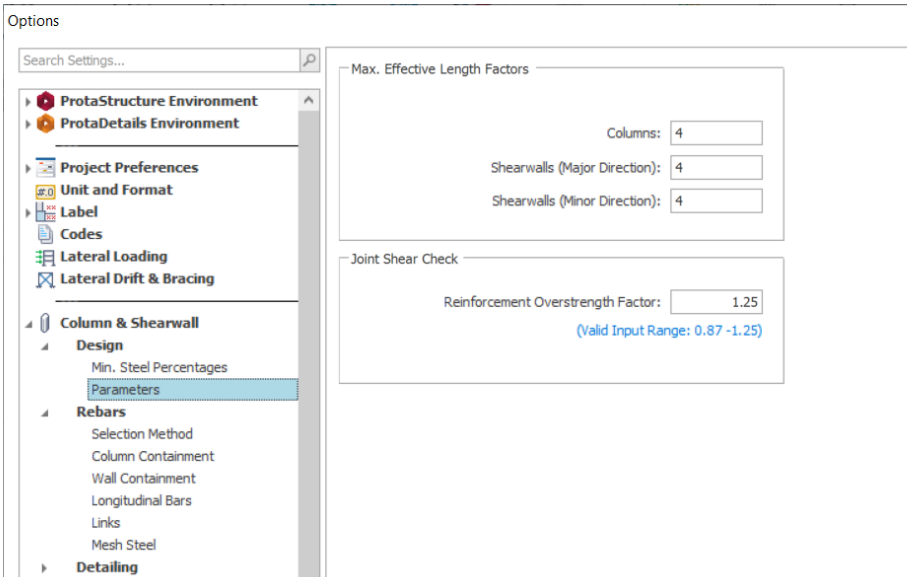




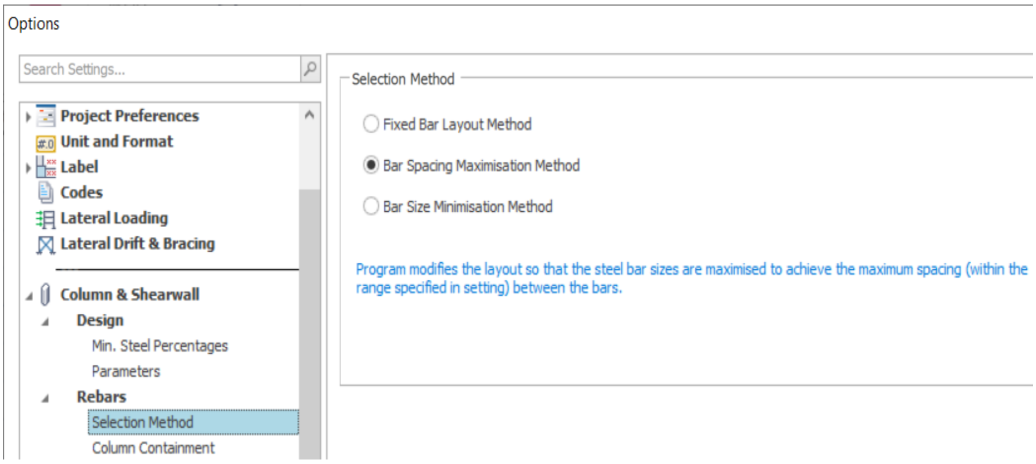
Column Design Settings

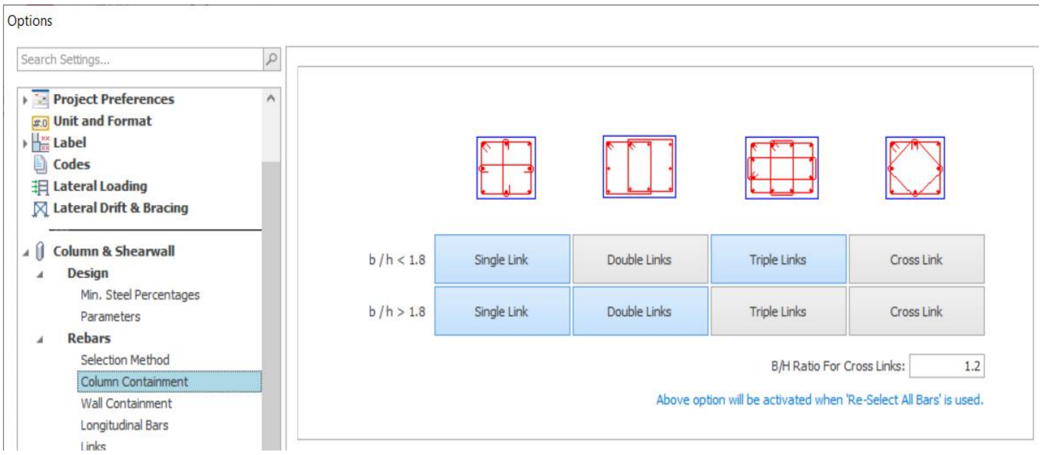
The column design settings initially adopted are as shown:

<u>Design Parameters:</u>

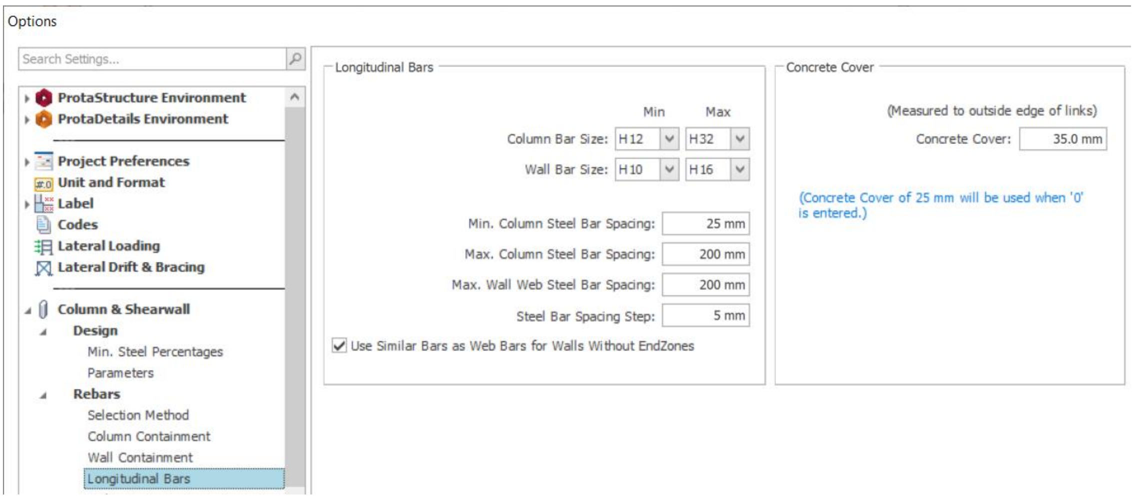


Steel Bars – Layout/Selection:

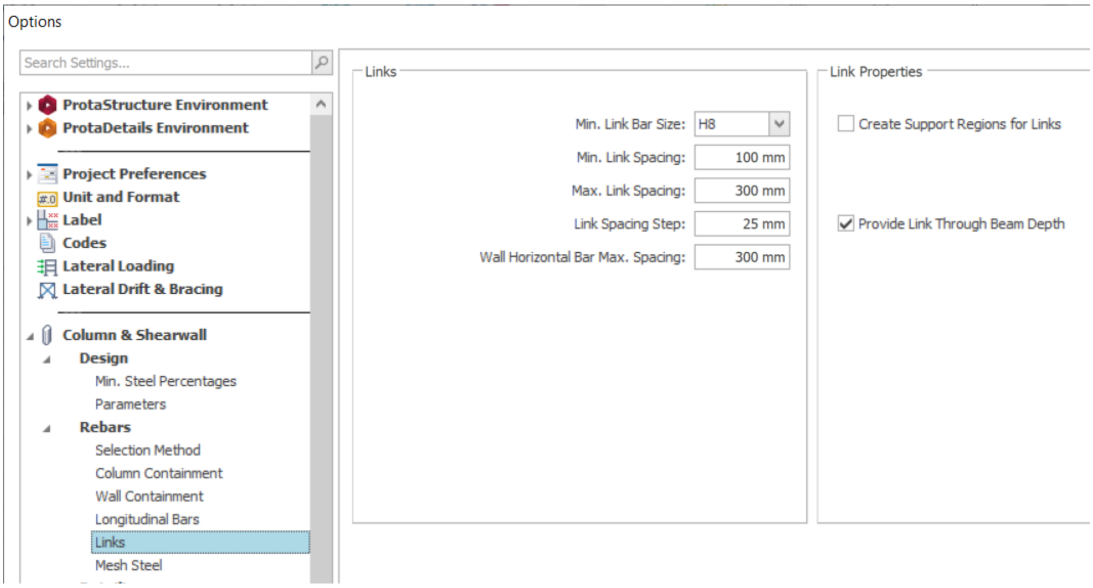




Steel Bars – Longitudinal Steel:

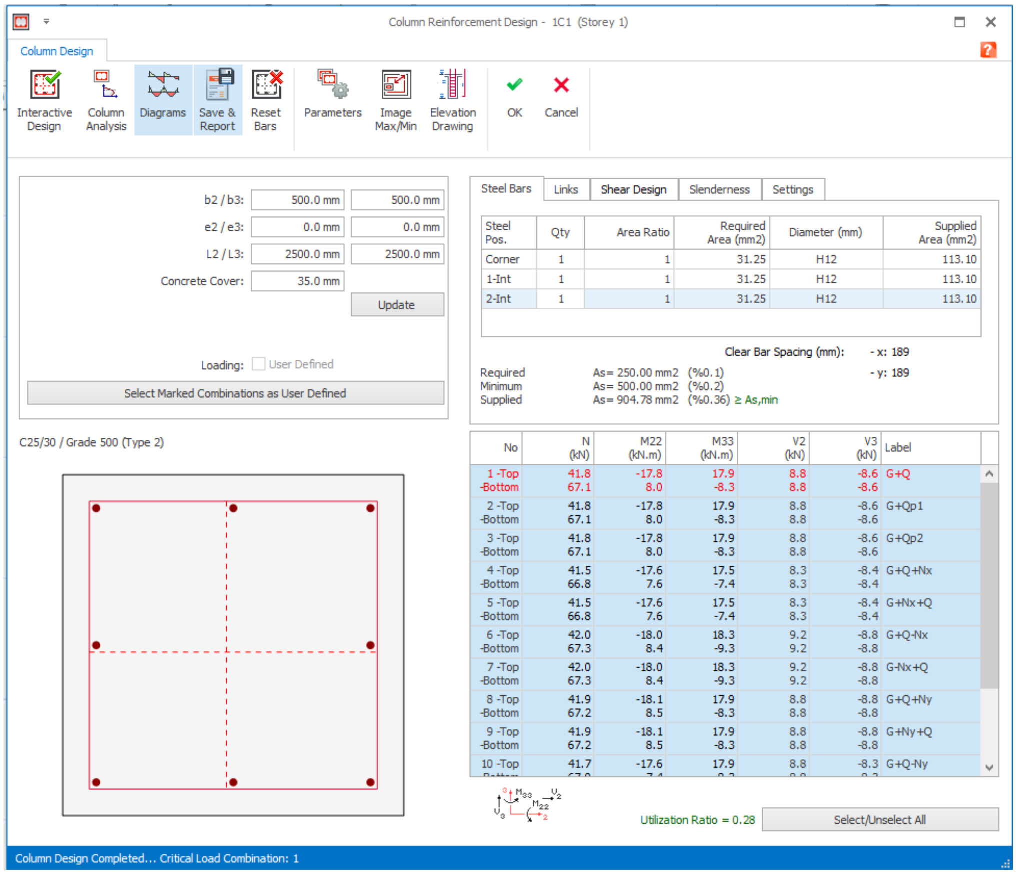


Steel Bars – Links:



Short Square Column Example

Column 1C1 will be used to demonstrate the design process for a square column.

