DESIGN OF STEEL STRUCTURES

by

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COMPRESSION MEMBERS

TYPES OF COMPRESSION MEMBERS

The types of column is based on the slenderness ratio or the length to diameter ratio of the columns.

They can be divided as follows:

(a) Short columns:

- The columns which have height less than eight times their diameter or slenderness ration less than 32 are called short column.

- In short columns bending or buckling is negligible and hence short columns fail by direct crushing or compressive stress.

(b) Medium columns:

- The columns which have length varying from 8 to 30 times their diameters or the slenderness ration lying between 32 to 120 are called intermediate or medium columns.

- In this types of columns, buckling and compressive stress are both considered for their failures.

(c) Long columns :

- Columns having their length more than 30 times their diameter or slenderness ratio more than 120 are called long columns.

- In such types of columns failure will occur due to buckling or bending but direct compressive stress is very small as compared to buckling stress.

SLENDERNESS RATIO

- The slenderness ratio of a member is the ratio of the effective length to the appropriate radius of gyration (KL/r).

- This valid only when the column has equal unbraced height for both axes and end condition are same for both axes. The appropriate radius of gyration is one which is minimum for a particular section.

- For example a section asymmetrical about the centroidal axes will bend about the principal axis for which the radius of gyration is minimum.

- On the other hand, a section symmetrical about both the centroidal axes (I-section) or even with one axis of symmetry (channel section, two angles back to back) will bend about one of the centroidal axis giving lesser radius of gyration.
- This is because for such section the principal axes coincide with the centroidal axes.

SLENDERNESS RATIO

The slenderness ratio of compression member is limited because of the following reason:

1. The effect of accidental and construction (fabrication, transportation, and erection) loads are automatically taken care of.

2. The bracing members may be used as a walkway for workmen or to provide temporary support for equipments.

3. To take care of the probability of member being subjected to unexpected vibrations.

CODAL PROVISIONS

- Design compressive stress cannot be more than f_y.

- Reduction in f_y due to all the above adverse factors is difficult to quantity.

- Based on statistical test data, lower bound curves are proposed as shown in above Figure.

- The curves a, b, c and d represent considering the effects of cumulative degree of imperfection due to cross-sectional layout, presence of residual, initial curvature and eccentric loading.

