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ProtaStructure Design Guide

Beam Design to BS8110

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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

ProtaStructure designs beams bent about the major axis using the code clauses given in BS 8110-1:1997: Part 1 Section 3.4. The following table summarises the various stages of the beam design process:

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1.	**If flanged – calculate effective width of flanged**	**3.4.1.5**
2.	**Analysis of Sections**	**3.4.4.1**
3.	**Design for Bending**	**3.4.4.4, 3.4.4.5**
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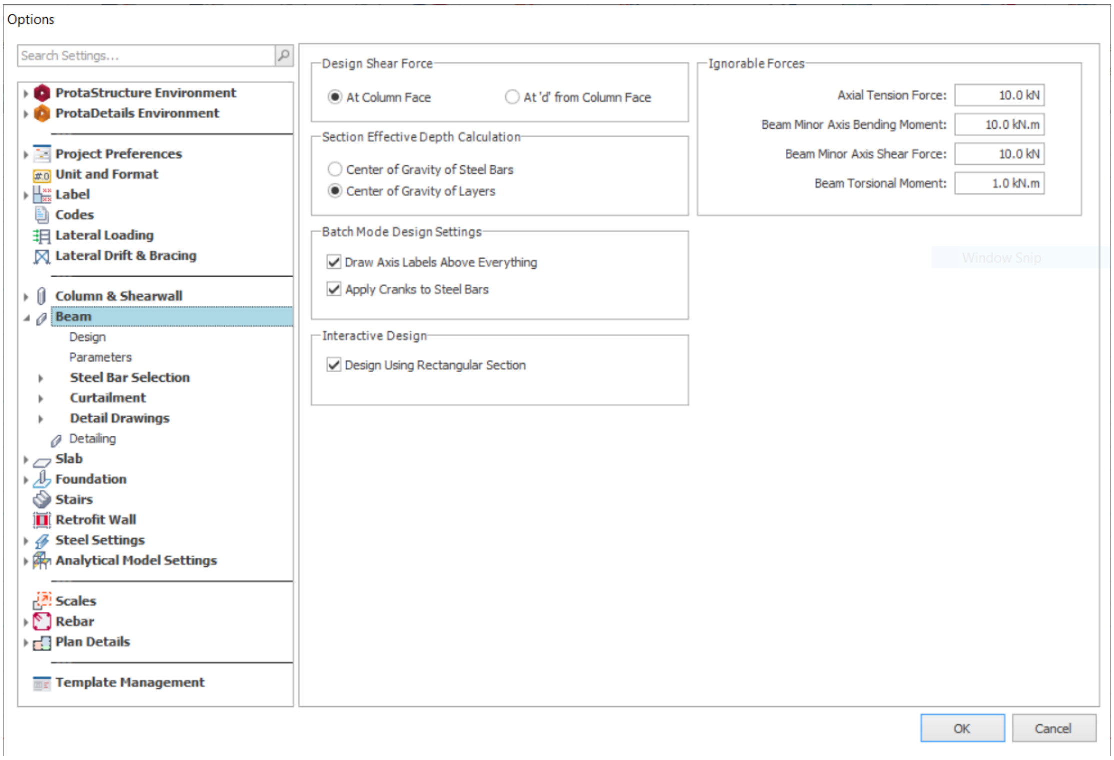
Beam Design Settings

You take control of the above design process by configuring the ***Beam Settings and Parameters*** in the ***Settings Center*** to your preference.

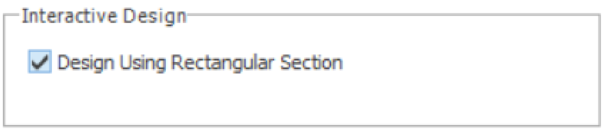


For further details of the implications of adjusting the various settings see the document Beam Detailing

The BS8110 Beam Design Process

1. Rectangular or flanged - Cl 3.4.1.5

The choice of this setting is set via the ***Beam > Design*** tab of ***Settings and Parameters*** as shown below:



The option to use the rectangular section (rather than the flanged section) when the flange is in compression will generally result in slightly more conservative steel area requirements, however if minimum steel requirements apply then design using the flanged section will introduce greater steel requirements.

If a flanged section is used the effective width is determined from Cl 3.4.1.5.

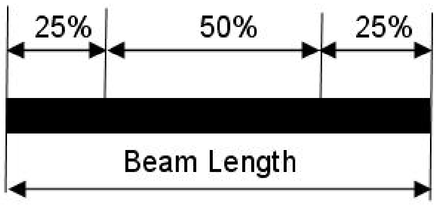
2. Analysis of Sections - Cl 3.4.4.1

All considerations stated in the Cl 3.4.4.1 are fulfilled. The simplified stress block for concrete as illustrated in Figure 3.3 is utilized.

3. Design for Bending- Cl 3.4.4.4 and Cl 3.4.4.5

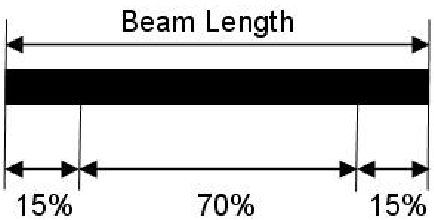
Bending is checked for the top edge in three regions:

1. left (worst case forces in end region - 25% clear span)
2. middle (worst case forces in mid region - 50% clear span)
3. right (worst case forces in end region - 25% clear span)

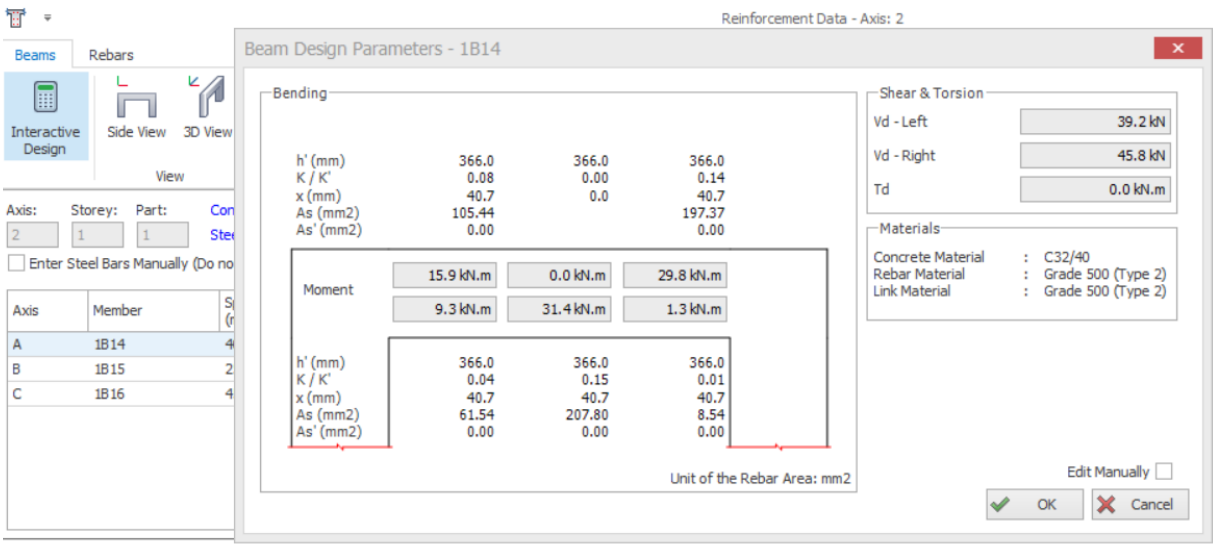


Similarly, bending is checked for the bottom edge in three regions:

4. left (worst case forces in end region - 15% clear span)
5. middle (worst case forces in mid region - 70% clear span)
6. right (worst case forces in end region - 15% clear span)

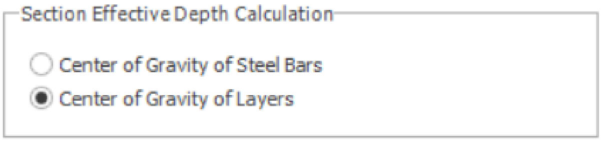


The design moments for each of the six regions can be displayed by from the ***Beams*** tab by firstly highlighting the beam required in the table and then clicking the ***Interactive Design*** button as shown below:



The effective depth h' to the centre of the bars is worked out separately at each location. This is automatically reduced if the steel does not fit in a single layer.