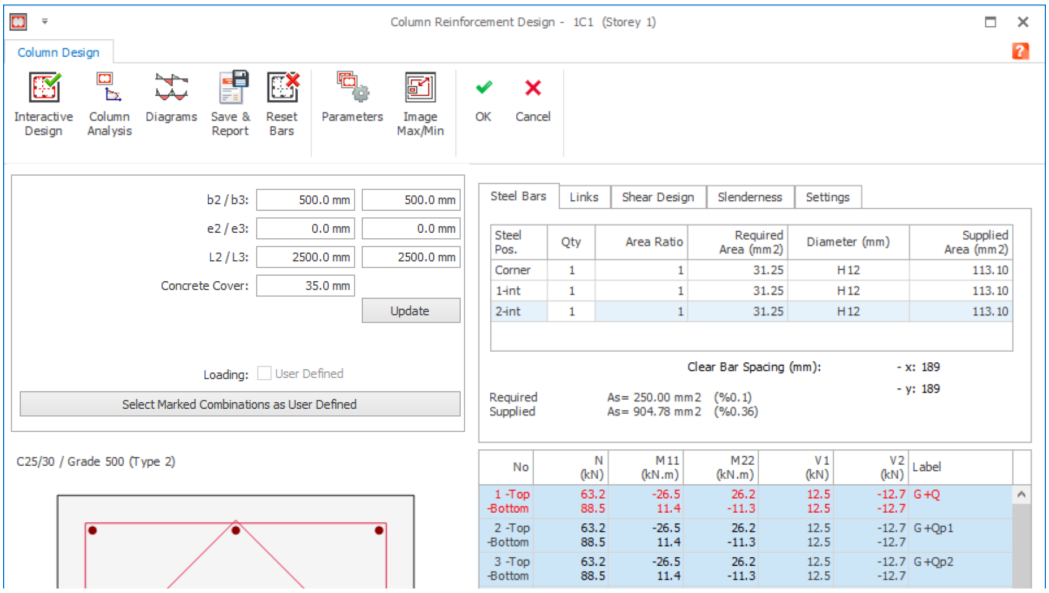


- Column dimension in direction 2, b2 = 500 mm
- Column dimension in direction 3, b2 = 500 mm

The clear height of column in the two directions takes account of the beams framing into the top of the column.

- L_o2 = 3000 mm - 500 mm = 2500 mm
- L_o3 = 3000 mm - 500 mm = 2500 mm

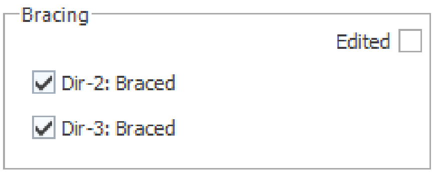
Click the Design button to perform the calculations. This will design the column for all the highlighted design combinations. Design combination 1 is found to be critical and is highlighted in red in the table as shown below.



Each stage of this design process will now be explained in detail.

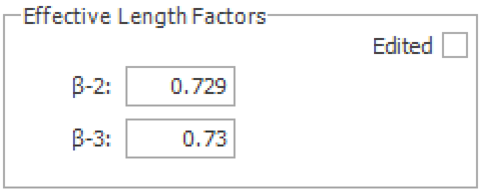
1. Braced or unbraced – Cl 5.8.3.2 (3)

In this example the column has been defined as braced in both directions. This can be confirmed by clicking on the Slenderness tab.



2. Calculate effective height – Cl 5.8.3.2 (3)

The effective length factors 1 and 2 that have been calculated are also displayed on the Slenderness tab as shown.



These effective length factors, β is calculated as follows:

<u>In Direction 2:</u>

At the bottom of the column is fix end, hence the relative flexibilities of rotational restraints at bottom end, k_1 will be taken as 0.1.

Beam stiffness at top of the column

L = 5000 mm, b = 250 mm, d = 500 mm

$$k_{b2} = b \times d^3/(12 \times L) = \mathbf{520833.33\ mm^3}$$

Column stiffness

$$k_{c2} = b_2 \times {b_1}^3/(12 \times L_{o1}) = \mathbf{2083333.33\ mm^3}$$

The relative flexibilities of rotational restraints at top ends, k_2:

$$k_2 = \left({}^{k_{c2}}/_{2 \times k_{b2}}\right) = 2$$

Calculation using the formulae given in EC 2: Cl. 5.8.3.2 (3)

$$Effective\ Length\ Factors, \beta = \left[0.5 \times \sqrt{\left(1 + \frac{k_1}{0.45 + k_1}\right) \times \left(1 + \frac{k_2}{0.45 + k_2}\right)}\right] = \mathbf{0.733}$$

<u>In Direction 3:</u>

At the bottom of the column is fix end, hence the relative flexibilities of rotational restraints at bottom end, k_1 will be taken as 0.1.

Beam stiffness at top of the column

L = 5000 mm, b = 250 mm, d = 500 mm

$$k_{b2} = b \times d^3/(12 \times L) = \mathbf{520833.33\ mm^3}$$

Column stiffness

$$k_{c2} = b_2 \times {b_1}^3/(12 \times L_{o1}) = \mathbf{2083333.33\ mm^3}$$

The relative flexibilities of rotational restraints at top ends, k_2:

$$k_2 = \left({}^{k_{c2}}/_{2 \times k_{b2}}\right) = 2$$

Calculation using the formulae given in EC 2: Cl. 5.8.3.2 (3)

$$Effective\ Length\ Factors, \beta = \left[0.5 \times \sqrt{\left(1 + \frac{k_1}{0.45 + k_1}\right) \times \left(1 + \frac{k_2}{0.45 + k_2}\right)}\right] = \mathbf{0.733}$$

<u>Effective Member Length</u>

$$l_{e2} = \beta_{dir-2} \times l_{o2} = \mathbf{1832.5\ mm}$$

$$l_{e3} = \beta_{dir-3} \times l_{o3} = \mathbf{1832.5\ mm}$$

3. Calculate First Order Moment – 5.2 (7a) & 5.8.8.2 (2)

According to the clause 5.8.8.2 (1), the Eurocode indicates that the first order moment must include the effect of geometric imperfections.

<u>In direction 2:</u>

- M_{Top} = 26.2 kN.m
- M_{Bot} = -11.3 kN.m
- e_i = $l_o/400$ = 4.58 mm
- N_{Ed} = 88.5 kN.m

$$\boldsymbol{M_{01} = \min\{|M_{top}|, |M_{bottom}|\} + e_i N_{Ed}}$$

$$M_{01} = \min\{|26.2|, |-11.3|\} + (4.58/1000)88.5 = \boldsymbol{-11.72\ kN.m}$$

$$\boldsymbol{M_{02} = \max\{|M_{top}|, |M_{bottom}|\} + e_i N_{Ed}}$$

$$M_{02} = \max\{|26.2|, |-11.3|\} + (4.58/1000)88.5 = \boldsymbol{26.62\ kN.m}$$

<u>In direction 3:</u>

- M_{Top} = -26.5 kN.m
- M_{Bot} = 11.4 kN.m
- e_i = $l_o/400$ = 4.58 mm
- N_{Ed} = 88.5 kN.m

$$\boldsymbol{M_{01} = \min\{|M_{top}|, |M_{bottom}|\} + e_i N_{Ed}}$$

$$M_{01} = \min\{|-26.5|, |11.4|\} + (4.58/1000)88.5 = \boldsymbol{11.80\ kN.m}$$

$$\boldsymbol{M_{02} = \max\{|M_{top}|, |M_{bottom}|\} + e_i N_{Ed}}$$

$$M_{02} = \max\{|-26.5|, |11.4|\} + (4.58/1000)88.5 = \boldsymbol{-26.91\ kN.m}$$

If the column is in tension on the same side, M_{01} and M_{02} should have the same sign.

4. Determine Minimum Moment – 6.1 (4)

Eurocode 2 dictates that it is necessary for all compression members to consider a minimum eccentricity, e_o which not less than 20 mm.

$$e_o = max\left({}^{h}/_{30}, 20\right) = max\left({}^{500}/_{30}, 20\right) = max(16.67, 20) = \boldsymbol{20\ mm}$$

$$M_{min} = N_{Ed} \times e_o = 88.5\ \times {}^{20}/_{1000} = \boldsymbol{1.77\ kN.m}$$

5. Check Slenderness - Cl 5.8.3.2 (2)

The slenderness in direction 2 and 3 are the same as the column is symmetrical.

$$\lambda = {}^{l_o}/_{i} = \frac{1832.5}{144} = \boldsymbol{12.73}$$

6. Check Slenderness limits and Classify as short or slender – Cl 5.8.3.1

The limiting slenderness can be calculated by the equation below:

$$\lambda_{lim} = 20 \times A \times B \times C/\sqrt{n}$$

<u>Calculation of A:</u>

To calculate the effective creep ratio, φ_{ef}, the final creep coefficient, $\varphi_{(\infty,t0)}$ and SLS/ULS ratio can be obtained from the column design report.

```
Column: 1C1

Concrete: C25/30 / Steel: Grade 500 (Type 2)
 (Rectangular)
    b2 = 500.0 mm
    b3 = 500.0 mm
    Area = 0.25 m2
    I-33 = 5.21E-03 m4
    I-22 = 5.21E-03 m4
    r2 = 1.44E+02 mm
    r3 = 1.44E+02 mm
    Es = 200000.00 N/mm2
    Ecd = 26229.84 N/mm2
    Eta Fcd = 12.75 N/mm2

EFFECTIVE CREEP RATIO

    SLS/ULS = 0.70      SLS/ ULS ratio
    RH = 50.00
    t0 = 14.00
    Fcm = 33.00 MPa
    h0 = 250.0 mm
    Beta-H = 625.04
    Phi-RH = 1.79
    Phi-0  = 2.92          Effective Creep
    Phi(inf,t0) = 2.90       Coefficient
```

$$\varphi_{ef} = \varphi_{(\text{inf},t0)} \times {}^{SLS}/_{ULS} = 0.7 \times 2.9 = \mathbf{2.03}$$