CODAL PROVISIONS

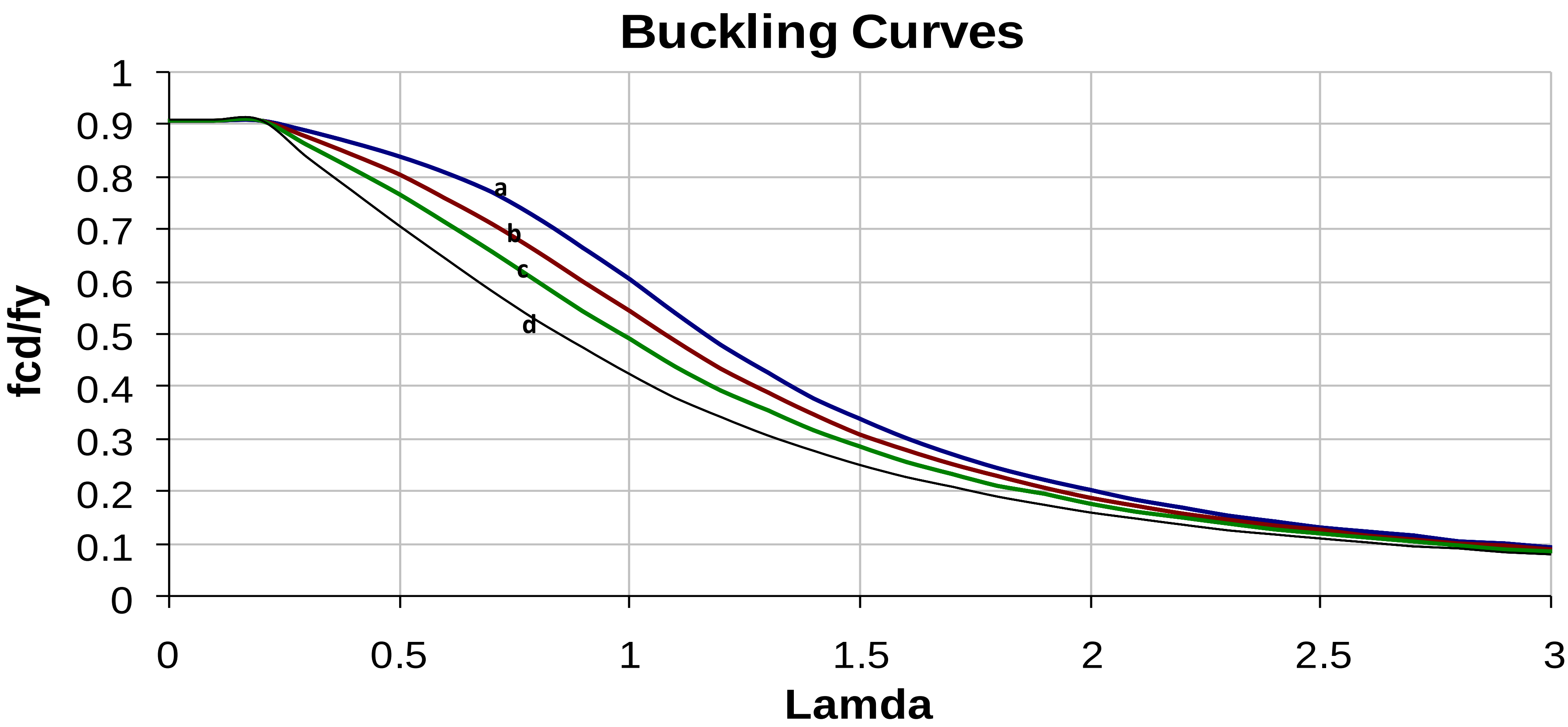


TABLE 1 IMPERFECTION FACTOR, α

Buckling Class	a	b	c	d
α	0.21	0.34	0.49	0.76

DESIGN STRENGTH

The design compressive strength of a member is given by $P_d = A_e f_{cd}$

$$f_{cd} = \frac{f_y / \gamma_{m0}}{\varphi + \left[\varphi^2 - \lambda^2\right]^{0.5}} = \chi f_y / \gamma_{m0} \leq f_y / \gamma_{m0}$$

$$\phi = 0.5[1 + \alpha(\lambda - 0.2) + \lambda^2]$$

$$\lambda = \sqrt{f_y / f_{cc}} = \sqrt{f_y \left(\frac{KL}{r}\right)^2 / \pi^2 E}$$

$$\chi = \frac{1}{\left[\phi + \left(\phi^2 - \lambda^2\right)^{0.5}\right]}$$

f_{cd} = the design compressive stress,
λ = non-dimensional effective slenderness ratio,

f_{cc} = Euler buckling stress = $\pi^2 E/(KL/r)^2$

α = imperfection factor as in Table 1

χ= stress reduction factor as in Table 8

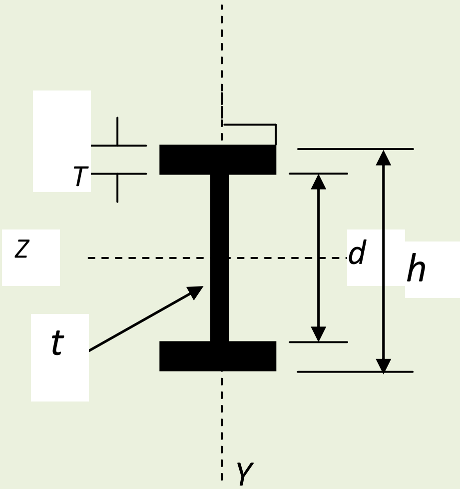
γ_{mo} = partial safety factor for material

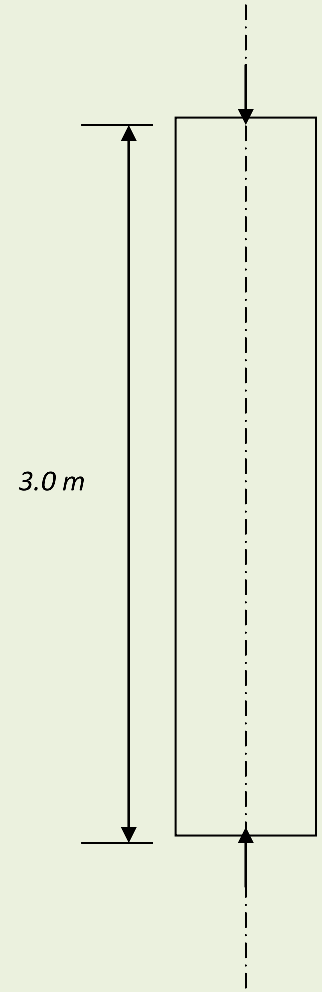
KL/r = Effective slenderness ratio

1.Obtain factored axial load on the column section ISHB400. The height of the column is 3.0m and it is pin-ended.