You can control this calculation via the ***Design*** tab of ***Beam Settings and Parameters*** as shown below:



Centre of Gravity of Steel Bars — the section effective depth will be determined based on the centre of gravity of the tension bars. In this method, the contribution of each tension bar in the section will be considered separately.

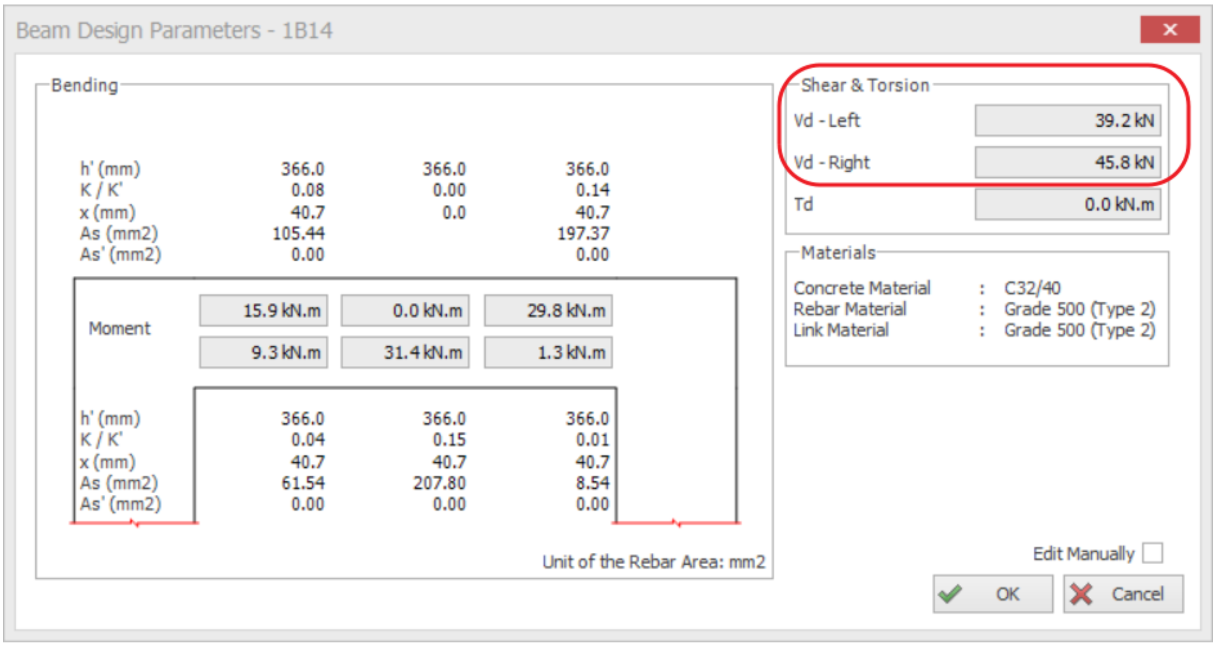
Centre of Gravity of Layers — in this more conservative method the calculation of section effective depth is based on the average of the distances of the steel bar layers.

Values for K, K', x, As, and As' are then all calculated for each region and are also shown in the same table.

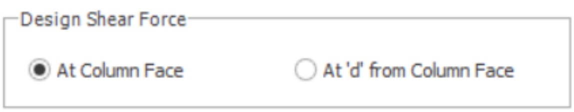
Where the ratio of K/K' is less than 1.0 no compression steel is required.

4. Design for Shear - Cl 3.4.5

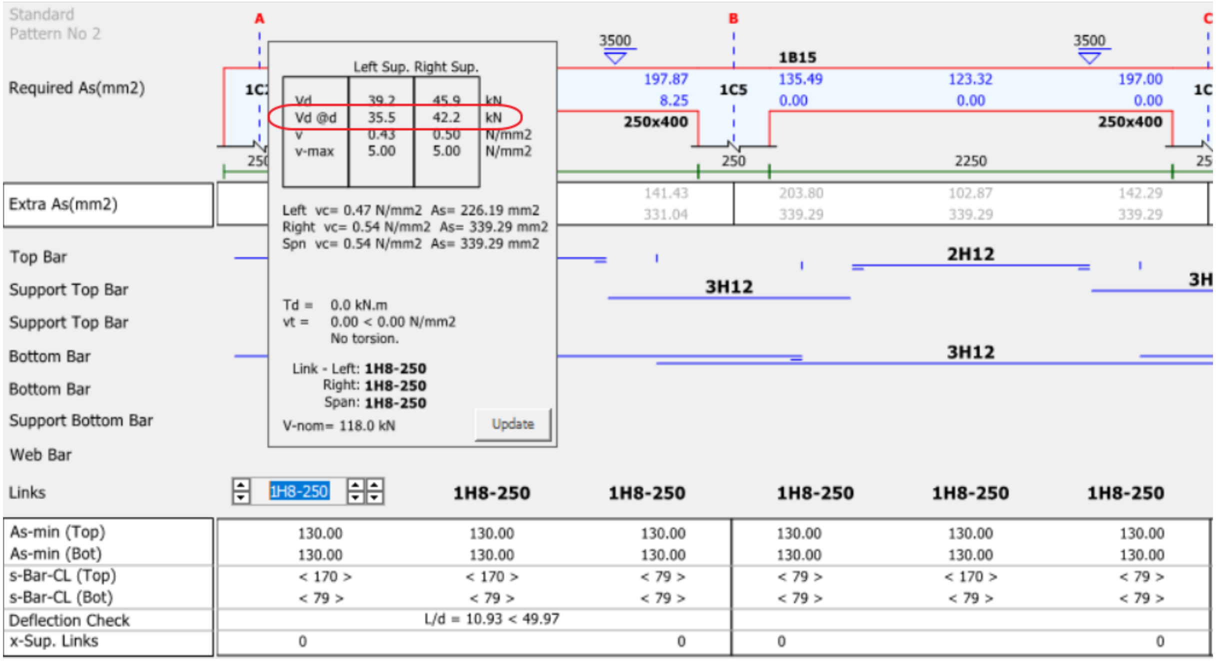
The design shear force at the column face, Vd is displayed in the same table as the design moments:



From the ***Design*** tab of ***Beam Settings and Parameters*** you can specify if you want to design for this value, or (if the conditions of Cl. 3.4.5.10 are met) you may choose to design for the shear at 'd' from the column face.