Hence,

$$A = {}^{1}/_{(1+0.2\varphi_{ef})} = {}^{1}/_{(1+0.2(2.03))} = \mathbf{0.71}$$

<u>Calculation of B:</u>

- Concrete Compressive Strength, $\boldsymbol{f_{cd} = \alpha\left({}^{f_{yk}}/_{\gamma_c}\right) = 0.85\left({}^{25}/_{1.5}\right) = 14.17 N/mm^2}$
- Steel Design Strength, $\boldsymbol{f_{yd} = {}^{f_{yk}}/_{\gamma_s} = {}^{500}/_{1.15} = 434.8\ N/mm^2}$
- Area of provided reinforcement, $A_{s,\text{ provided}}$ = 904.78 mm^2
- Area of concrete, $\boldsymbol{A_c = (500 \times 500) - 904.78 = 249095.22\ mm^2}$
- The mechanical reinforcement ratio, ϖ:

$$\boldsymbol{\omega = {}^{A_s f_{yd}}/_{A_c f cd} = {}^{(904.78 \times 434.8)}/_{(249095.22 \times 14.17)} = 0.11}$$

Hence,

$$B = \sqrt{1+2\omega} = \sqrt{1+2(0.11)} = \mathbf{1.11}$$

<u>Calculation of C:</u>

$$C = 1.7 - rm, \qquad where\ rm = M_{01}/M_{02}$$

$$C\ in\ dir-2=1.7-\left(-\frac{11.3}{26.2}\right)=\mathbf{2.13}$$

$$C\ in\ dir-3=1.7-\left(-\frac{11.4}{26.5}\right)=\mathbf{2.13}$$

<u>Calculation of n:</u>

- The design axial load, N_{Ed} = 88.5 kN

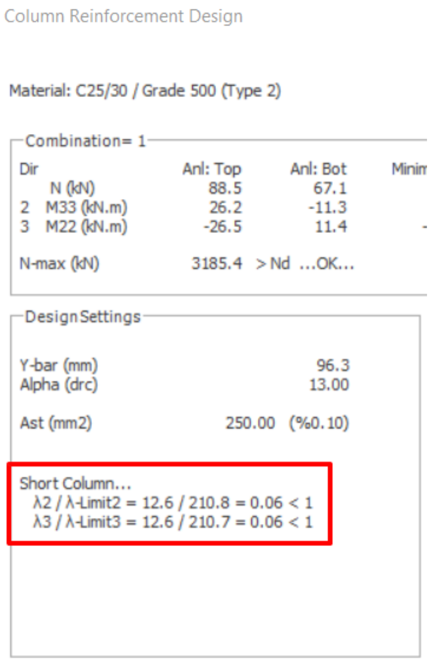
$$n={N_{Ed}}/{(A_c f_{cd})}={88.5\times1000}/{(249095.22\times14.17)}=\mathbf{0.03}$$

Hence, the limiting slenderness will be:

$$\lambda_{lim}={20\times A\times B\times C}/{\sqrt{n}}={20\times A\times B\times C}/{\sqrt{n}}={20\times0.71\times1.11\times2.13}/{\sqrt{0.03}}=\mathbf{211.71}$$

$$\lambda_{lim}=\mathbf{211.71}\ \leq\lambda=12.73,\qquad \boldsymbol{hence\ the\ column\ is\ classified\ as\ short\ column.}$$

The classification is shown on the Column Reinforcement Design dialog.



7. If short, calculate design moments – Cl 5.8.8.2 (2)

If the column is not slender, the design moment, M_{Ed} = M_{02}.

<u>In direction 1:</u>

$$M_{Ed}=M_{02}=\mathbf{26.62\ kN.m}$$

<u>In direction 2:</u>

$$M_{Ed}=M_{02}=\mathbf{-26.91\ kN.m}$$

Column Reinforcement Design

Material: C25/30 / Grade 500 (Type 2)

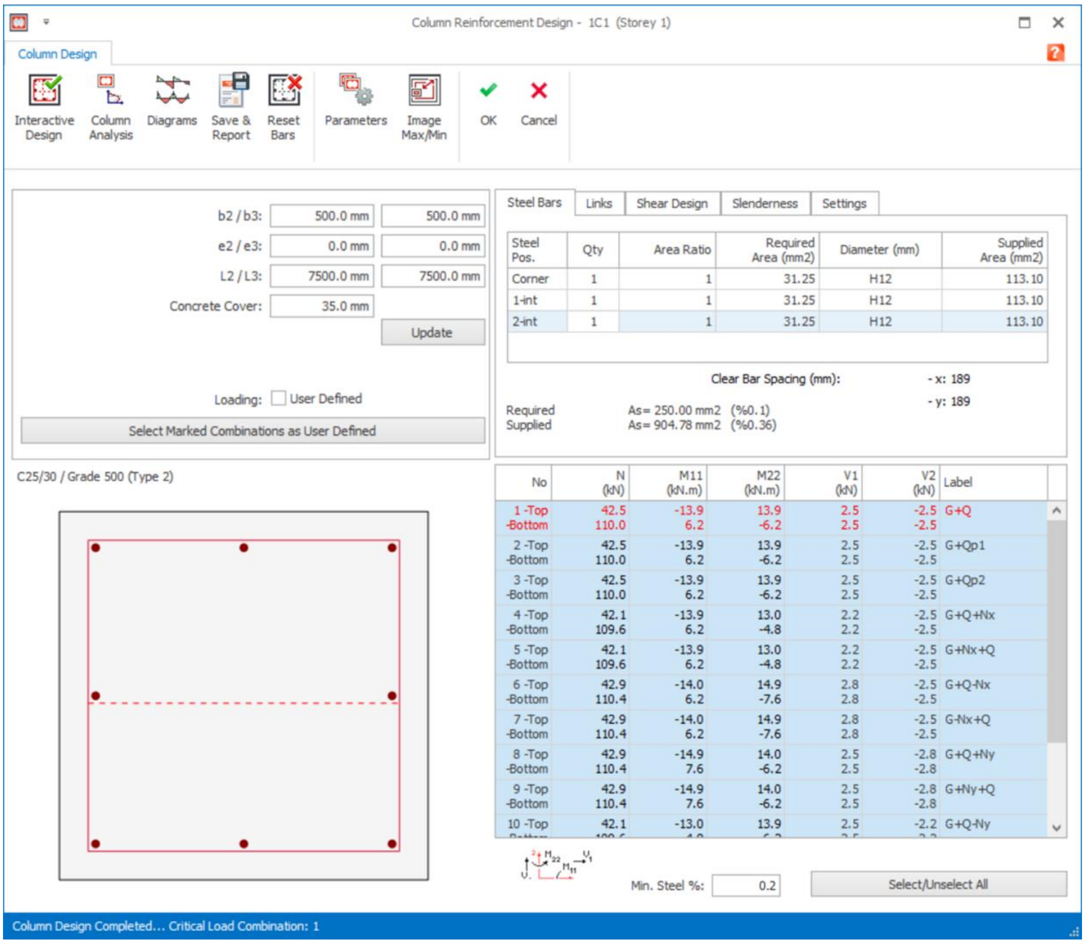
Combination= 1

Dir		Anl: Top	Anl: Bot	Minimum	Beta	Design
	N (kN)	88.5	67.1			88.5
2	M33 (kN.m)	26.2	-11.3	1.8	0.729	26.6
3	M22 (kN.m)	-26.5	11.4	-1.8	0.730	-26.9

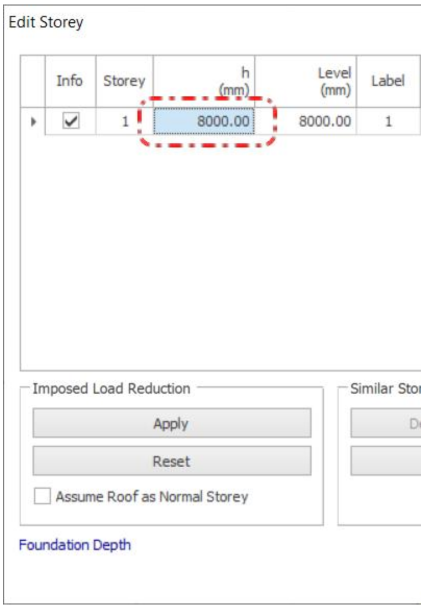
N-max (kN) 3185.4 > Nd ...OK...

Slender Square Column Example

Column 1C1 will be used to demonstrate the design process for a slender square column.



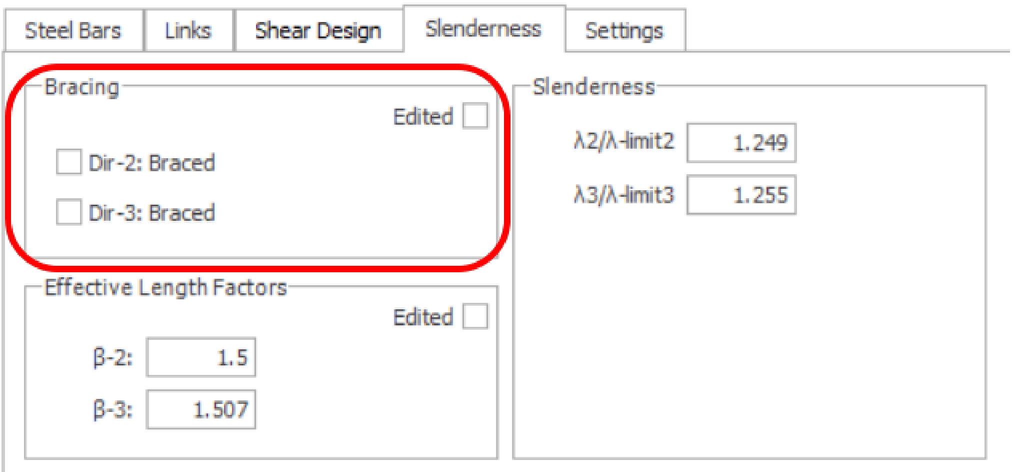
The longer the column, the higher the tendency of the column to be slender. Thus, the height of the storey has been increased from 3.5 m to 8 m.



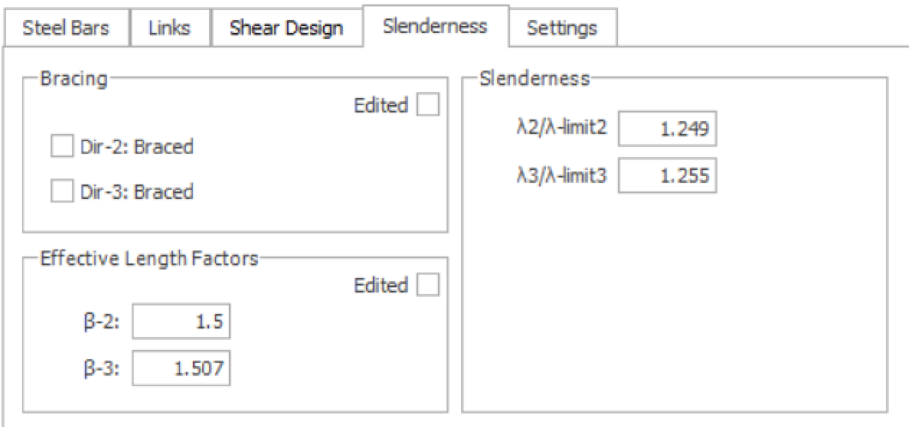
The clear height of column in the two directions takes account of the beams framing into the top of the column.

- L_o2 = 8000 mm - 500 mm = 7500 mm
- L_o3 = 8000 mm - 500 mm = 7500 mm

Uncheck the options of Dir-2: Braced and Dir-3: Braced to design 1C1 as bracing column.