[f_y = 250 N/mm^2 ; E = 2 x10^5 N/mm^2 ; γ_m = 1.10]

CROSS-SECTION PROPERTIES:





Flange thickness	=	T	=	12.7 mm
Overall height of ISHB400	=	h	=	400 mm
Clear depth between flanges	=	d	=	400 – (12.7 x 2)
			=	374.6 mm
Thickness of web	=	t	=	10.6mm
Flange width	=	2b	=	b_f = 250 mm
Hence, half Flange Width	=	b	=	125 mm
Self –weight	=	w	=	0.822 kN/m
Area of cross-section	=	A	=	10466 mm^2
Radius of gyration about x	=	r_x	=	166.1 mm
Radius of gyration about y	=	r_y	=	51.6 mm

(i)**Type of section:**

$$\frac{b}{T} = \frac{125}{12.7} = 9.8 < 10.5\varepsilon$$

$$\frac{d}{t} = \frac{374.6}{10.6} = 35.3 < 42\varepsilon$$

(Table 3.1 of IS: 800)

$$where, \varepsilon = \sqrt{\frac{250}{f_y}} = \sqrt{\frac{250}{250}} = 1.0$$

Hence, cross-section can be classified as "COMPACT".

(ii)Effective Sectional Area, A_e = 10,466 mm^2

(Since there is no hole, (Clause 7.3.2 of IS: 800)

no reduction has been considered)

(iii) Effective Length:

As, both ends are pin-jointed effective length

(Clause 7.2 and Table 7.5 of IS:800)

$KL_x = KL_y = 1.0 \text{ x } L_x = 1.0 \text{ x } L_y = 1.0 \text{ x } 3.0 \text{ m} = 3.0 \text{ m}$

(iv) Slenderness ratios:

$$KL_x / r_x = \frac{3000}{166.1} = 18.1$$

$$KL_y / r_y = \frac{3000}{51.6} = 58.1$$

(v) Non-dimensional Effective Slenderness ratio, λ :

$$\lambda = \sqrt{f_y / f_{cc}} = \sqrt{f_y \left(KL/r\right)^2 / \pi^2 E} = \sqrt{250x\left(58.1\right)^2 / \pi^2 x 2 x 10^5}$$

$= 0.654$

(*Clause 7.1.2.1 of IS: 800)*

(vi) ***Value of ϕ from equation $\phi = 0.5[1+\alpha(\lambda - 0.2)+ \lambda^2]$:***

Where, α = Imperfection Factor which depends on Buckling Class

Now, from Table 7.2 of Chapter 7, for $h/b_f = 400 / 250 = 1.6 >$ *1.2 and also thickness of flange, T = 12.7 mm, hence for z-z axis buckling class 'a' and for y-y axis buckling class 'b' will be followed.*

(Table 7.1 of IS: 800)

Hence, α = 0.34 for buckling class 'b' will be considered.

Hence, $\boldsymbol{\phi = 0.5 \times [1+0.34 \times (0.654-0.2)+0.654^2] = 0.791}$

(Table 7.1 of IS: 800)

(vii) ***Calculation of χ from equation χ =*** $\left[1 \Big/ \left[\phi + \left(\phi^2 - \lambda^2 \right)^{0.5} \right] \right]$

$$\chi = \left[1 \Big/ \left[\phi + \left(\phi^2 - \lambda^2 \right)^{0.5} \right] \right] = \left[1 \Big/ \left[0.791 + \left(0.791^2 - 0.654^2 \right)^{0.5} \right] \right]$$

$= 0.809$

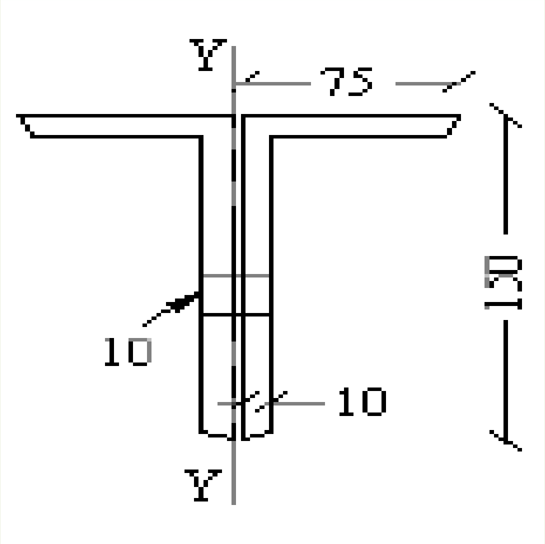
(vii) Calculation of f_{cd} from the following equation:

$$f_{cd} = \frac{f_y / \gamma_{m0}}{\phi + \left[\phi^2 - \lambda^2 \right]^{0.5}} = \chi\ f_y / \gamma_{m0} = 0.809 x 250 / 1.10 = 183.86 \ \mathbf{N/mm^2}$$

(ix) Factored axial load in kN.

$$p_d = A_g f_{cd} = 10466 \times 183.86/1000 = 1924.28 \text{ kN.}$$

2. A double angle discontinuous strut ISA 150x75x10mm long leg back to back is connected to either side by gusset plate of 10mm thick with 2 bolts. The length of the strut between the intersections is 3.5m. Determine the safe load carrying capacity of the section.



