DESIGN OF RIGID BOLTED CONNECTION IN STEEL STRUCTURE

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Abstract - *Connections are more complex than members to analyse and contrariety between analysis and actual behaviour is large. Further, in case of overloading, failure confined to an individual member is prefer rather than in a connection, which could affect many members. Steel as an artifact, has been used extensively in various sorts of structures, like high rise building, industrial building etc. The new code IS 800:2007 is used for steel members design. The code include variety of elements like compression member, tension member, combined connection, flexural member, combined axial and bending design of members. Bolted connections are the foremost commonly used ones in modern steel constructions. If sorted by beam-column profiles, bolt types, connection types and therefore the forces to be transferred, there might be many bolted beam-column connections while just some of them are commonly used. A properly designed bolted connection is in a position to transfer shear force and/or moment and tension. Different connections require seprate items to be checked. But in some common calculations is required for almost all bolted connections, such as bolt shear, tension, bolt tension, connection member bearing, and shear block etc.*

In this paper bolted beam-column connections with stiffener plate and end plate at various steel section properties design procedure of these connections is carried out and a ready reference table is made for various size of bolts having certain end plate thickness at certain web depth. An example will be explained in more detailed and a spreadsheet will be developed for the design of this connection.

Key Words: Bolted connection, moment connection, shear connection, IS 800:2007, bolts, end plate.

1. INTRODUCTION

Connection is necessity of any steel structure and designed critically than a member. This need occurs due to the complications of design connections than member and difference between the results and practical way of action is large. In many situations, we encounter steel member subjected to combined effect of shear and bending, axial force and bending, axial force shear and bending. Hence it is necessary to study how the structural member react when it is subjected to combined effect of the above forces and moments.

Generally two types of forces are transferred by bolted beam-column connections: i.e shear and moment. A connection could also be designed to transfer shear force if the beam is meant to be hinge connected to the column only. If the beam is rigidly connected to the column, then the requirement of a moment connection arises. Shear force is typically involved in moment connections also. Bolts are arranged to be in shear condition so as to resist shear force in the beam web and tensile and compressive force in the flanges invoked by moment. Another situation is that the connection is meant to transfer tension from the beam to the column or bracing. The bolts then may be in shear or tensile condition or combined shear and tensile and If prying is intend to happen, it should be taken into consideration. In all these conditions, usually four members need to be checked for strength or buckling: the column, the beam, and the connection member and the bolts. If shop weld is involved, that's another item to be calculated. Different connections could be used to fulfil a certain beam-column joint.

Beam-to-column connections are widely used for steel structures as they provide moment resistant connections between beams and columns at the corners of frames or a moment resistant connection to elongate beams. The analysis of the beam-to-beam connection is complex: thanks to the geometrical arrangement, different failure modes are possible, and a few of them can't be presented by simple equations.

2. OBJECTIVE OF PROJECT

The main objective of the project is to design the connections as per an Indian standard code, using various diameter of bolts and section properties with excel spread sheet.

3. METHODOLOGY

List of varied steps to be followed in manual calculation:
1. Determine factored load and factored moment
2. Choose arbitrary section and give section property.
3. Choose connection type.
4. Choose bolt grade, size and connection part grade and size.
5. Check for tension in top or bottom flange
6. Evaluation of weld at flanges and web
   a) Determine weld size around flange
   b) Determine weld size around web
7. To determine the size & number of bolts required
   a) Tension capacity of bolt T_b
   b) Shear capacity of bolt 'V_{dsb}'

c) Bearing capacity of bolt 'V_{dpb}'
8. Check bolts subject to combined shear & tension
9. Check end plate for moment
10. Gross shear capacity of plate
11. Design of stiffener plate
a) Check Tension Capacity of the Stiffener
b) Check weld between stiffener & End Plate
c) Check weld between stiffener & beam flange

Since these steps are tedious and time consuming hence design aids are necessary for reducing time consumption. List of steps followed in preparing design aids:
[1] Preparing excel program spreadsheet.