1. Braced or Unbraced – Cl 5.8.3.2 (3)



The circular column in this model should be considered as unbraced. If the column is designed as such, the effective length factors in the two directions will be calculated using the equation 5.16 as stated in EC 2.

In Direction 2:

The stiffness constant at both ends is the same as the stiffness constant in the previous example. At the bottom of the column is fix end, hence the relative flexibilities of rotational restraints at bottom end, k_1 will be taken as 0.1.

The relative flexibilities of rotational restraints at top ends, k_2:

$$k_2 = 0.6$$

Calculation using the formulae given in **EC 2: Cl. 5.8.3.2 (3).** The effective length factors are whichever greatest of:

$$Effective\ Length\ Factors, \beta = \left[\sqrt{\mathbf{1 + 10\frac{k_1 \cdot k_2}{k_1 + k_2}}}\right] = \mathbf{1.36}$$

or

$$Effective\ Length\ Factors, \beta = \left(1 + \frac{\boldsymbol{k_1}}{1 + \boldsymbol{k_1}}\right) \cdot \left(1 + \frac{\boldsymbol{k_2}}{1 + \boldsymbol{k_2}}\right) = \mathbf{1.50}$$

Hence, $\beta = 1.50$

In Direction 3:

At the bottom of the column is fix end, hence the relative flexibilities of rotational restraints at bottom end, k_1 will be taken as 0.1.

The relative flexibilities of rotational restraints at top ends, k_2:

$$k_2 = 0.6$$

Calculation using the formulae given in **EC 2: Cl. 5.8.3.2 (3).** The effective length factors are whichever greatest of:

$$Effective\ Length\ Factors, \beta = \left[\sqrt{\mathbf{1} + \mathbf{10}\frac{\boldsymbol{k_1} \cdot \boldsymbol{k_2}}{\boldsymbol{k_1} + \boldsymbol{k_2}}}\right] = \mathbf{1.36}$$

or

$$Effective\ Length\ Factors, \beta = \left(1 + \frac{\boldsymbol{k_1}}{1 + \boldsymbol{k_1}}\right) \cdot \left(1 + \frac{\boldsymbol{k_2}}{1 + \boldsymbol{k_2}}\right) = \mathbf{1.50}$$

Hence, $\beta = 1.50$

2. Calculate effective height – Cl 5.8.3.2 (3)

The values of β_2 and β_3 are calculated in the same way as in the previous square column example. Therefore, the full calculations will not be repeated here.

The effective height of the column is calculated as:

$$l_{e,2} = \beta_2 l_{o2} = 1.50 \times 7500 = \mathbf{11250\ mm}$$

$$l_{e,3} = \beta_3 l_{o3} = 1.50 \times 7500 = \mathbf{11250\ mm}$$

3. Determine First Order Moment – Cl. 5.2 (7a) & 5.8.8.2 (2)

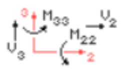
Column Reinforcement Design

Material: C25/30 / Grade 500 (Type 2)

Combination= 1

Dir		Anl: Top	Anl: Bot	Minimum	Beta	Design
	N (kN)	110.0	88.5			110.0
2	M33 (kN.m)	13.9	-6.2	2.2	1.500	$\boxed{24.0}$
3	M22 (kN.m)	-13.9	6.2	-2.2	1.507	$\boxed{-23.9}$

N-max (kN) 3185.4 > Nd ...OK...



In direction – 2:

- M_{Top} = 13.9 kN.m
- M_{Bot} = -6.2 kN.m
- e_i = l_o/400 = 11250/400 = 28.13 mm
- N_{Ed} = 110 kN

$$\boldsymbol{M_{01}} = \mathbf{min}\{|\boldsymbol{M_{top}}|, |\boldsymbol{M_{bottom}}|\} + \boldsymbol{e_i N_{Ed}}$$

$$M_{01} = \min\{|13.9|, |-6.2|\} + (28.13/1000)110 = \mathbf{-3.1057\ kN.m}$$

$$\boldsymbol{M_{02}} = \mathbf{max}\{|\boldsymbol{M_{top}}|, |\boldsymbol{M_{bottom}}|\} + \boldsymbol{e_i N_{Ed}}$$

$$M_{02} = \max\{|13.9|, |-6.2|\} + (28.13/1000)110 = \mathbf{16.99\ kN.m}$$

$$M_{0e} = (0.6 \times M_{02}) + (0.4 \times M_{01}) \geq 0.4(M_{02})$$

$M_{0e} = (0.6 \times 16.99) + (0.4 \times -3.1057) = \mathbf{8.95\ kN.m} \geq 6.796\ kN.m$

Hence, $\boldsymbol{M_{0e} = 8.95\ kN.m}$

<u>In direction – 3:</u>

- M_{Top} = -13.9 kN.m
- M_{Bot} = 6.2 kN.m
- e_i = $l_o/400$ = 11310/400 = 28.3 mm
- N_{Ed} = 110 kN

$\boldsymbol{M_{01} = \min\{|M_{top}|, |M_{bottom}|\} + e_i N_{Ed}}$

$M_{01} = \min\{|-13.9|, |6.2|\} + (28.3/1000)110 = \mathbf{9.313\ kN.m}$

$\boldsymbol{M_{02} = \max\{|M_{top}|, |M_{bottom}|\} + e_i N_{Ed}}$

$M_{02} = \max\{|-13.9|, |6.2|\} + (28.3/1000)110 = \mathbf{-10.787\ kN.m}$

$M_{0e} = (0.6 \times M_{02}) + (0.4 \times M_{01}) \geq 0.4(M_{02})$

$M_{0e} = (0.6 \times -10.787) + (0.4 \times 9.313) = -2.747\ kN.m \geq \mathbf{-4.315}\ kN.m$

$Hence, M_{0e} = -2.747\ kN.m$

4. Determine Minimum Moment – Cl. 6.1 (4)

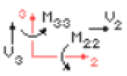
Column Reinforcement Design

Material: C25/30 / Grade 500 (Type 2)

Combination= 1

Dir		Anl: Top	Anl: Bot	Minimum	Beta	Design
	N (kN)	110.0	88.5			110.0
2	M33 (kN.m)	13.9	-6.2	2.2	1.500	24.0
3	M22 (kN.m)	-13.9	6.2	-2.2	1.507	-23.9

N-max (kN) 3185.4 > Nd ...OK...



<u>In Direction-2 :</u>

$e_o = max\left(h/_{30}, 20\right) = max\left(500/_{30}, 20\right) = max(16.67, 20) = \mathbf{20\ mm}$

$M_{min} = N_{Ed} \times e_o = 110\ \times {}^{20}/_{1000} = \mathbf{2.2\ kN.m}$

<u>In Direction-3 :</u>

$e_o = max\left(h/_{30}, 20\right) = max\left(500/_{30}, 20\right) = max(16.67, 20) = \mathbf{20\ mm}$

$M_{min} = N_{Ed} \times e_o = 110\ \times {}^{20}/_{1000} = \mathbf{-2.2\ kN.m}$

5. Check Slenderness – Cl. 5.8.3.2 (2)

The slenderness of the square column:

In direction - 2:

$$\lambda = {}^{l_o}/_{i} \quad = {}^{11250}/_{144.25} = \mathbf{77.99}$$

In direction - 3:

$$\lambda = {}^{l_o}/_{i} \quad = {}^{11250}/_{144.25} = \mathbf{77.99}$$

6. Check Slenderness limits and Classify as short or slender – Cl 5.8.3.1

The limiting slenderness can be calculated by the equation below:

$$\lambda_{lim} = 20 \times A \times B \times C/\sqrt{n}$$

Calculation of A:

To calculate the effective creep ratio, φ_{ef}, the final creep coefficient, $\varphi_{(\infty,t0)}$ and SLS/ULS ratio can be obtained from the column design report.

```
Column: 1C1

Concrete: C25/30 / Steel: Grade 500 (Type 2)
 (Rectangular)
    b1 = 500.0 mm
    b2 = 500.0 mm
    Area = 0.25 m2
    I-22 = 5.21E-03 m4
    I-11 = 5.21E-03 m4
    r1 = 1.44E+02 mm
    r2 = 1.44E+02 mm
    Es = 200000.00 N/mm2
    Ecd = 26229.84 N/mm2
    Eta Fcd = 12.75 N/mm2

EFFECTIVE CREEP RATIO

    SLS/ULS = 0.70
    RH = 50.00
    t0 = 14.00
    Fcm = 33.00 MPa
    h0 = 250.0 mm
    Beta-H = 625.04
    Phi-RH = 1.79
    Phi-0  = 2.92
    Phi(inf,t0) = 2.90
```

$$\varphi_{ef} = \varphi_{(\text{inf},t0)} \times {}^{SLS}/_{ULS} = 2.9 \times 0.7 = \mathbf{2.03}$$

Hence,

$$A = {}^{1}/_{(1+0.2\varphi_{ef})} = {}^{1}/_{(1+0.2(2.03))} = \mathbf{0.71}$$

Calculation of B:

- Concrete Compressive Strength, $\boldsymbol{f_{cd}} = \boldsymbol{\alpha}\left({}^{\boldsymbol{f_{yk}}}/_{\boldsymbol{\gamma_c}}\right) = \mathbf{0.85}\left({}^{\mathbf{25}}/_{\mathbf{1.5}}\right) = \mathbf{14.17}\boldsymbol{N/mm^2}$
- Steel Design Strength, $\boldsymbol{f_{yd}} = {}^{\boldsymbol{f_{yk}}}/_{\boldsymbol{\gamma_s}} = {}^{\mathbf{500}}/_{\mathbf{1.15}} = \mathbf{434.8}\ \boldsymbol{N/mm^2}$
- Area of provided reinforcement, $A_{s,\ provided}$ = 904.78 mm^2
- Area of concrete, $\boldsymbol{A_c} = (\mathbf{500} \times \mathbf{500}) - \mathbf{904.78} = \mathbf{249095.22}\ \boldsymbol{mm^2}$
- The mechanical reinforcement ratio, ϖ:

$$\omega = {}^{A_s f_{yd}}/_{A_c f cd} = {}^{(904.78 \times 434.8)}/_{(249095.22 \times 14.17)} = \mathbf{0.11}$$

Hence,

$$B = \sqrt{1 + 2\omega} = \sqrt{1 + 2(0.14)} = \mathbf{1.10}$$

<u>Calculation of C:</u>

$$C = 1.7 - rm, \qquad where\ r_m = M_{01}/M_{02}$$

$$r_m = 1\ if\ column\ is\ unbraced.$$

$$C = 1.7 - 1 = 0.7$$

<u>Calculation of n:</u>

- The design axial load, N_{Ed} = 110 kN

$$n = {}^{N_{Ed}}/_{(A_c f_{cd})} = {}^{110 \times 1000}/_{(249095.22 \times 14.17)} = \mathbf{0.03}$$

Hence, the limiting slenderness will be:

$$\lambda_{lim} = {}^{20 \times A \times B \times C}/_{\sqrt{n}} = {}^{20 \times A \times B \times C}/_{\sqrt{n}} = {}^{20 \times 0.71 \times 1.10 \times 0.7}/_{\sqrt{0.03}} = \mathbf{63.13}$$

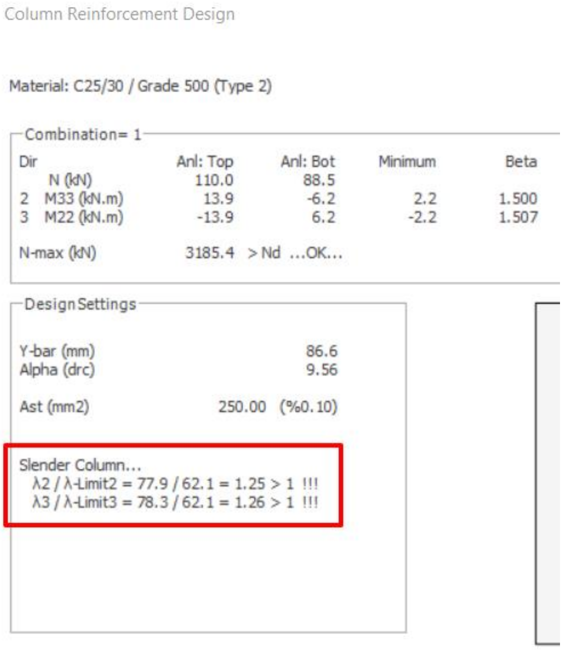
<u>In direction - 2:</u>

$$\lambda_{lim} = 63.13 \ \leq \lambda = 77.99, \qquad \boldsymbol{hence\ the\ column\ is\ classified\ as\ slender\ column}.$$

<u>In direction - 3:</u>

$$\lambda_{lim} = 63.13 \ \leq \lambda = 77.99, \qquad \boldsymbol{hence\ the\ column\ is\ classified\ as\ slender\ column}.$$

The classification is shown on the Column Reinforcement Design dialog.