Ref. CL 7.5.2.1, P48, IS800:2007

Effective length factor is between 0.7 and 0.85

Assume k=0.85

Effective length of the member = 0.85x3500

=2975mm

From steel table (P 45) A= 4312mm^2 ; r_{min}= 29.0

KL/r_{min} = 2975/29.0 = 102.58

From Table 10/IS 800/ P 44

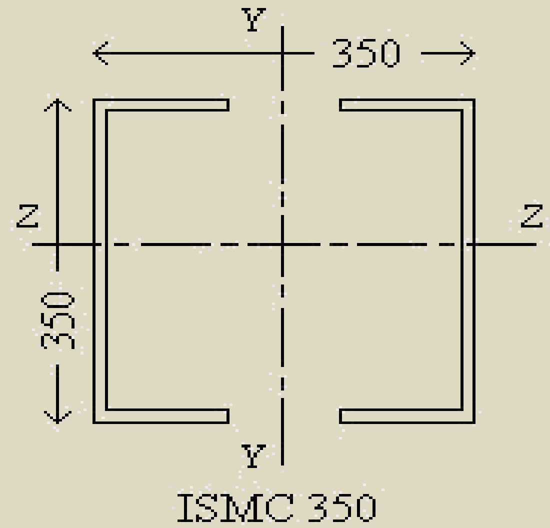
The given section is belonged to **Buckling Class C**

Therefore Design Compressive stress, from **Table 9(c)/P42**

f_{cd} = 107- 2.58 x 12.4/10 = 103.8

Strength of member = (103.8x4312)/ 1000 = 447.58kN

3. Calculate the safe load of a bridge compression member of two channels ISMC 350 @ 421.1 kg/m placed toe to toe. The effective length of member is 7m. The widths over the back of the channel are 350mm and the section is properly connected by lacings.



$$A = 2(53.66) = 107.32 cm^2$$

$$I_{zz} = 2(10008) = 20016 cm^4$$

$$I_{yy} = 2[430.6 + 53.66(17.5 - 2.44)^2] = 25201.7 cm^4$$

$$\gamma_{min} = \sqrt{I_{min}}/A = 13.6 \text{ cm}$$

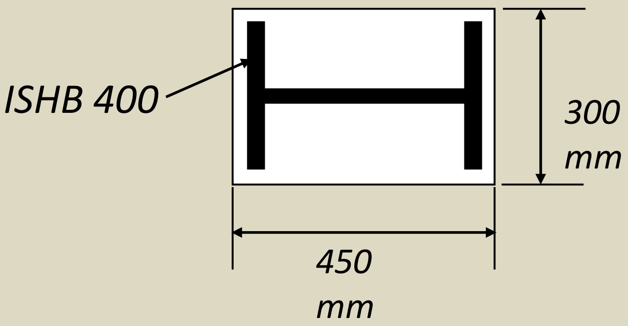
KL/γ = 700/13.6 = 51.2 (Table 9c of code)

$$f_{cd} = 183 - 1.2/10 \, x15 = 181.2 \, N/mm^2$$

Strength of the member = 181.2 *x* 10732 = 1944.6*kN*

4. Design a simple base plate for a ISHB400 @ 0.822 kN/m column to carry a factored load of 1800 kN.

[f_{cu} = 40 N/mm^2; f_y = 250 N/mm^2; γ_m = 1.10]



Thickness of Flange for ISHB400 = T = 12.7 mm

Bearing strength of concrete = 0.4f_{cu} = 0.4 x 40 = 16 N/mm^2

Area required =1800 x 10^3/16 = 112500 mm^2

Use plate of 450 X 300 mm (135000 mm^2)

Assuming projection of 25 mm on each side, a = b = 25 mm

$w = \left(1800 \times 10^3 / 450 \times 300\right) = 13.33$ N/mm^2

Now thickness of Slab Base, t_s

$$t_s = \sqrt{2.5w\,(a^2 - 0.3b^2)\gamma_{m0} / f_y} \quad > \; T$$

Clause 7.4.3.1 of IS: 800

$$= \sqrt{\frac{2.5w\,(a^2 - 0.3b^2)\times 1.10}{f_y}} = \sqrt{\frac{2.5\times 13.33\times (25^2 - 0.3\times 25^2)\times 1.10}{250}} = 8.01\ mm$$

< T = 12.7 mm, Hence provide a base plate of thickness not less than 12.7 mm and since the available next higher thickness of plate is 16 mm

Use 450 X 300 X 16 mm plate.