4. MANUAL DESIGN EXAMPLE OF BOLTED CONNECTIONS OF STEEL STRUCTURE METHODOLOGY

A steel frame structure having dimensions of 20m*110mm*7.5mm with different load combinations and maximum forces such as moment, shear, and axial acing on it is considered. Where members are connected by 8 bolts of 8.8 grade and fe410 steel grade. A table is made for range of moment connections, varying in web depth and having various diameter of bolts, keeping the plate thickness same throughout all sections is analysed by designing vertical connection using a stiffener plate.

Table -1: maximum and minimum forces acting on the members:

MEMBER		101	102	201	202	301	302	401	402
MOMENT	MAX	85.75	173.2	78.56	196.4	197.7	93.84	75.77	176.89
	MIN	78.56	196.4	88.29	176.1	173.9	75.77	93.84	197.74
SHEAR	MAX	32.86	26.18	26.18	31.81	61.57	34.81	34.81	61.571
	MIN	26.18	31.81	33.39	26.18	49.30	27.77	28.09	49.616
AXIAL	MAX	66.45	65.52	66.45	65.52	35.51	37.04	36.48	35.254
	MIN	65.52	63.70	65.52	63.70	35.25	35.51	37.04	35.511

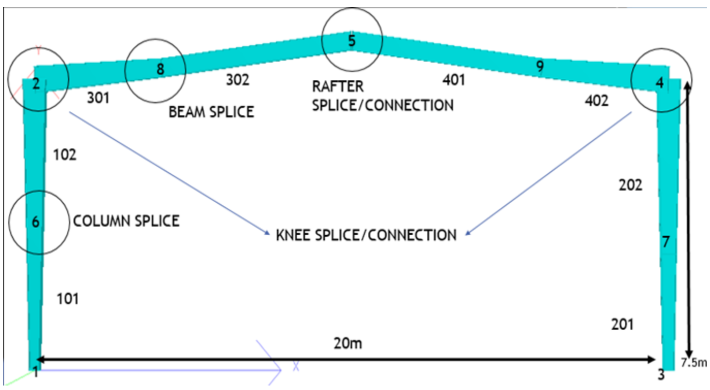

Fig -1: portal steel frame

Vertical Connection with stiffener

A Beam ISHB450 @87.2 transmits an end shear of 62 KN, axial of 36 KN and moment of 198 KN to the flange of the column ISHB450 @87.2.Design the connection. Using 24 mm diameter bolt of grade 8.8 and steel grade FE410. (Joint 2)

Design force (MAXIMUM) FACTORED FORCE

AXIAL $A_t = 54$ kN

SHEAR $F_y = 93$ kN

$F_z = 0$ kN `

MOMENT $M_z = 297$ kNm

CONNECTION TYPE = MC with Stiffeners

Column Section Properties ISHB450
D = Total Depth = 450 mm
B_f = Flange Width = 250 mm
t_f = Thickness of flange = 13.7 mm
t_w = Thickness of web = 9.8 mm
d_w = Clear depth of web ($D-2t_f$) = 422.6 mm
Beam Section Properties ISHB450
D_b = Total Depth = 450 mm
B_{fb} = Flange Width = 250 mm
t_{fb} = Thickness of flange = 13.7 mm
t_{wb} = Thickness of web = 9.8 mm
d_{wb} = Clear depth of web (D-2tf) = 422.6 mm
Grade of steel FE410
A_{xb}= Area of section = 111.1 cm^2
F_y = Yield stress = 250 N/mm^2
f_u = Ultimate Tensile stress = 410 N/mm^2
E.D = 60 mm, Gauge g =120 mm, Pitch =150 mm
Bolt Properties Using 24 mm Dia Bolts with 8.8 Grade
Hole Dia D_o = 26 mm
f_{yb} = 640 N/mm^2, F_u = 800 N/mm^2
Net Area of Bolt = 352.862 mm^2
Weld thickness for Beam web to Column = 8 mm
Weld thickness for Stiffener to Beam = 8 mm
Weld thickness for Stiffener to Column = 12 mm
End Plate Thickness = 32 mm