7. If slender – Calculate Nominal Second Order Moment and design moment – Cl 5.8.8.2 (3) & 5.8.8.3

Calculation of correction factor depending on axial load, K_r

$$K_r = \frac{(n_u - n)}{(n_u - n_{bal})} \leq 1 \qquad (Eq\ 5.36)$$

- $n = N_{Ed}/(A_c\, f_{cd})$ = 110 x 1000 / (249095.22 x 14.17) = **0.031**
- $\omega = A_s\, f_{yd} / (A_c\, f_{cd})$ = 904.78 x 434.8 / (249095.22 x 14.17) = **0.11**
- $n_u = 1 + \omega$ = 1+ 0.11 = **1.11**
- n_{bal} = 0.4 as recommended by EC 2.

$$K_r = \frac{(n_u - n)}{(n_u - n_{bal})} = \frac{(1.11 - 0.031)}{(1.11 - 0.4)} = \mathbf{1.54} \leq 1 \quad , hence\ \boldsymbol{K_r = 1}$$

The effect of creep should be taken into account by the following factor:

$$K_\varphi = 1 + \beta\varphi_{ef} \geq 1 \qquad (Eq\ 5.37)$$

- φ_{ef} = **2.03**
- β = 0.35 + f_{ck}/200 – λ/150 = 0.35 + 25/200 – 77.9/150 = **-0.04**

$$K_\varphi = 1 + (-0.04)(2.03) = 0.92 \ \leq 1, \ \ hence\ \ \boldsymbol{K_\varphi = 1}$$

Calculation of reference curvature, r:

$$\boldsymbol{r = K_r K_\emptyset \left(\frac{1}{r_o}\right)} \qquad \boldsymbol{(Eq\ 5.34)}$$

- d = (h/2) + i_s where i_s is the radius of gyration of the total reinforcement area
  d = (500/2) + 174.10 = **424.1 mm**
- $\varepsilon_{yd} = f_{yd} / E_s$ = 424.1 / 200000 = **0.002121**

- $r_o = 0.45\ d / \varepsilon_{yd} = (0.45 \times 424.1) / 0.002121 =$ **89978.78**

$$\frac{1}{r} = K_r K_\phi \left(\frac{1}{r_o}\right) = (1 \times 1)\left(\frac{1}{89986.96}\right) = \mathbf{0.000011114}$$

Calculation of the deflection, e_2

$$e_2 = \frac{(1/r) l_o{}^2}{c} = \frac{(0.000011114)11250^2}{10} = \mathbf{140.66\ mm} \qquad (\boldsymbol{Eq\ 5.33})$$

Additional Moment, M_{add}

$$M_{add}\ in\ dir-2\ \&\ dir-3 = 110 \times \frac{140.66}{1000} = \mathbf{15.5\ kN.m}$$

The nominal second order moment, as known as additional moment in both directions will be shown in the design report:

```
LOADINGS (COMBINATION)

   Analysis Results:

   No              N        M22        M33         V2         V3
                (kN)     (kN.m)     (kN.m)       (kN)       (kN)
  ----------------------------------------------------------------
  1-Bot       110.00     -13.90      13.90       8.75      -8.59
   -Top        88.50       6.20      -6.20       8.75      -8.59
  ----------------------------------------------------------------

   Design Loads:

   No              N        M22        M33   M22(min)   M33(min)
                (kN)     (kN.m)     (kN.m)     (kN.m)     (kN.m)
  ----------------------------------------------------------------
     1        110.00     -23.87      24.02      -2.20       2.20
  ----------------------------------------------------------------

CRITICAL COMBINATION: #1 ()

   Added Moment-22   =    14.91 kN.m
   Added Moment-33   =    15.05 kN.m

   N-Design          =   110.00 kN
   M22-Design        =   -23.87 kN.m
   M33-Design        =    24.02 kN.m

   As(Req)           =   250.00 mm2

   Y                 =    86.61 mm
   Alpha             =     9.56
   EpsC              =     0.0035
```

8. Calculate Design Moment

In Direction - 2:

- M_{01} = -3.11 kN.m
- M_{02} = 16.99 kN.m
- M_{add} = 15.5 kN.m
- M_{oe} = 8.95 kN.m

$$M_{Ed} = \max(M_{02}, M_{0e} + M_{add}, M_{01} + 0.5M_{add}) = \max(16.99, 24.45, 4.64) = \mathbf{24.45\ kN.m}$$

In Direction - 3:

- M_{01} = 9.313 kN.m
- M_{02} = -10.787 kN.m
- M_{add} = 15.5 kN.m

- M_{oe} = -2.747 kN.m

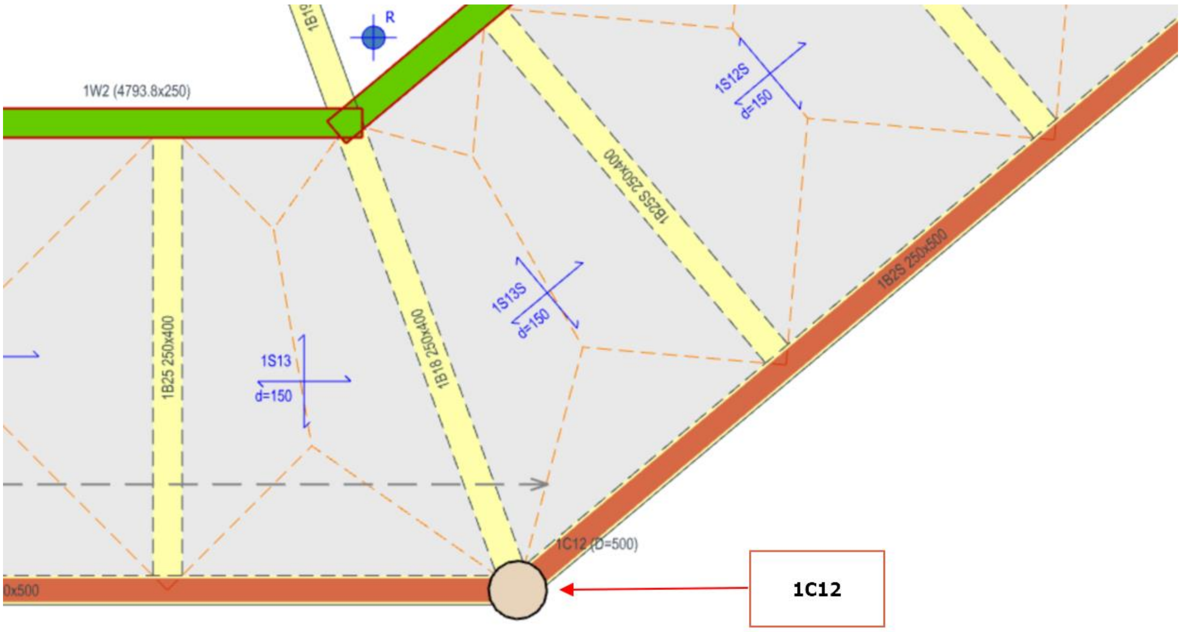
$$M_{Ed} = \max(M_{02}, M_{0e} + M_{add}, M_{01} + 0.5M_{add}) = \max(-10.787, 12.753, 17.063) = \mathbf{17.06\ kN.m}$$