5. Design a laced column 10-m long to carry a factored axial load of 1100 kN.

The column is restrained in position but not in direction at both ends. Provide single lacing system with bolted connection.

(a) Design the column with two channels back-to-back

(b) Design the column with two channels placed toe-to-toe

(c) Design the lacing system with welded connections for channels back-to-back.

Solution:

Design of column:

$P = 1100 \times 10^3$ N

$L = 1.0 \times 10 = 10$m

Assume design strength of 125MPa

Required area = $1100 \times 10^3 / 125 = 8800 \text{mm}^2$

Select two ISMC 300 at 363 N/m. The relevant properties of ISMC 300 are

$A = 4630\ mm^2$, $r_{zz} = 118.0\ mm$, $r_{yy} = 26.0\ mm$

$C_{yy} = 23.5mm$, $I_{zz} = 6420 \times 10^4 mm^4$, $I_{yy} = 313 \times 10^4 mm^4$

Area available = 2 x 4630 = 9260 mm^2

Built up sections will be economical, when the radius of gyration of the y-y axis is increased in such a way that it is more or less equal to the radius of Gyration about the z-z axis .This is achieved by spacing the sections in such a way that r_{zz} becomes r_{min} .Let us first check the safety of the section and then Workout the required spacing between the two channels.

$L/r_{zz} = 10 \times 10^3/118.0 = 84.74$

The L/r of the built-up column should be taken as 1.05 x (L/r_{zz}) =1.05 x 84.74

=88.98

For $L/r_{zz} = 88.98$ and $f_y = 250MPa$,using table 9c of the code ,

$f_{cd} = 122.53\ MPa$,

Load carrying capacity $A_e f_{cd}$ = 9260 x 122.53/1000

= 1135 kN > 1100 kN.

Hence the column is safe.

(a) Let us provide two channels back to back and connect them by lacing and denote S as the spacing between two channels[See fig below].

Spacing of channels:

$$2I_{zz} = 2\,[I_{yy} + A(S/2) + c_{yy})^2$$

Thus, $2 \times 6420 \times 10^4 = 2 \times [313 \times 10^4 + 4630$

$(S/2+23.5)^2$

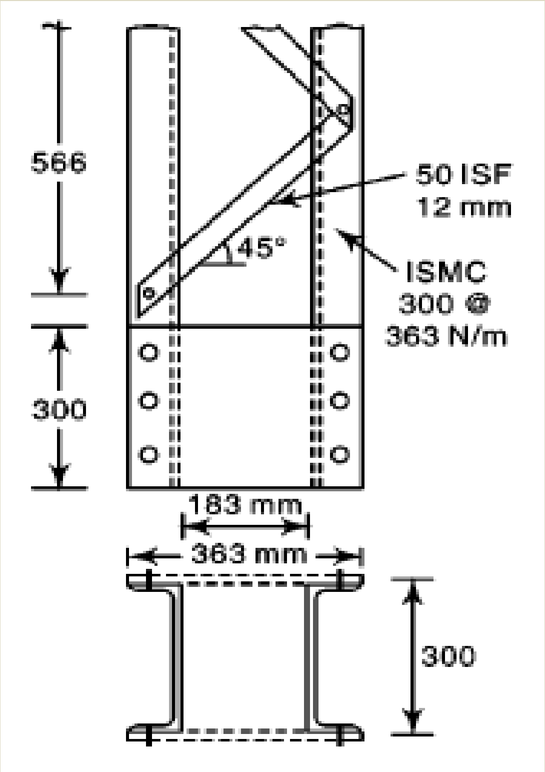
=13190

S = 182.70mm

Let us keep the channels at a spacing of 183mm.

Lacing system

Using single lacing system with the inclination of



(a)

lacing bar =45° (gauge length for a 90 mm flange = 50mm)

Spacing of lacing bars, L_o = (2 x 183+ 50 +50) cot 50°

= 2 x 283 x 1 = 566 mm

L_o /r_{yy} should be < 0.7 x L/r of whole column.

21.77 < 0.7 x 88.98 =62.3

Hence safe.

Maximum shear = (2.5 /100) x 1100 x 10^3 = 27,500N.

Transverse shear in each panel =(V/N) = 27500/2 =13750N.

Compressive force in the lacing bar = (V/N) cosec 45°

= 13750 x 1.414 = 19445 N.