If the latter option is adopted the design shear force at 'd' is then displayed and used in the design calculations as shown below:

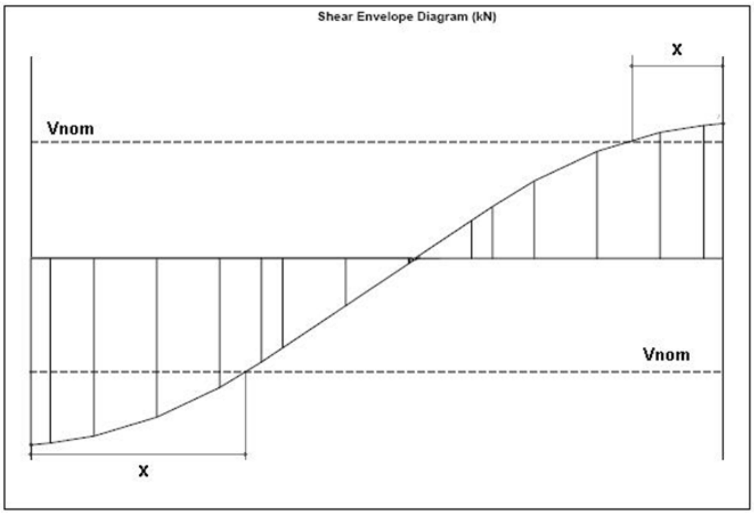


In the above table, the maximum shear stress v is determined from Cl 3.4.5.2 and is always based on Vd (not Vd@d).

vc is calculated using the equation in table 3.8. In BS8110 the concrete grade considered for shear is capped at 40N/ mm2.

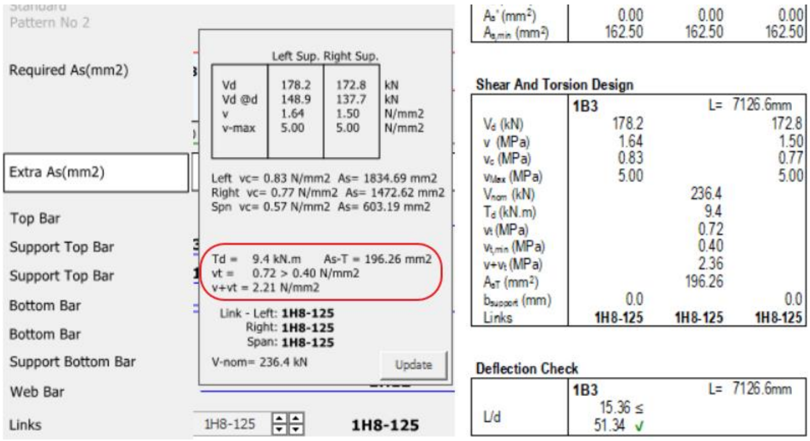
Link requirements are established from Table 3.7 as follows - v is determined from either Vd or Vd@d depending on your choice in the beam design settings and Vnom – Nominal shear capacity (based on minimum link provision) is established.

The maximum shear requirement is then checked at each end of the beam and if the nominal capacity is not sufficient additional links are provided over a distance (x) extending to the point where the nominal capacity is adequate (or beyond if user preferences dictate minimum lengths).



5. Design for Torsion - BS8110-2:1985 Cl 2.4

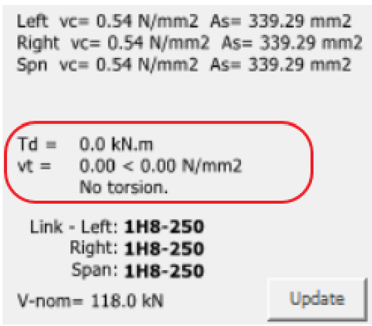
The highest torsion at any point along the beam is determined and used in the torsional shear calculations. These calculations are performed in accordance with the relevant clauses in Part 2 of BS8110 (as listed below). The values determined are displayed by clicking on the link fields in the ***Reinforcement Data*** form. They are also output to the ***Design Report***:



In the above table, the maximum torsional shear stress vt is determined from the torsional moment Td according to Cl 2.4.4.1. This is then cross checked against the limiting torsional shear stress as per Cl 2.4.5, taking into account if required the different limit that applies to small sections (where y1 < 550mm).

Provided the section is adequate, vt is compared to the minimum torsional stress vt,min.

If vt is smaller than vt,min then the links are designed for 'normal' shear only - no torsion reinforcement required. In which case although a non-zero value of Td is displayed, vt is set to 0.00 as shown below:



If vt is greater than vt,min then designed torsion shear reinforcement is provided as per Table 2.4 as follows:

If v <= vc + 0.4

Designed torsion shear reinforcement is provided, (but not less than minimum shear reinforcement) and longitudinal torsion reinforcement is provided.

Else

Designed shear and torsion reinforcement is provided and longitudinal torsional reinforcement is provided.

Where torsion reinforcement is provided the spacing is checked in accordance with Cl. 2.4.8 and uniform links will be provided along the whole beam.

Where longitudinal torsion reinforcement is provided this is distributed equally inside the perimeter links, (between the top and bottom faces for smaller beams, or between all four faces for deeper beams). The clear distance between these bars should not exceed 300mm and at least four bars, one in each corner of the perimeter links, should be used.

6. Deflection Checks - Cl 3.4.6

Basic span/effective depth ratios are calculated from Table 3.9 and modification factors applied according to Table 3.10 and 3.11.

The beam size is not automatically increased to satisfy the deflection criteria - it is highly unusual for beams to be sized so that deflection is a controlling factor. Also, it should be noted that increasing the steel is usually a highly uneconomic way of controlling deflection. It is more normal to conclude that the beam is not deep enough if beam deflection checks fail.

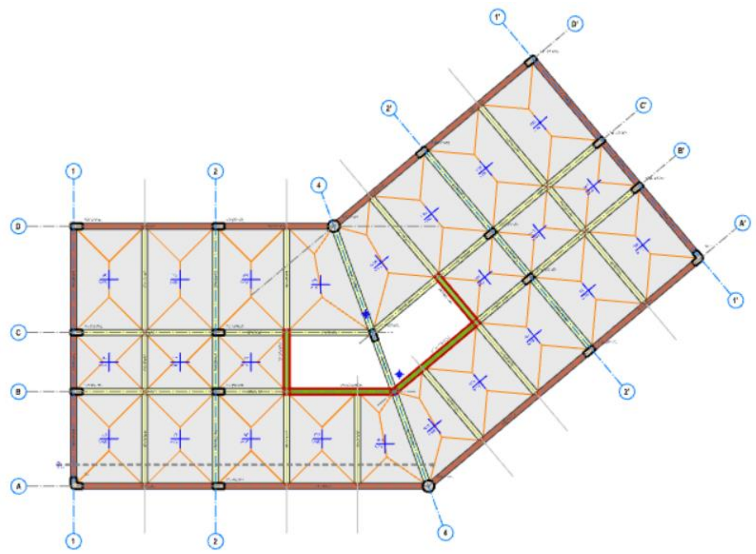
Worked Example

The Design Model

The example model ***Doc_Example_4*** is opened and saved to a new name (so as not to destroy the original example). In the calculations that follow, the steel grade has been set to 500 with a steel material factor of 1.15. Bar diameters permitted for the longitudinal steel in the beams have been limited to 10, 12, 16, 20 and 25mm. The minimum link diameter is set to 10mm. The concrete grade is C32/40 and the unit weight of concrete is set as 25kN/m3. Note that to obtain similar results you will need to apply the same settings. However, the actual design process would be identical irrespective of which material grades, material factors and bar diameters are used.