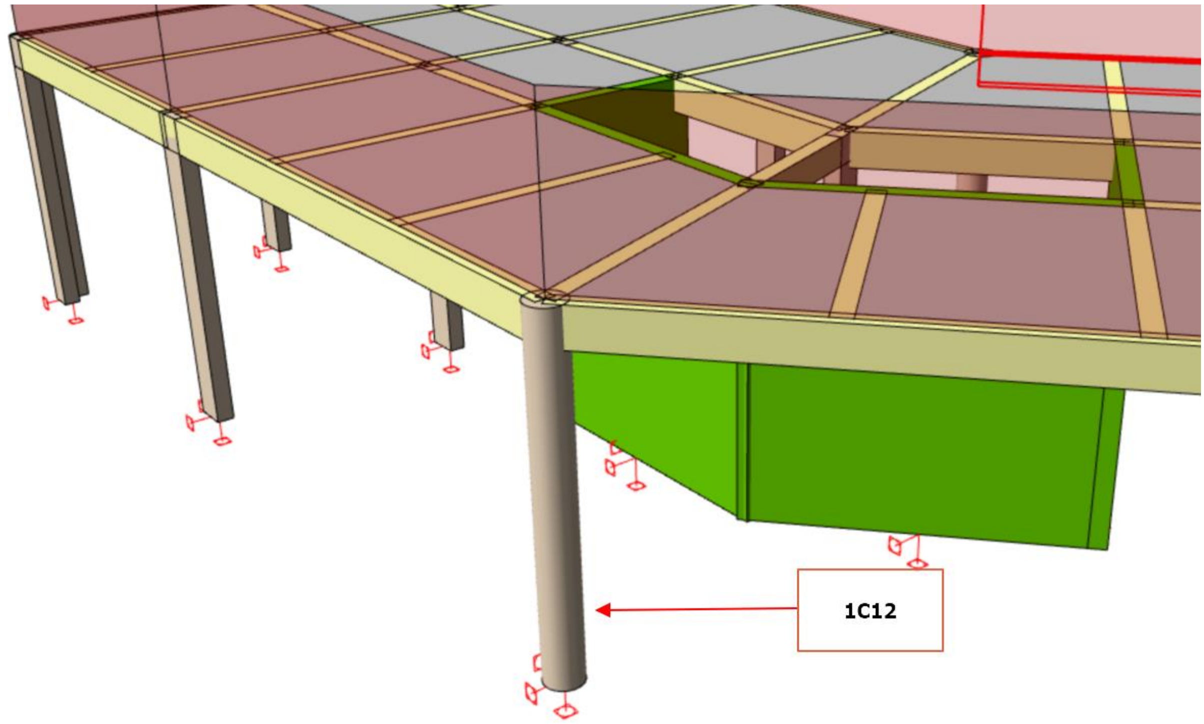
Braced Circular Column Example

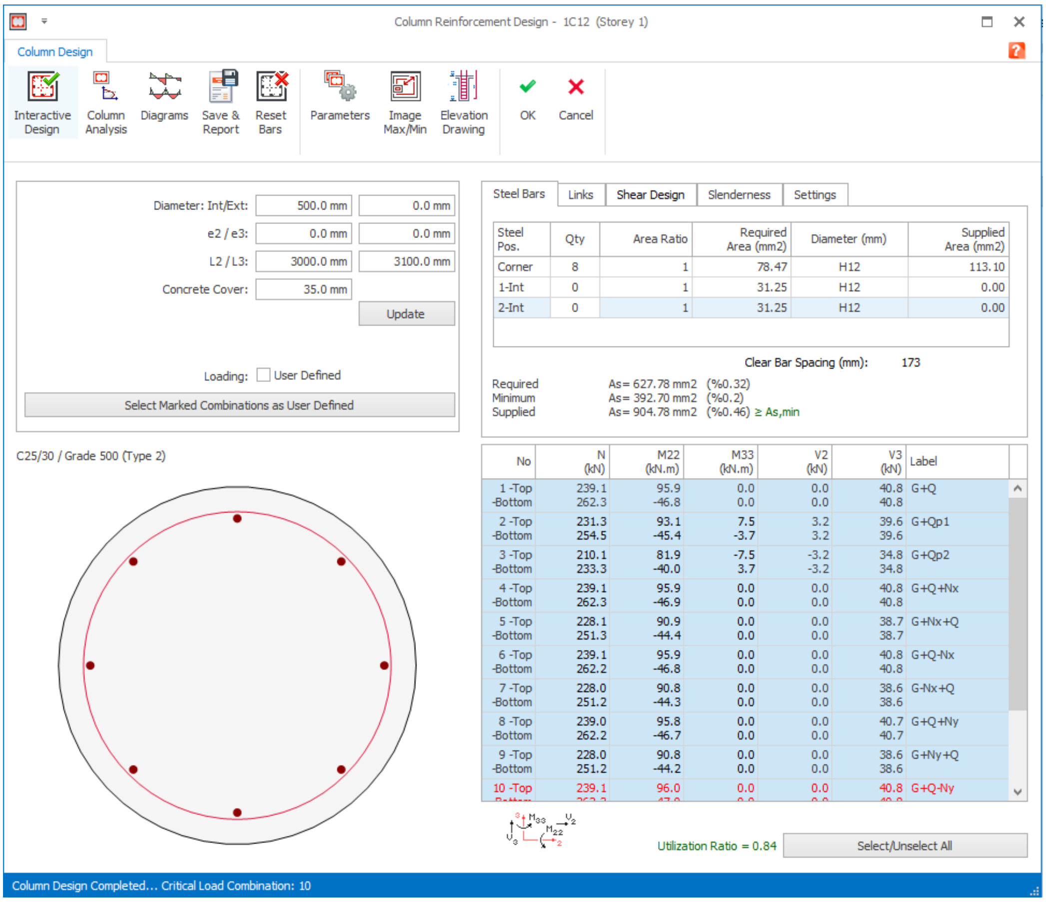
Open the example model ***Doc_Example_4*** and save to a new name (so not to destroy the original example). The copied model is then adjusted so that its storey height is increased to 5.5 m and it is then re-analysed. In this model the steel grade is 500 and the steel material factor is 1.15. Bar diameters of 12 mm are used. The minimum link diameter is set to 8 mm.

The actual design process would be identical irrespective of which steel grade and material factor and bar diameters are used.

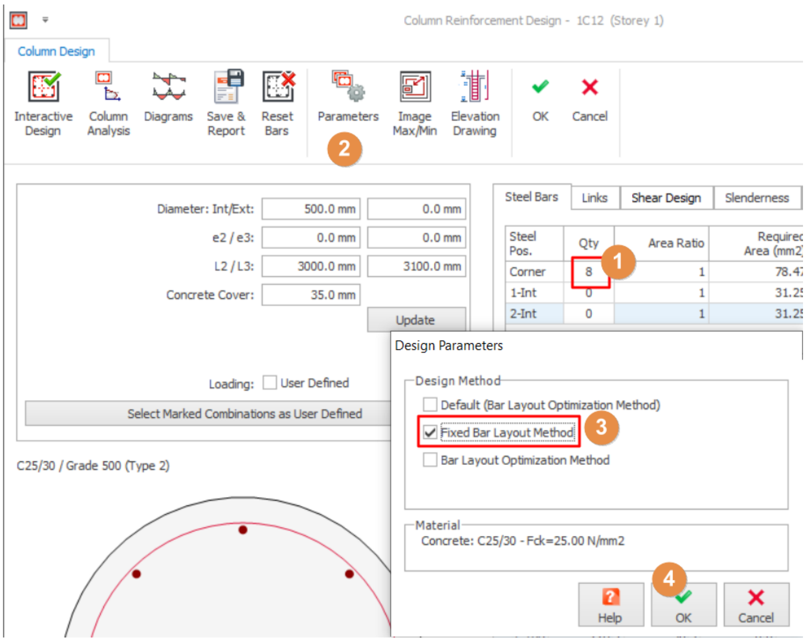
Column 1C12 will be used to demonstrate the design process for a circular column.







Click on the Parameters button and change to fixed bar layout.



This will force the design to adopt the number of bars shown in the 'Qty' cell of the above table. In this example we will use 8 bars in the design, (Qty = 8). When the design is performed, the bar sizes will be adjusted to obtain an economic solution based on this layout.

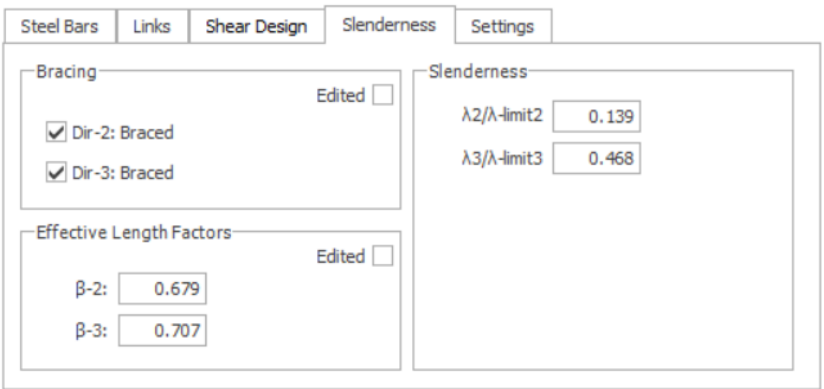
Column Diameter, D = 500 m

The clear height of column in the two directions takes account of the beams framing into the top of the column.

L_{o2} = 3500 mm – 500 mm = **3000 mm**

L_{o3} = 3500 mm – 400 mm = **3100 mm**

1. **Braced or Unbraced – Cl 5.8.3.2 (3)**



The circular column in this model should be considered as braced. If the column is designed as such, the effective length factors in the two directions are calculated as:

β_2 = 0.679

β_3 = 0.707

2. Calculate effective height – Cl 5.8.3.2 (3)

The values of β_1 and β_2 are calculated in the same way as in the previous rectangular column example. The full calculations will therefore not be repeated here.

The effective height of the column is calculated as:

$$l_{e,2} = \beta_2 l_{o2} = 2037\ mm$$

$$l_{e,3} = \beta_3 l_{o3} = 2192\ mm$$

3. Determine First Order Moment – Cl. 5.2 (7a) & 5.8.8.2 (2)

Column Reinforcement Design

Material: C25/30 / Grade 500 (Type 2)

Combination= 1

Dir	Anl: Top	Anl: Bot	Minimum	Beta	Design
N (kN)	239.1	267.9			267.9
2 M33 (kN.m)	0.0	0.0	-5.4	0.679	0.0
3 M22 (kN.m)	97.3	-47.6	5.4	0.707	98.8
N-max (kN)	2569.8	> Nd ...OK...			

- M_{Top} = 97.3 kN.m
- M_{Bot} = -47.6 kN.m
- e_i = $l_o/400$ = 5.70 mm
- N_{Ed} = 267.9 kN

$$\boldsymbol{M_{01} = \min\{|M_{top}|, |M_{bottom}|\} + e_i N_{Ed}}$$

$$M_{01} = \min\{|97.3|, |-47.6|\} + (5.70/1000)267.90 = \boldsymbol{-46.07\ kN.m}$$

$$\boldsymbol{M_{02} = \max\{|M_{top}|, |M_{bottom}|\} + e_i N_{Ed}}$$

$$M_{02} = \max\{|97.3|, |-47.6|\} + (5.70/1000)267.90 = \boldsymbol{98.83\ kN.m}$$

4. Determine Minimum Moment – Cl. 6.1 (4)

Column Reinforcement Design

Material: C25/30 / Grade 500 (Type 2)

Combination= 1

Dir	Anl: Top	Anl: Bot	Minimum	Beta	Design
N (kN)	239.1	267.9			267.9
2 M33 (kN.m)	0.0	0.0	-5.4	0.679	0.0
3 M22 (kN.m)	97.3	-47.6	$\boxed{5.4}$	0.707	98.8
N-max (kN)	2569.8	> Nd ...OK...			

$$e_o = max\left({}^{d}/_{30}, 20\right) = max\left({}^{500}/_{30}, 20\right) = max(16.67, 20) = \boldsymbol{20\ mm}$$

$$M_{min} = N_{Ed} \times e_o = 267.90 \times {}^{20}/_{1000} = \mathbf{5.36\ kN.m}$$

5. **Check Slenderness – Cl. 5.8.3.2 (2)**

The slenderness of the circular column:

$$\lambda_3 = 4\left({}^{l_o}/_{d}\right) = 4 \times \frac{2192}{500} = \mathbf{17.54}$$

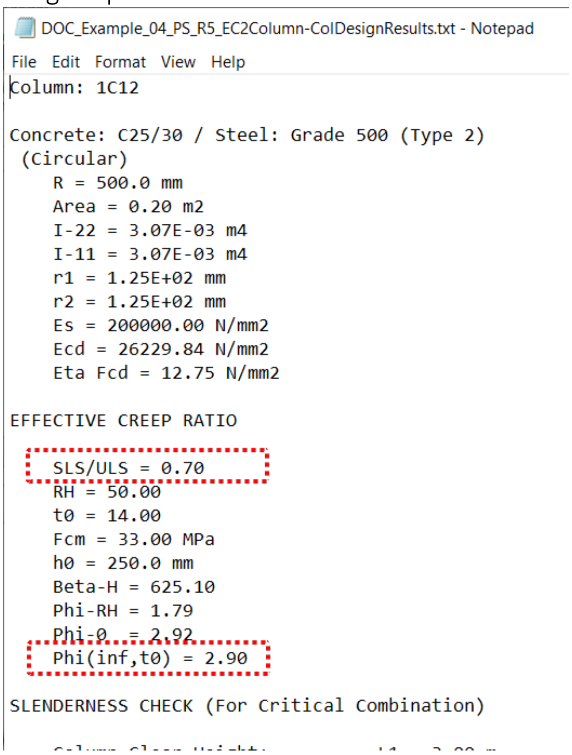
6. **Check Slenderness limits and classify as short or slender – Cl 5.8.3.1**

The limiting slenderness can be calculated by the equation below:

$$\lambda_{lim} = 20 \times A \times B \times C/\sqrt{n}$$

<u>Calculation of A:</u>

To calculate the effective creep ratio, φ_{ef}, the final creep coefficient, $\varphi_{(\infty,t0)}$ and SLS/ULS ratio can be obtained from the column design report.