Assuming 16-mm diameter bolts,

Minimum width of lacing flat (clause 7.6.2 of the code)= 3x 16,say 50mm

Minimum thickness = (1/40) (183+50+50)cosec 45° =10.01 mm

Provide 12 mm thick plate with a width of 50 mm

Minimum r = t / √12 =12/√12 = 3.464 mm

L/r of the lacing bar = 283 x cosec 45˚/3.464=115.5 <145

Hence safe.

For L/r = 115.5 and f_y = 250MPa ,using table 9c of the code

f_{cd}= 88.6 Mpa

Load carrying capacity = 88.6 x 50 x 12=53,163N>19,445N.

Hence the lacing bar is safe.

Tensile strength of lacing flat = $0.9(B-d)tf_u/\gamma_{ml}$ or $f_y A_g/\gamma_{mo}$

Thus 0.9(50-18) x 12 x 410/1.25 or 250 x 50x 12/1.1

113,356N or 136,363N.

Thus, the tensile strength of the lacing flat = 113,356 N > 19,445N

Hence ,the lacing flat is safe

Check,

r_{min} of the built -up column =118mm

r_{min} of the individual chords=26.0mm

$L_o / r = 566/26 = 21.77$

λ of the built up column

$\lambda_e = \sqrt{\{84.74^2+3.142(9260/600)x400.223/(566x2302)\}}$

$= 86.64 < 88.98$

Hence , the column is safe.

Connection: Assuming that the 16mm bolts of grade 4.6 are connecting both lacing flats with the channel at one point and that the shear plane will not pass through the threaded portion of bolt.

Strength of bolt in double shear = $2 \times A_{sb}(f_u/ \sqrt{3})/\gamma_{mb}$

$= 2 \times \pi \times 16^2/4 \times (400 /\sqrt{3})/1.25 = 74{,}293N$

Strength in bearing = $2.5\, k_b d t f_u/\gamma_{mb}$

$= 2.5 \times 0.49 \times 16 \times 12 \times 410/1.25$

$= 77{,}145$ N

Hence ,Strength of bolt =74,293N >19,445N

Hence one 16-mm diameter bolt of grade 4.6 is required.

Connection Assuming that the 16mm bolts of grade 4.6 are connecting both lacing flats with the channel at one point and that the shear plane will not pass through the threaded portion of bolt.

Strength of bolt in double shear = $2 \times A_{sb}(f_u/ \sqrt{3})/\gamma_{mb}$

$=2 \times \pi \times 16^2/4 \times (400 /\sqrt{3})/1.25 = 74,293$N

Strength in bearing = $2.5\ k_b d t f_u/\gamma_{mb}$

$= 2.5 \times 0.49 \times 16 \times 12 \times 410/1.25$

$= 77,145$ N

Tie plates:

Tie plates must be provided at the ends of the laced column

Effective depth = $183 + 2 \times C_{yy} > 2 \times b_f$

$= 183 + 2 \times 23.5 = 230$mm $> 2 \times 90 = 180$mm

Hence ,

Required overall depth of tie plate =230 + 2 x 25 =280mm (edge distance of 16-mm diameter bolts = 25mm)

Provide a tie plate of 300 mm depth

Length of tie plate = 183 + 2 x 90 = 363mm

Required thickness of tie plate =1/50 (183 +2g) = 1/50(183+2x50) =5.66mm (where g = gauge distance –(see appendix D))

Hence ,provide a tie plate of 6-mm thickness

Provide a tie plate of size = 363 x 300 x 6 mm at both ends with six 16-mm diameter bolts .

(b) Consider the case of laced columns with two channels provided toe – to – toe

Spacing:

$$2I_{zz} = 2\,[I_{yy} + A\,(S/2) - C_{yy}\,)^2] = 13190$$

$$S = 276.7mm$$

Let us place the channel at a spacing of 280mm

Connecting system

Assuming single lacing system is provided with an inclination of 45° ;gauge length for 90mm flange = 50mm

L_o= (280-50-50)cot 45° =360mm

L_o/r_{yy} = 360/26 =13.8 < 50

Hence L_o/r_{yy} ratio is fine

0.7(L/r) of combined channel = 0.7 x 88.98 = 62.3 >13.8

Hence, L/r ratio is ok.

Compressive force in lacing bar =19,445N.

Minimum width of lacing flat for 16mm bolt (clause 7.6.2 of code)

= 50mm

Minimum thickness = 1/40 (280-50-50) x cosec45°

= 6.36 mm

Hence ,Provide a 50 x 8 mm flat

Check $r_{min} = t/\sqrt{12} = 8/\sqrt{12} = 2.309$mm

$L/r = 180 \times \text{cosec } 45^\circ / 2.309 = 110.2 < 145$

Hence, the chosen flat is safe.