A building analysis is run with no rigid arms specified, followed by a batch design for all beams.

The focus of the example will be the continuous beam on grid line 2 and the design of beam 1B14 in particular.



Beam 1B14

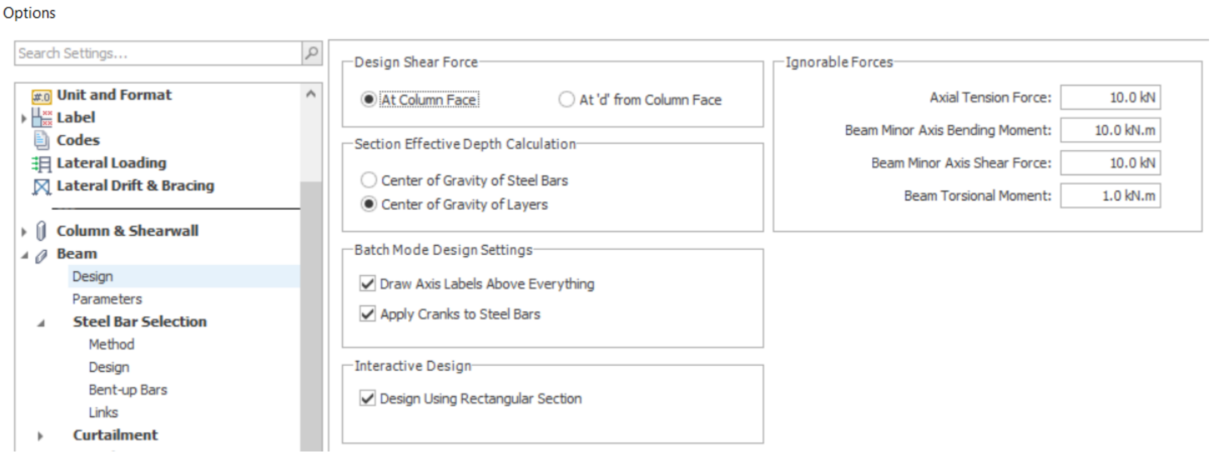
This beam has the following geometry:

- span = 4m
- beam depth, h = 400mm; beam width, b = 250mm
- cover = 20mm

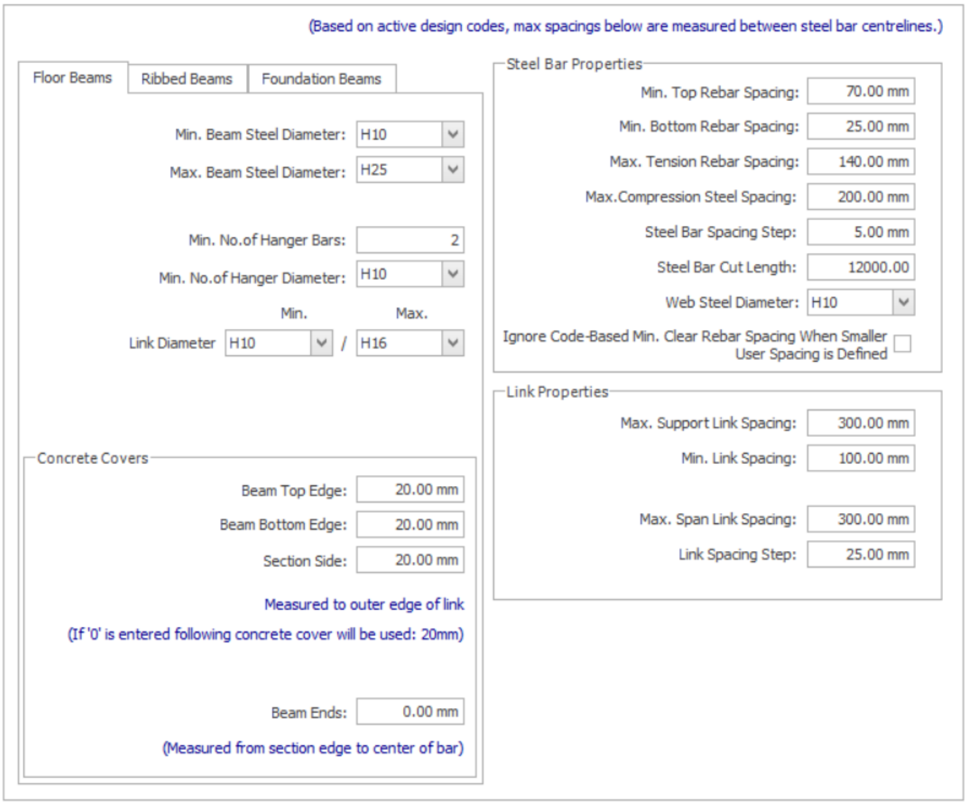
Beam Design Settings

The beam design settings initially adopted are as shown:

Settings on the Design tab

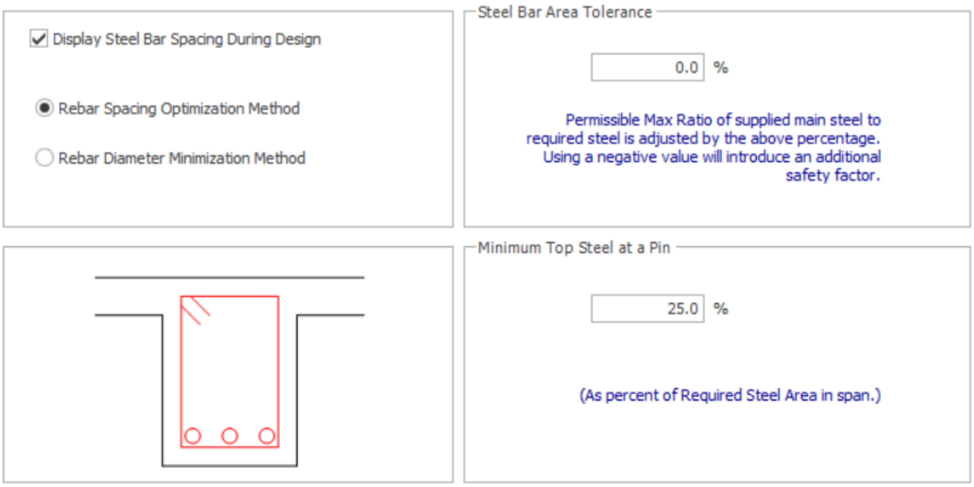


Settings on the Parameters tab

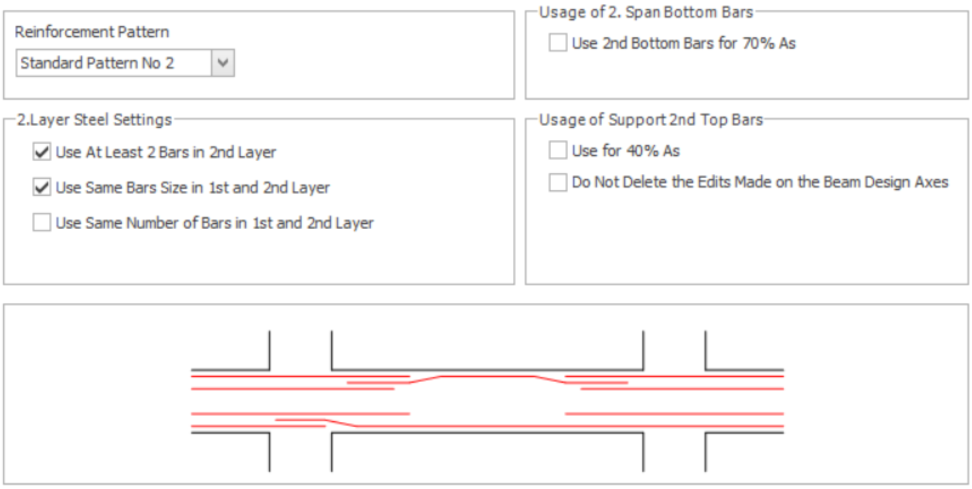


Where the cover shown above has been set to 0 - as noted on the dialog, the cover is then based on code requirements - (i.e. a default cover of 20mm is applied). You may prefer to enter a value directly into each field to set the cover required.

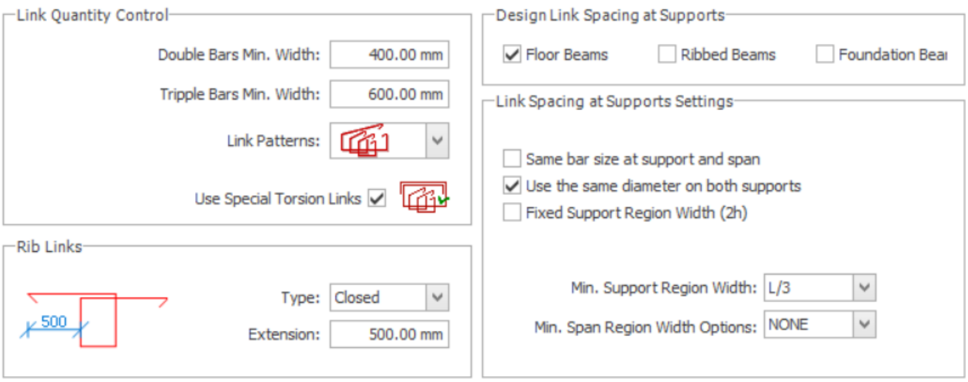
Settings on the Bar Selection/Method tab

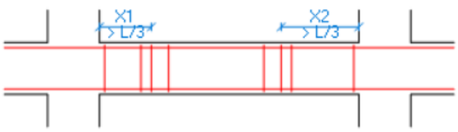


Settings on the Bar Selection/Design tab



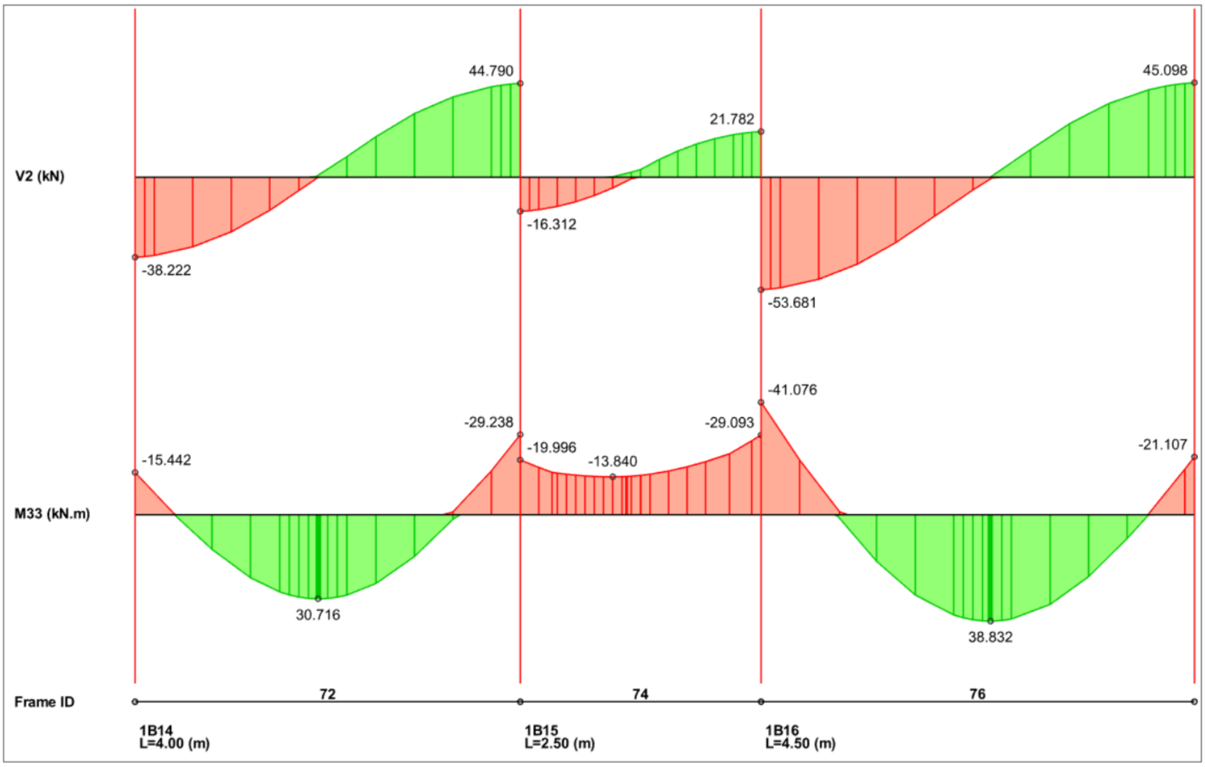
Settings on the Bar Selection/Links tab





Analysis Results

Having run a building analysis using default analysis settings, the design envelope for all combinations is as follows:

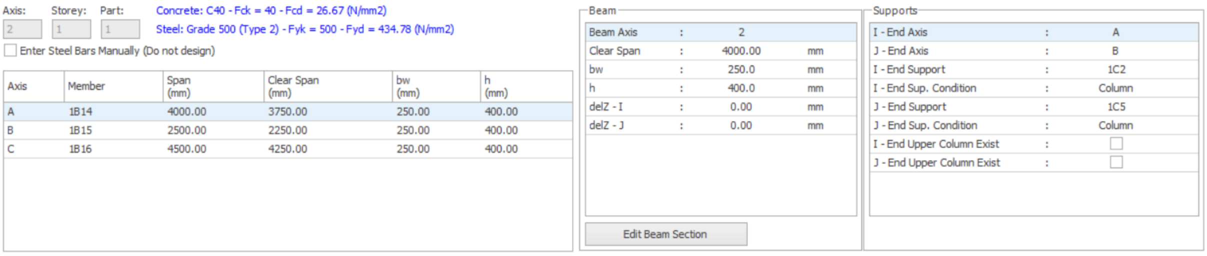


Performing the Design

To perform the design calculations, select beam 1B14 in the plan view, right click and choose ***Section Design*** from the menu. This will display the Steel Bars data for the three beams on Axis 2.