DOC_Example_04_PS_R5_EC2Column-ColDesignResults.txt - Notepad

File Edit Format View Help

```
Column: 1C12

Concrete: C25/30 / Steel: Grade 500 (Type 2)
 (Circular)
    R = 500.0 mm
    Area = 0.20 m2
    I-22 = 3.07E-03 m4
    I-11 = 3.07E-03 m4
    r1 = 1.25E+02 mm
    r2 = 1.25E+02 mm
    Es = 200000.00 N/mm2
    Ecd = 26229.84 N/mm2
    Eta Fcd = 12.75 N/mm2

EFFECTIVE CREEP RATIO

    SLS/ULS = 0.70
    RH = 50.00
    t0 = 14.00
    Fcm = 33.00 MPa
    h0 = 250.0 mm
    Beta-H = 625.10
    Phi-RH = 1.79
    Phi-0  = 2.92
    Phi(inf,t0) = 2.90

SLENDERNESS CHECK (For Critical Combination)
```

$$\varphi_{ef} = \varphi_{(\inf,t0)} \times {}^{SLS}/_{ULS} = 0.7 \times 2.9 = \mathbf{2.03}$$

Hence,

$$A = {}^{1}/_{(1 + 0.2\varphi_{ef})} = {}^{1}/_{(1 + 0.2(2.03))} = \mathbf{0.71}$$

<u>Calculation of B:</u>

- Concrete Compressive Strength, $\boldsymbol{f_{cd} = \alpha\left({}^{f_{yk}}/_{\gamma_c}\right) = 0.85\left({}^{25}/_{1.5}\right) = 14.17N/mm^2}$

- Steel Design Strength, $\boldsymbol{f_{yd}} = {}^{\boldsymbol{f_{yk}}}/_{\boldsymbol{\gamma_s}} = {}^{\mathbf{500}}/_{\mathbf{1.15}} = \mathbf{434.8}\ \boldsymbol{N/mm^2}$
- Area of provided reinforcement, $A_{s,\ provided}$ = 904.78 mm^2
- Area of concrete, $\boldsymbol{A_c} = (\boldsymbol{\pi} \times (\mathbf{250})^2) - \mathbf{904.78} = \mathbf{195444.76}\ \boldsymbol{mm^2}$
- The mechanical reinforcement ratio, ϖ:

$$\omega = {}^{A_s f_{yd}}/_{A_c fcd} = {}^{(904.78 \times 434.8)}/_{(195444.76 \times 14.17)} = \mathbf{0.14}$$

Hence,

$$B = \sqrt{1 + 2\omega} = \sqrt{1 + 2(0.14)} = \mathbf{1.13}$$

<u>Calculation of C:</u>

$$C = 1.7 - rm, \qquad where\ rm = \frac{M_{01}}{M_{02}}$$

$$C = 1.7 - \frac{-46.07}{98.83} = \mathbf{2.17}$$

<u>Calculation of n:</u>

- The design axial load, N_{Ed} = 267.94 kN

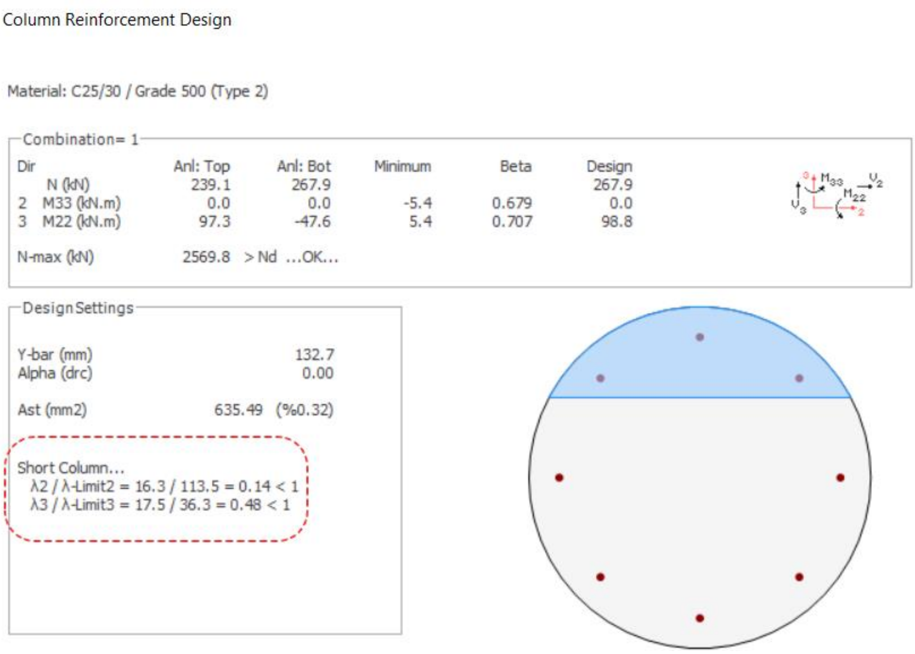
$$n = {}^{N_{Ed}}/_{(A_c f_{cd})} = {}^{267.94 \times 1000}/_{(195444.76 \times 14.17)} = \mathbf{0.1}$$

Hence, the limiting slenderness will be:

$$\lambda_{lim} = {}^{20 \times A \times B \times C}/_{\sqrt{n}} = {}^{20 \times A \times B \times C}/_{\sqrt{n}} = {}^{20 \times 0.71 \times 1.13 \times 2.17}/_{\sqrt{0.1}} = \mathbf{110.11}$$

$$\lambda_{lim} = 110.11 \geq \lambda = 17.54, \qquad \boldsymbol{hence\ the\ column\ is\ classified\ as\ short\ column.}$$

The classification is shown on the Column Reinforcement Design dialog.



7. If short – Calculate Design moment – Cl 5.8.8.2 (2)

If the column is not slender, the design moment, $M_{Ed} = M_{02}$.

$$M_{Ed} = M_{02} = \mathbf{98.83\ kN.m}$$

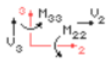
Column Reinforcement Design

Material: C25/30 / Grade 500 (Type 2)

Combination= 1

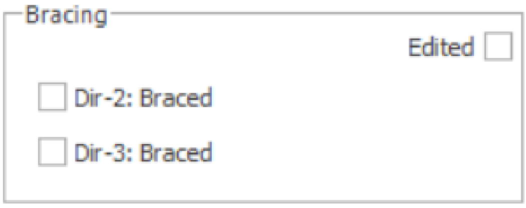
Dir		Anl: Top	Anl: Bot	Minimum	Beta	Design
	N (kN)	239.1	267.9			267.9
2	M33 (kN.m)	0.0	0.0	-5.4	0.679	0.0
3	M22 (kN.m)	97.3	-47.6	5.4	0.707	$\boxed{98.8}$

N-max (kN) 2569.8 > Nd ...OK...



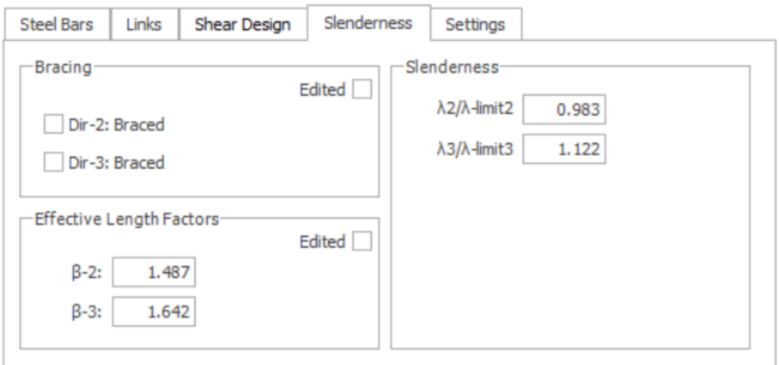
Bracing (Unbraced) and Slender Circular Column Example

Column 1C12 again will be used to demonstrate the design process for an unbraced circular column. The column can be set to unbraced column by unchecking the Dir-1 and Dir-2 in the Slenderness tab.



Then, click the Interactive Design button to update all the parameters.

1. **Braced or Unbraced – Cl 5.8.3.2 (3)**



The circular column in this model should be considered as bracing (unbraced). If the column is designed as such, the effective length factors in the two directions are calculated as:

β_2 = 1.487

β_3 = 1.642

2. **Calculate effective height – Cl 5.8.3.2 (3)**

The values of β_1 and β_2 are calculated in the same way as in the previous example. Therefore, the full calculations will therefore not be repeated here.

The effective height of the column is calculated as:

$$l_{e,2} = \beta_2 l_{o2} = 4460\ mm$$

$$l_{e,3} = \beta_3 l_{o3} = 5090\ mm$$

3. Determine First Order Moment – Cl. 5.2 (7a) & 5.8.8.2 (2)

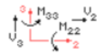
Column Reinforcement Design

Material: C25/30 / Grade 500 (Type 2)

Combination= 1

Dir		Anl: Top	Anl: Bot	Minimum	Beta	Design
	N (kN)	239.1	267.9			267.9
2	M33 (kN.m)	0.0	0.0	-5.4	1.487	0.0
3	M22 (kN.m)	97.3	-47.6	5.4	1.642	$\boxed{101.5}$

N-max (kN) 2569.8 > Nd ...OK...