For , $L/r = 110.2$ and $f_y = 250$ MPa ,from table 9c of the code

$f_{cd} = 94.4 \text{ N/mm}^2$

Capacity of the lacing flat = 94.4 x 50 x 8

= 37,760 N > 19,445N.

Tensile Strength of lacing flat = $0.9(B – d)tf_u/\gamma_{ml}$ or f_yA_g/γ_{m0}

= 0.9 (50-18) x 8 x 410/1.25 or 250 x 50 x 8/1.1

= 75, 571N or 90,909N both > 19,445 N

Hence ,the lacing flat is safe .

Connection:

Strength of bolt in double shear {from a }=74,293N

Strength in bearing = $2.5k_b dtf_u/\gamma_{mb}$ = 2.5 x 0.49 x 16 x 8 x 410/1.25

= 51,430N

Hence,Strength of bolt = 51,430N > 19,445N.

Therefore,provide one 16-mm diameter bolts of grade 4.6

Tie plate:

Effective depth of tie plate = $S-2C_{yy}$

= 280-2x23.5 =233mm > 2 x 90 = 180mm

Required overall depth = 230 +2 x 25 =280mm (edge distance of 16 mm diameter bolt =25mm)

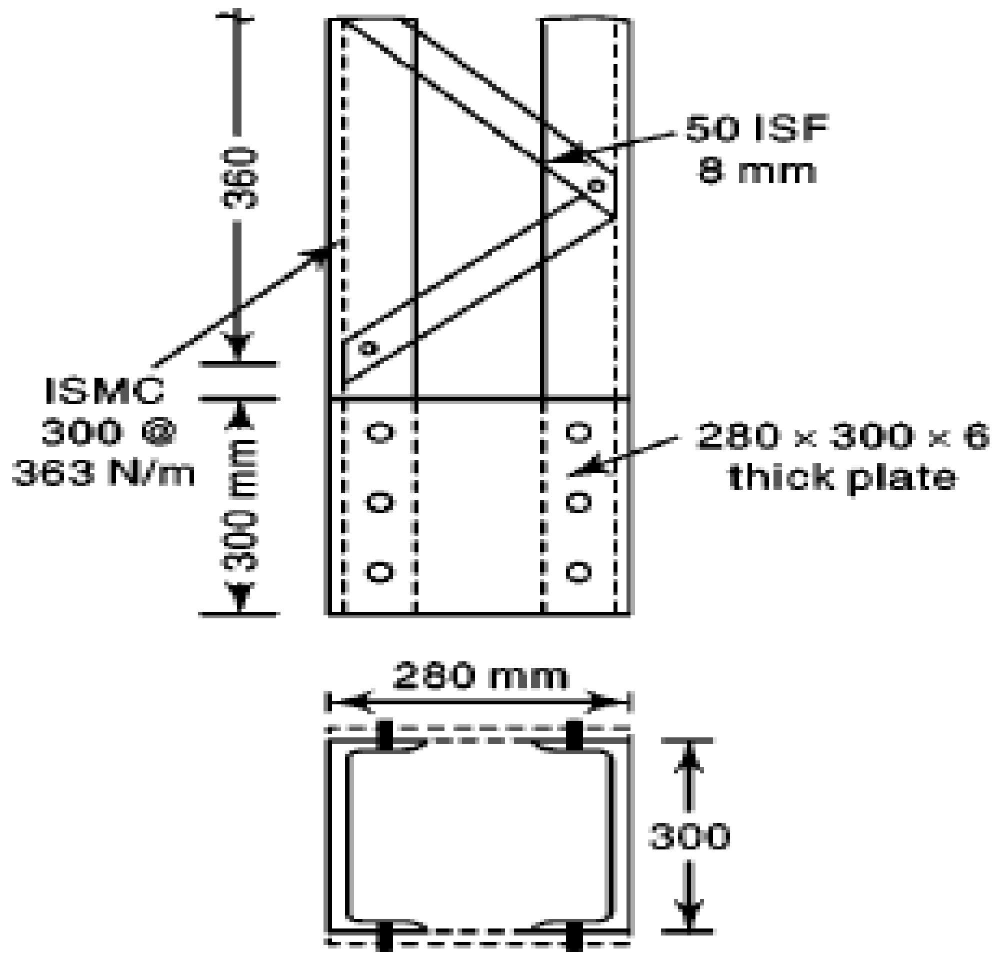
Provide a 300mm plate .