Each stage of the design process will now be examined in detail.

Click the ***Beams*** tab to see the Axis and Beam Data with beam 1B14 highlighted:



Axis: 2 Storey: 1 Part: 1

Concrete: C40 - Fck = 40 - Fcd = 26.67 (N/mm2)

Steel: Grade 500 (Type 2) - Fyk = 500 - Fyd = 434.78 (N/mm2)

☐ Enter Steel Bars Manually (Do not design)

Axis	Member	Span (mm)	Clear Span (mm)	bw (mm)	h (mm)
A	1B14	4000.00	3750.00	250.00	400.00
B	1B15	2500.00	2250.00	250.00	400.00
C	1B16	4500.00	4250.00	250.00	400.00

Beam

Beam Axis	:	2	
Clear Span	:	4000.00	mm
bw	:	250.0	mm
h	:	400.0	mm
delZ - I	:	0.00	mm
delZ - J	:	0.00	mm

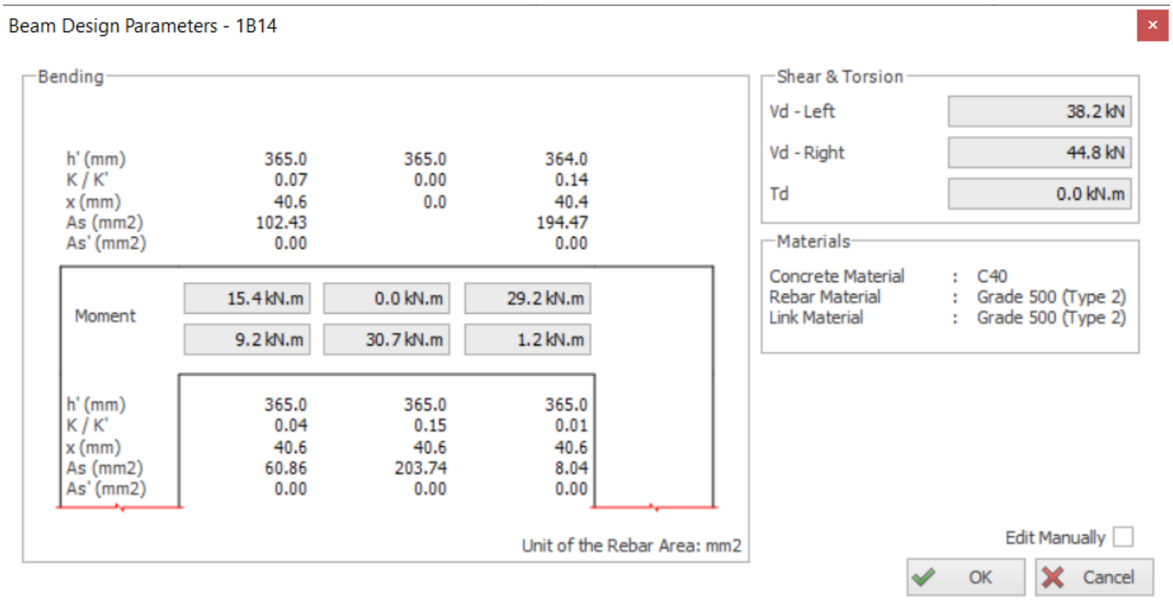
Edit Beam Section

Supports

I - End Axis	:	A
J - End Axis	:	B
I - End Support	:	1C2
I - End Sup. Condition	:	Column
J - End Support	:	1C5
J - End Sup. Condition	:	Column
I - End Upper Column Exist	:	☐
J - End Upper Column Exist	:	☐

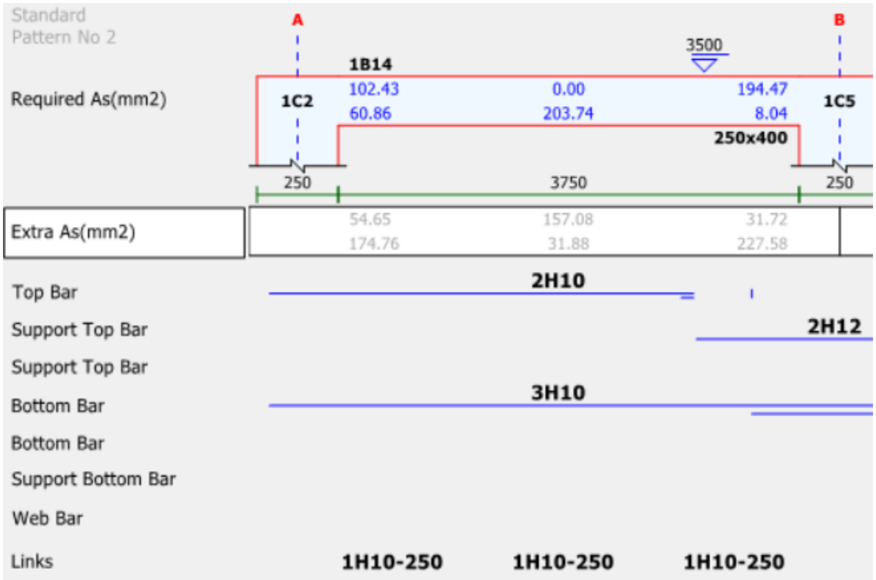
Design for Bending - Cl 3.4.4.4

Click the ***Interactive Design*** button to see the six design moments for 1B14 determined from the analysis moments shown previously:



The area of steel calculations is listed below the design moments. These can be confirmed with simple hand calculations using Cl 3.4.4.4. However, before this can be done, we need to know the bar sizes used to accurately calculate the effective depth.

Click the ***Rebars*** tab to see the steel bars provided:



Effective depth to bar centre

d (RHS top edge) = 400 – 20 – 10 – 12/2= 364mm

d (other locations) = 400 – 20 – 10 – 10/2 = 365mm

Area of Steel Required: Top Edge - Left Hand Side

$K = M/bd^2f_{cu} = 0.0116$

$K' = 0.156$

$K/K' = 0.1 < 1.0$ compression steel not required

$z = d(0.5 + (0.25 – K/0.9)^{0.5}) = 0.987d$

$z = \min(0.982d, 0.95d) = 347\text{mm}$

$x = (d–z) / 0.45 = 40mm$ - - OK

As required = $M / 0.87fyz = 102.5mm^2$

Minimum As from Table 3.25:
$0.13x250x400 = 130mm^2$

Area of Steel Required: Top Edge - Right Hand Side

$K = M/bd^2fcu = 0.0219$
$K' = 0.156$
$K/K' = 0.186 < 1.0$ compression steel not required

$z = d(0.5 + (0.25 – K/0.9)^{0.5}) = 0.975d$
$z = min (0.975d, 0.95d) = 346mm$
$x = (d – z) / 0.45 = 40mm$ - - OK