<u>In direction – 3:</u>

- M_{Top} = 97.3 kN.m
- M_{Bot} = -47.6 kN.m
- e_i = l_o/400 = 6455/400 = 16.14 mm
- N_{Ed} = 267.9 kN.m

$$\boldsymbol{M_{01} = \min\{|M_{top}|, |M_{bottom}|\} + e_i N_{Ed}}$$

$$M_{01} = \min\{|97.3|, |-47.6|\} + (16.14/1000)267.90 = \boldsymbol{-51.79\ kN.m}$$

$$\boldsymbol{M_{02} = \max\{|M_{top}|, |M_{bottom}|\} + e_i N_{Ed}}$$

$$M_{02} = \max\{|97.3|, |-47.6|\} + (1614/1000)267.90 = \boldsymbol{101.49\ kN.m}$$

$$M_{0e} = (0.6 \times M_{02}) + (0.4 \times M_{01}) \geq 0.4(M_{02})$$

$$M_{0e} = (0.6 \times 101.49) + (0.4 \times -51.79) = \boldsymbol{40.18\ kN.m} \leq 40.596\ kN.m$$

$$M_{0e} = 40.596 + \left(\frac{16.14}{1000}\right)267.9 = \boldsymbol{44.92\ kN.m}$$

4. Determine Minimum Moment – Cl. 6.1 (4)

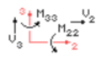
Column Reinforcement Design

Material: C25/30 / Grade 500 (Type 2)

Combination= 1

Dir		Anl: Top	Anl: Bot	Minimum	Beta	Design
	N (kN)	239.1	267.9			267.9
2	M33 (kN.m)	0.0	0.0	-5.4	1.487	0.0
3	M22 (kN.m)	97.3	-47.6	$\boxed{5.4}$	1.642	101.5

N-max (kN) 2569.8 > Nd ...OK...



$$e_o = max\left({}^{d}/_{30}, 20\right) = max\left({}^{500}/_{30}, 20\right) = max(16.67, 20) = \boldsymbol{20\ mm}$$

$$M_{min} = N_{Ed} \times e_o = 267.90\ \times {}^{20}/_{1000} = \boldsymbol{5.36\ kN.m}$$

5. Check Slenderness – Cl. 5.8.3.2 (2)

The slenderness of the circular column:

<u>In direction - 3:</u>

$$\lambda = 4\left({}^{l_o}/_{d}\right) = 4 \times \frac{5090}{500} = \mathbf{40.7}$$

6. Check Slenderness limits and Classify as short or slender – Cl 5.8.3.1

The limiting slenderness can be calculated by the equation below:

$$\lambda_{lim} = 20 \times A \times B \times C/\sqrt{n}$$

<u>Calculation of A:</u>

To calculate the effective creep ratio, φ_{ef}, the final creep coefficient, $\varphi_{(\infty,t0)}$ and SLS/ULS ratio can be obtained from the column design report.

```
EFFECTIVE CREEP RATIO

   SLS/ULS = 0.70
   RH = 50.00
   t0 = 14.00
   Fcm = 33.00 MPa
   h0 = 250.0 mm
   Beta-H = 625.10
   Phi-RH = 1.79
   Phi-0  = 2.92
   Phi(inf,t0) = 2.90
```

$$\varphi_{ef} = \varphi_{(\text{inf},t0)} \times {}^{SLS}/_{ULS} = 2.9 \times 0.7 = \mathbf{2.03}$$

Hence,

$$A = {}^{1}/_{(1+0.2\varphi_{ef})} = {}^{1}/_{(1+0.2(2.03))} = \mathbf{0.71}$$

<u>Calculation of B:</u>

- Concrete Compressive Strength, $\boldsymbol{f_{cd} = \alpha\left({}^{f_{yk}}/_{\gamma_c}\right) = 0.85\left({}^{25}/_{1.5}\right) = 14.17 N/mm^2}$
- Steel Design Strength, $\boldsymbol{f_{yd} = {}^{f_{yk}}/_{\gamma_s} = {}^{500}/_{1.15} = 434.8\ N/mm^2}$
- Area of provided reinforcement, $A_{s,\ provided}$ = 904.78 mm^2
- Area of concrete, $\boldsymbol{A_c = \left(\pi \times (250)^2\right) - 904.78 = 195444.76\ mm^2}$
- The mechanical reinforcement ratio, ϖ:

$$\omega = {}^{A_s f_{yd}}/_{A_c f cd} = {}^{(904.78 \times 434.8)}/_{(195444.76 \times 14.17)} = \mathbf{0.14}$$

Hence,

$$B = \sqrt{1+2\omega} = \sqrt{1+2(0.14)} = \mathbf{1.13}$$

Calculation of C:

$C = 0.7$ when the column is bracing.

Calculation of n:

- The design axial load, N_{Ed} = **267.94 kN**

$$n = {N_{Ed}}/{(A_c f_{cd})} = {267.94 \times 1000}/{(195444.76 \times 14.17)} = \mathbf{0.1}$$

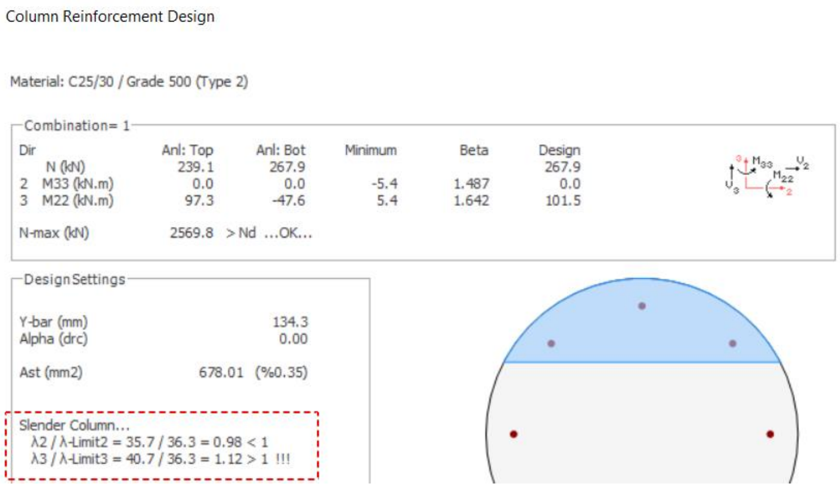
Hence, the limiting slenderness will be:

$$\lambda_{lim} = {20 \times A \times B \times C}/{\sqrt{n}} = {20 \times A \times B \times C}/{\sqrt{n}} = {20 \times 0.71 \times 1.13 \times 0.7}/{\sqrt{0.1}} = \mathbf{35.52}$$

In direction - 3:

$$\lambda_{lim} = 35.52 \ \leq \lambda = 40.7, \qquad \boldsymbol{hence\ the\ column\ is\ classified\ as\ slender\ column.}$$

The classification is shown on the Column Reinforcement Design dialog.



7. If slender – Calculate Nominal Second Order Moment and design moments – Cl 5.8.8.2 (3) & 5.8.8.3

Calculation of correction factor depending on axial load, K_r

$$K_r = \frac{(n_u - n)}{(n_u - n_{bal})} \leq 1 \qquad\qquad (Eq\ 5.36)$$

- $n = N_{Ed}/(A_c f_{cd})$ = 267.9 x 1000 / (195444.761 x 14.17) = **0.097**
- $\omega = A_s f_{yd} / (A_c f_{cd})$ = 904.78 x 434.8 / (195444.761 x 14.17) = **0.142**
- n_u = 1 + 0.142 = **1.142**
- n_{bal} = 0.4 as recommended by EC 2.

$$K_r = \frac{(n_u - n)}{(n_u - n_{bal})} = \frac{(1.142 - 0.097)}{(1.142 - 0.4)} = \mathbf{1.41} \geq 1 \quad , hence\ \boldsymbol{K_r} = \mathbf{1}$$

The effect of creep should be taken into account by the following factor:

$$K_{\varphi} = 1 + \beta\varphi_{ef} \geq 1 \qquad (Eq\ 5.37)$$

- φ_{ef} = **2.03**
- β = 0.35 + f_{ck}/200 – λ/150 = 0.35 + 25/200 – 40.7/150 = **0.204**

$$K_{\varphi} = 1 + (0.204)(2.03) = 1.41\ \geq 1,\ \ hence\ \ \boldsymbol{K_{\varphi} = 1.41}$$

Calculation of reference curvature, r:

$$\boldsymbol{r = K_r K_{\emptyset}\left(\frac{1}{r_o}\right)} \qquad \boldsymbol{(Eq\ 5.34)}$$

- d = (h/2) + i_s where i_s is the radius of gyration of the total reinforcement area
  d = (500/2) + 142.16 = **392.16**
- ε_{yd} = f_{yd} / E_s = 434.8 / 200000 = **0.002174**
- r_o = 0.45 d / ε_{yd} = (0.45 x 392.16) / 0.002174 = **81173.87**

$$\frac{1}{r} = K_r K_{\emptyset}\left(\frac{1}{r_o}\right) = (1 \times 1.26)\left(\frac{1}{81173.87}\right) = \boldsymbol{0.000017}$$

Calculation of the deflection, e_2

$$e_2 = \frac{(1/r)l_o{}^2}{c} = \frac{(0.000017)5090^2}{10} = \boldsymbol{44.46\ mm} \qquad \boldsymbol{(Eq\ 5.33)}$$

Additional Moment, M_{add}

$$M_{add}\ in\ direction - 3 = 267.9 \times \frac{44.46}{1000} = \boldsymbol{11.91\ kN.m}$$

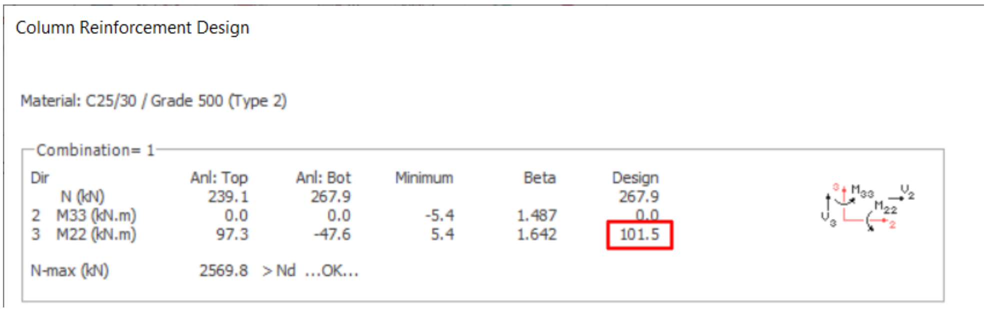
The nominal second order moment, as known as additional moment in both directions will be shown in the design report:

```
LOADINGS (COMBINATION)

   Analysis Results:

   No               N         M22         M33          V2          V3
                 (kN)      (kN.m)      (kN.m)        (kN)        (kN)
  ---------------------------------------------------------------------
  1-Bot        267.90       97.30        0.00        0.00       40.78
   -Top        267.90      -47.60        0.00        0.00       40.78
  ---------------------------------------------------------------------


   Design Loads:

   No               N         M22         M33    M22(min)    M33(min)
                 (kN)      (kN.m)      (kN.m)      (kN.m)      (kN.m)
  ---------------------------------------------------------------------
      1        267.90      101.43        0.00        5.36       -5.36
  ---------------------------------------------------------------------

CRITICAL COMBINATION: #1 ()

   Added Moment-22   =    11.80 kN.m
   Added Moment-33   =     0.00 kN.m

   N-Design          =   267.90 kN
   M22-Design        =   101.43 kN.m
   M33-Design        =     0.00 kN.m

   As(Req)           =   684.23 mm2

   Y                 =   133.89 mm
   Alpha             =     0.00
   EpsC              =   0.0035
```

Calculate Design Moments, M_{Ed}

- M_{01} = -51.79 kN.m
- M_{02} = 101.49 kN.m
- M_{add} = 11.91 kN.m
- M_{oe} = 44.92 kN.m

$$M_{Ed} = \max(M_{02}, M_{0e} + M_2, M_{01} + 0.5M_2) = \max(101.49\,, 56.83\,, -29.33) = \mathbf{101.49\ \mathit{kN.m}}$$



Column Reinforcement Design

Material: C25/30 / Grade 500 (Type 2)

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3	M22 (kN.m)	97.3	-47.6	5.4	1.642	$\boxed{101.5}$

N-max (kN) 2569.8 > Nd ...OK...

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