1) CHECK FOR TENSION IN TOP OR BOTTOM FLANGE

$$T = \frac{297X\,103 + 17}{(450 - 13.7)} = 697 \text{ kN}$$

Tension Taken by Flange = 15.1 KN
Tension Taken by the Web = 20.70 KN
Tension Capacity of the Flange $= \frac{A_g F_y}{1.1} = 778.40$ KN *SAFE*
Shear Capacity of Flange for $F_z = \frac{A_v X F_y}{\sqrt{3} \times 1.1} = 449$KN

$$\frac{T}{T_d} + \frac{V}{V_d} = 0.89$$

FLANGE IS SAFE

2) EVALUATION OF WELD AT FLANGES AND WEB

a) Determine weld size around flange

Length of weld available in flange = 2 x250-9.8= 500 mm
Design strength of Shop fillet weld 'f_{wd}'= f_{wn} / ((3^0.5) x γ_{mw}) = 189.4 N/mm^2
Design strength of Field fillet weld 'f_{wd}' = 157.8 N/mm^2
Force per mm length = 697/500 = 1.39 KN /mm

Weld Strength for Size 12 WELD = 1.607 KN /mm

WELD SIZE IS OK

Provide 12 fillet weld for the Beam Flange

b) Determine weld size around web

Resultant shear = 93 KN
Length of weld available =2x (450-2x13.7-2x13.7) =790.4mm
Checking the size of weld = 8 mm fillet weld
Weld capacity = 0.7x8x189x790.4 = 847KN > 93 KN
Therefore, 8 mm fillet weld to the Web

3) TO DETERMINE THE SIZE & NUMBER OF BOLTS REQUIRED

a) Tension capacity of bolt Tb
Tension on each bolt= 697/4 = 174 KN
Tension capacity of 24 dia 8.8 grade bolts
$= (0.9 \times f_{ub} \times A_n / \gamma_{mw}) > (f_{yb} \times A_{sb} \times (\gamma_{mb} / \gamma_{mo}))$
= 203.24 > 174 *SAFE*

b) Shear capacity of bolt 'V_{dsb}'
Shear force in each bolt= (93/8) = 12 KN
Shear capacity of bolt 'V_{dsb}' = 130 KN *SAFE*
Bearing capacity of bolt 'V_{dpb}'
=2.5x0.77x24x13.7x410/ 1.25
= 207.39 kN *SAFE*

4) CHECK BOLTS SUBJECT TO COMBINED SHEAR & TENSION

$$\left(\frac{T}{T_{db}}\right)^2 + \left(\frac{V}{V_{nsb}}\right)^2 \leq 1$$

0.74 < 1 *SAFE*

5) CHECK END PLATE FOR MOMENT

Taking moment at stiffener plate Distance between bolt centre to fillet weld of stiffeners plate= (120 - 12 - 2x12)/2 = 42 mm

Tension in each bolt = 4.39 KN.m

Thk. Of plate, $t = \sqrt{\dfrac{4 \times 4.39 \times 10^6}{250/1.1 \times 125}}$ =24.9 mm

Therefore, Provide 32 thick End plate.

6) GROSS SHEAR CAPACITY OF PLATE

Gross shear area= (530x32) =16960 mm^2
Design shear strength of end plate = 1958 KN > 93 KN
SAFE

7) DESIGN OF STIFFENER PLATE

Tensile force transferred to flanges=2 x174= 348.68 KN
B. M. = 348.68 x 10^3x60 = 20.9 x10^6 N.mm
B. M. =20.9x10^6x0.6=12.55 x 10^6 N.mm
thk. Of plate =12 mm & depth =300 mm
Section modulus of plate= (12 x90000) / 4 =270x 103mm^3
Shear in the Stiffener = 209.21 KN
Shear Stress = 58.11 N/mm^2
M/Z = (12.55x 10^6)/ (270x 10^3) = 46.5 N/mm^2 *SAFE*

a) Check Tension Capacity of the Stiffener
Tension in the Stiffener = 209.21KN
Tension Capacity = 322 KN *SAFE*

b) Check weld between stiffener & End Plate
Tension Force in the Stiffener =348.68 x 0.6 =209.21KN
Weld length available =118.15 mm
12 mm weld, strength of the stiffener = 316.37 KN
12 mm weld between Stiffener & End Plate

c) Check weld between stiffener & beam flange
Total tension on stiffener =2x265 =530 KN
Depth of stiffener plate = 300mm
Total tension in plate = 530 x 0.6 =318 kN
Force per mm weld length = 0.53 kN/mm
Using 6 mm thk fillet weld