As required = $M / 0.87fyz = 194.3mm^2$

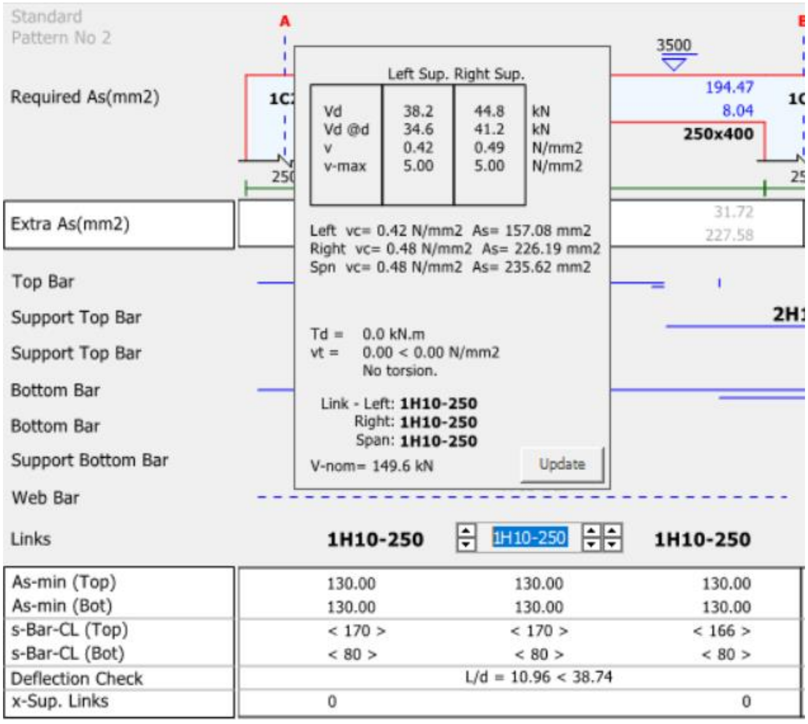
Similar calculations to those shown above are performed for the other four regions.

Area of Steel Provided:

The steel provision is dictated by the current ***Beam Design Settings***. The bar selection and curtailment options chosen will greatly influence the weight of steel and the complexity of the resulting detail.

Design for Shear - Cl 3.4.5

On the ***Reinforcement Data*** dialog, click on any of the link fields for 1B14 to see the shear design calculations:



Left Hand Support

Max shear stress from Cl 3.4.5.2 —

$v = V_d / b_v d = 0.42$ N/mm^2 < v-max - - OK

v_c is calculated using the equation in table 3.8 —

d = 365mm, As = 157.08mm^2

$100As/b_v d = 0.172$

As provided is used in the above calculation.

$v_c = (f_{cu}/25)^{0.33}\ 0.79(100As/b_v d)^{0.33}\ (400/d)^{0.25}\ /1.25$

$v_c = (40/25)^{0.33}\ 0.79(0.172)^{0.33}\ (400/365)^{0.25}\ /1.25 = 0.42$

Right Hand Support

Max shear stress from Cl 3.4.5.2 —

$v = V_d / b_v d = 0.49$ N/mm2 < v-max - - OK

v_c is calculated using the equation in table 3.8 —

d = 364mm, As = 226.2mm2

$100As/b_v d = 0.248$

$v_c = (40/25)^{0.33}\ 0.79(0.248)^{0.33}\ (400/364)^{0.25}/1.25 = 0.48$

Span

v_c is calculated using the equation in table 3.8 —

$d = 365mm$, $As = 235.6mm2$ $100As/b_vd = 0.258$

$v_c = (40/25)^{0.33}\ 0.79(0.258)^{0.33}\ (400/365)^{0.25}/1.25 = 0.48$

Link requirements

Determine if minimum bars at maximum spacing provide "minimum links" —

$A_{sv\_req} / s_v = (0.4.b_v)/0.87f_{yv} = 0.23$

For minimum bars at maximum spacing, provide H10 links at 250mm centres

$A_{sv\_prov} / s_v = 2 \times 78.5 / 250 = 0.63$

In this case OK - - (if not OK decrease the spacing until requirement is met).

Calculate v_{nom} using the minimum links —

capacity from span v_c

$v_c\ b_vd = 0.48 \times 250 \times 365 = 43.8kN$

capacity from links

$(0.87\ f_{yv}\ A_{sv\_prov} / (b_vs_v)).\ (b_vd) = 100.03\ kN$

$v_{nom} = 43.8 + 100.03 = 143.2\ kN$

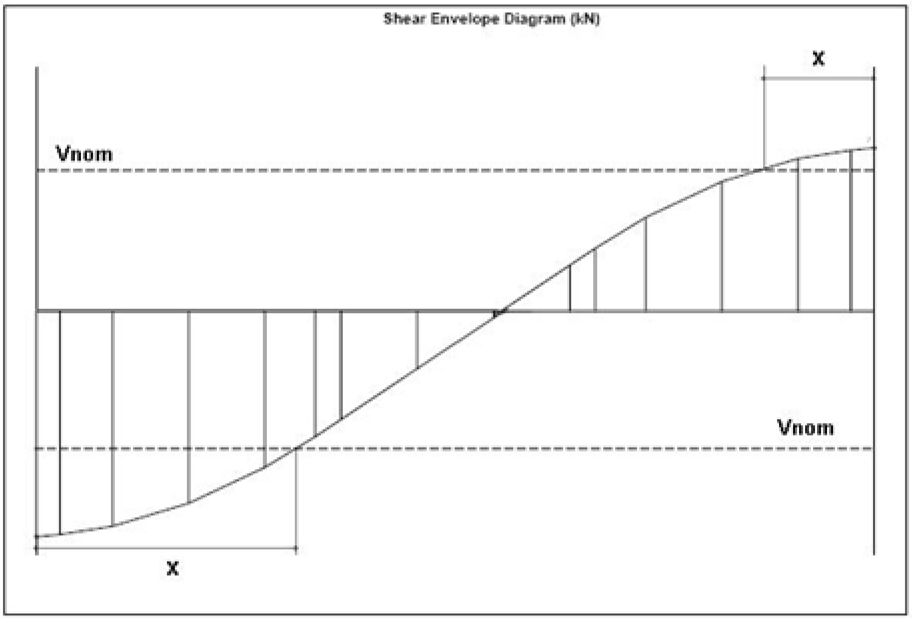
Determine if shear at the ends exceeds v_{nom} —

$v_d@d < V_{nom}$

$41.2kN < 143.2kN$

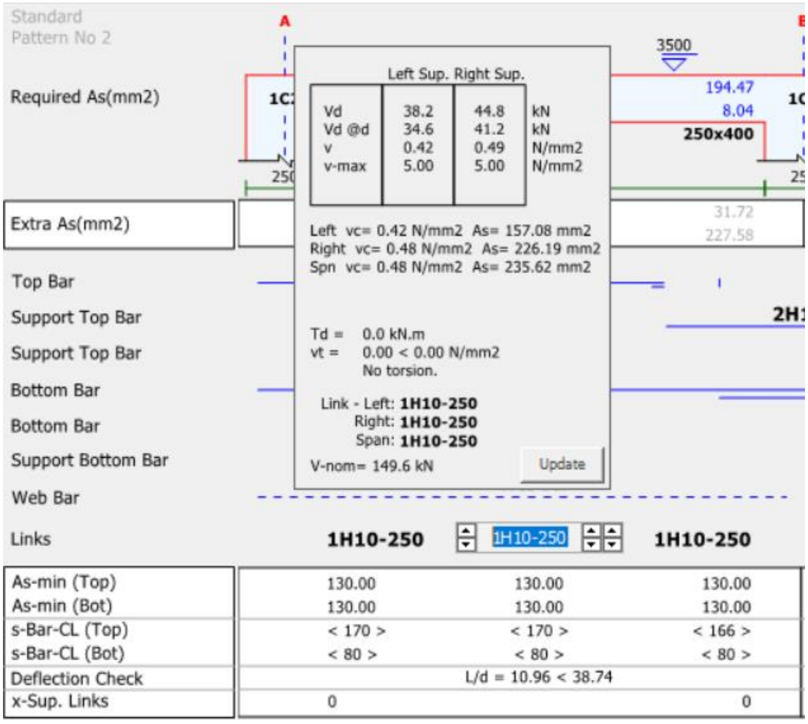
In this case OK -- hence minimum links apply for whole length of beam.