Length of tie plate = 280mm

Thickness of tie plate = (1/50)(280-2 X 50) = 3.6mm

Provide 6 mm

Provide a tie plate of size 280 x 300x 6 mm and use six of bolts 16-mm diameter and grade 4.6 to connect it to the channels.The arrangement is shown in fig (b)



(b)

It is seen that by providing channels toe-to-toe ,the lacing size and the tie plate Size are reduced.

(c) From part (a)

Spacing of the channels =183mm

Compressive force in the lacing = 19,445N.

Effective length of lacing flat (welded) = 0.7 x 183 x cosec 45° = 181.16mm

Minimum thickness of flat = 1/40 x (183 x cosec 45°)

= 6.47 mm

Provide 50 x 8 mm lacing flat.

Minimum radius of gyration ,r = $t/\sqrt{12}$ = = $8/\sqrt{12}$ =2.31 mm.

L/r = 181.16 /2.31 = 78.4 <145.

Hence the L/r ratio is ok.

For L/r = 78.4 and f_y =250MPa,Using table 9c of the code

f_{cd} = 138.56 N/mm^2

Capacity of lacing bar =138.56 x 50 x 8 =55,424 N > 19,445N

Hence, the lacing bar is safe.

Overlap of lacing flat = 50mm > 4 x 8 = 32 mm

Hence, the lacing flat is safe.

Connection:

Thickness of flange of ISMC 300 = 13.6mm

Minimum size of weld = 5 mm (Table 21 of code)

Strength of weld/unit length = 0.7 x 5 x 410/(√3 x 1.5)

= 552 N/mm

Required length of weld = 19,445/552 = 35.2 mm

Adding extra length for ends,the weld length to be provided

= 36 + 2(2 x 5) = 56mm

Provide 100mm weld length at both ends.

Tie plate:

Overall depth of plate = 183 + 2 x C_{yy}

=183 + 2 x 23.5

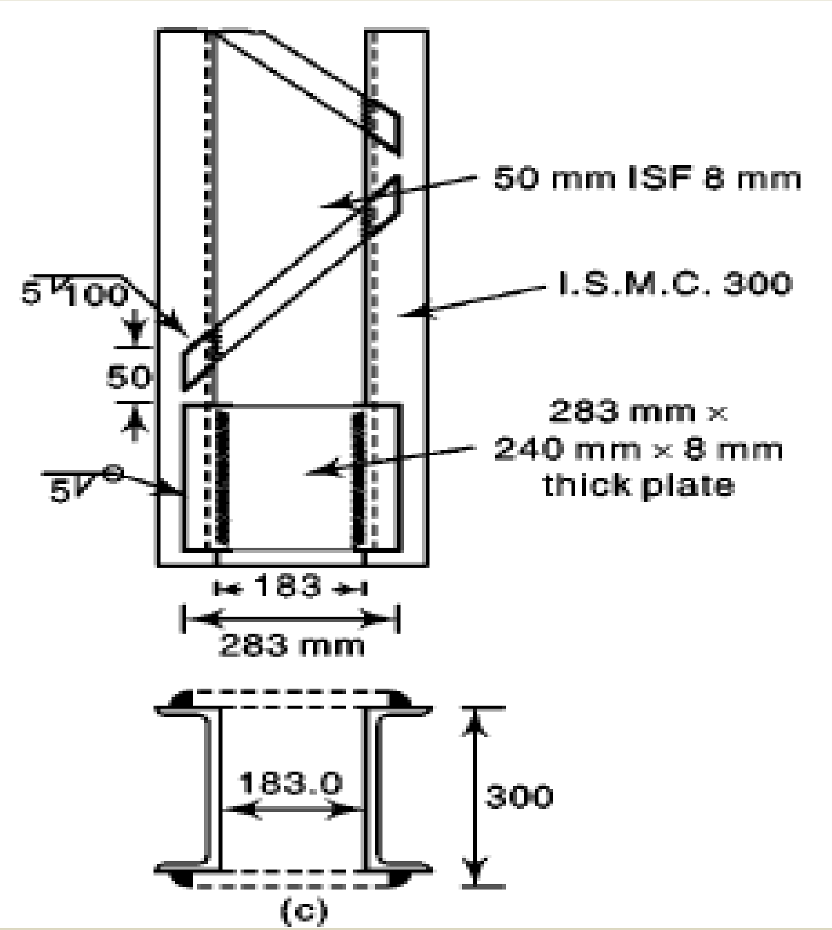
=230mm > 2 x 90mm

Let,length of tie plate =183 + 2x 50 = 283 mm

Thickness of tie plate = 1/50(183 + 2 x 50) = 5.66 mm

Provide a 8mm plate to accommodate a 5 mm weld.

Provide a tie plate of 283 x 240 x 8 mm size and connect it with 5 mm welds as in fig (c).



Thank You