If the shear at either end had exceeded v_{nom} - the distance, x to the point where v_{nom} is adequate would be determined as shown below, and a calculation performed to determine the increased links to apply over that length.



Design for Torsion - BS8110 - 2:1985 Cl 2.4

On the ***Reinforcement Data*** dialog, click on any of the link fields for 1B14 to see if torsion shear calculations are required:



In this example there is no torsion in the beam and so it is designed for 'normal' shear only - no torsion reinforcement is required.

Deflection Checks - Cl 3.4.6

Checks are based on the span values for sagging moment design.

$L/d = 4000/365 = 10.96$

Table 3.9 – For a rectangular beam

basic permissible ratio = 26

Table 3.10 – modification for tension reinforcement

$M/bd^2 = 30.716 \times 10^6/(250 \times 365^2)$

$= 0.92$

$A_{s,req} = 203.7$

$A_{s,prov} = 235.6$

$f_s = 2f_y.A_{s,req} / (3_{As,prov}) = 288.2 N/mm^2$

Modification Factor $=0.55 + (477-f_s)/(120(0.9+(m/bd^2))) = 1.414 < 2$ -- OK

Table 3.11– modification for compression reinforcement

$100As'prov /bd = 100(157/250*365) = 0.172$

Modification Factor $=1+(100A'_{s,prov}/bd)/(3+100A'_{s,prov}/bd) = 1.05$

Therefore, adjusted Permissible L/d = 26*1.414*1.05 = 38.6 > 10.96 -- OK

Output Calculations

The following report shows the output for the beams along axis 2:

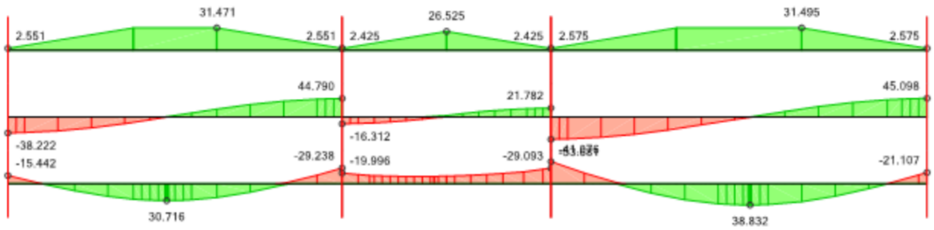
	Prota Asia (21838)
Beam Reinforcement Design Rev: 1	Calc. By: Checked By:

Beam Reinforcement Design

Axis: 2 Storey: 1

Materials: C40 / Grade 500 (Type 2) (Links: Grade 500 (Type 2))

Diagrams



Bending

	1B14	L= 4000mm		1B15	L= 2500mm		1B16	L= 4500mm	
B_w x H (mm)		250 x 400			250 x 400			250 x 400	
Flange B_f x H_f (Left) (Right)	---		---		---				
Top Edge									
M (kN.m)	15.4	0.0	29.2	20.0	18.2	29.1	41.1	0.0	21.1
d (mm)	365.0	365.0	364.0	364.0	365.0	364.0	364.0	365.0	365.0
K/K'	0.07	0.00	0.14	0.10	0.09	0.14	0.20	0.00	0.10
x (mm)	40.6	40.6	40.4	40.4	40.6	40.4	40.4	40.6	40.6
A_s (mm^2)	102.43	0.00	194.47	133.00	121.01	193.51	273.21	0.00	140.01
A_s' (mm^2)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$A_{s,min}$ (mm^2)	130.00	130.00	130.00	130.00	130.00	130.00	130.00	130.00	130.00
Bottom Edge									
M (kN.m)	9.2	30.7	1.2	0.0	0.0	0.0	0.0	38.8	11.1
d (mm)	365.0	365.0	365.0	365.0	365.0	365.0	364.0	364.0	364.0
K/K'	0.04	0.15	0.01	0.00	0.00	0.00	0.00	0.19	0.05
x (mm)	40.6	40.6	40.6	40.6	40.6	40.6	40.4	40.4	40.4
A_s (mm^2)	60.86	203.74	8.04	0.00	0.00	0.00	0.31	258.28	73.69
A_s' (mm^2)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$A_{s,min}$ (mm^2)	130.00	130.00	130.00	130.00	130.00	130.00	130.00	130.00	130.00

Shear And Torsion Design

	1B14	L= 4000mm		1B15	L= 2500mm		1B16	L= 4500mm	
V_d (kN)	38.2		44.8	16.3		21.8	53.7		45.1
v (MPa)	0.42		0.49	0.18		0.24	0.59		0.49
v_c (MPa)	0.42		0.48	0.48		0.54	0.54		0.42
v_{Max} (MPa)	5.00		5.00	5.00		5.00	5.00		5.00
V_{nom} (kN)		149.6			143.8			155.5	
T_d (kN.m)		0.0			0.0			0.0	
v_t (MPa)		0.00			0.00			0.00	
$v_{t,min}$ (MPa)		0.00			0.00			0.00	
$b_{support}$ (mm)	0.0		0.0	0.0		0.0	0.0		0.0
Links	**1H10-250**	**1H10-250**	**1H10-250**	**1H10-250**	**1H10-250**	**1H10-250**	**1H10-250**	**1H10-250**	**1H10-250**

Deflection Check

	1B14 L= 4000mm	1B15 L= 2500mm	1B16 L= 4500mm
L/d	10.96 ≤ 38.74 √	---	12.36 ≤ 39.69 √

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	Prota Asia (21838)
Beam Reinforcement Design Rev: 1	Calc. By: Checked By:

Supplied Steel Areas (mm²)

	1B14	L= 4000mm		1B15	L= 2500mm		1B16	L= 4500mm	
Top Edge	157.08	157.08	226.19	226.19	157.08	339.29	339.29	157.08	157.08
Bottom Edge	235.62	235.62	235.62	235.62	235.62	235.62	339.29	339.29	339.29
Steel Bars									
Top Bars		**2H10**			**2H10**			**2H10**	
Top.Sup.Bars			**2H12**	**2H12**		**3H12**	**3H12**		
Top.Sup.Bars									
Bottom Bars		**3H10**			**3H10**			**3H12**	
Bottom Bars									
Bot.Sup.Bars									
Side Bars									

Thank You…

Thank you for choosing the ProtaStructure Suite product family.

It is our top priority to make your experience excellent with our software technology solutions.

Should you have any technical support requests or questions, please do not hesitate to contact us at all times through globalsupport@protasoftware.com and asiasupport@protasoftware.com

Our dedicated online support center together with our responsive technical support team is available to help you get the most out of Prota's technology solutions.

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