SUMMARY

End plate	= 32mm Thk 686 mm X 240 mm
Bolts	= 8 Nos 24mm Dia Bolts
Stiffeners	= 12mm thk stiffeners
Weld	= provide 12 fillet weld for the Beam Flange
	8 mm fillet weld to the Web
	Provide 6 mm Weld to Stiffener & Flange
	12 mm weld between Stiffener & End Plate

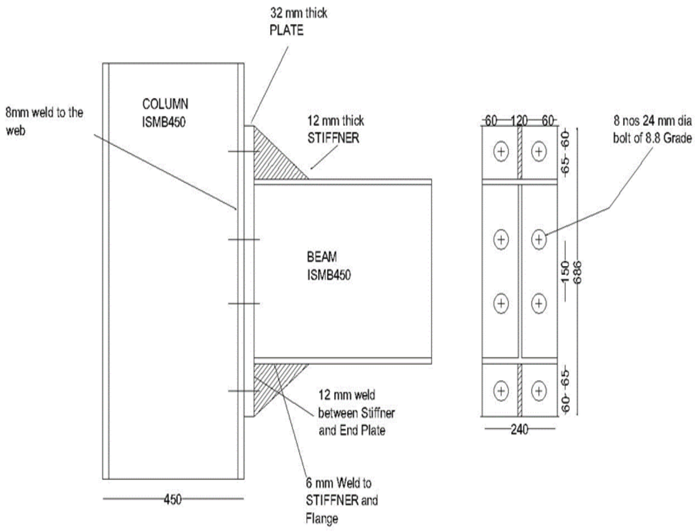

Fig -2: Detailing of connection.

5. RESULT

Analysis and design of bolted connection of steel frame structure for various diameter of bolts, and heavy and medium section sizes, by keeping the plate thickness same throughout all the sections. The following results are observed for the design of connection and a ready reference table is made.

•It is observed that bolts having smaller diameter have more chances of structure failure.
•The tension capacity of bolt should be greater than the tension in each bolt, but in case of bolt 16mm, 20 mm the tension capacity of bolt fails and combine shear and tension is also not less than 1. So bolts of 16mm, and 20 mm is not at all preferable for medium and heavy sections of steel.
•But for the section having web depth more than 550mm, 20mm bolt diameter is safe. Because of more web depth the section is safe. For 24mm bolt diameter the section having web depth 200-350mm fails in tension capacity and combine shear and tension.
•Bolt of 30mm, 32mm, 36mm, 48mm, 54mm, 60mm, 72mm are safer for all the section sizes.

•If compared 32mm and 24mm thick end plate. There is no need to increase the plate thickness as provided plate thickness is more than the obtained plate thickness for 32mm thick end plate. But in case of 24mm thick plate sections having web depth of 200-400mm the plate thickness obtain is greater than the provided thickness therefore in such cases plate thickness has to be increased.
•Lesser is the depth of section more chances for failure of section, So it is always preferable to go for higher sections have depth of 450-600mm, And to prefer bigger diameter of bolts as it reduces the chances of bolt failure.
•If the connected plates are made of high strength steel then failure of bolt can take place by bearing of the plates on the bolts. If the plate material is weaker than the bolt material, then failure will occur by bearing of the bolt on the plate and the hole will elongate.

Table -2: Ready reference table for Combine shear and tension for 32 mm thick plate of 8.8 grade bolt.

section size	T_p	d_w	combine shear & tension									
	Diameter(mm)		16	20	24	30	32	36	48	54	60	72
ISMB300	32	275.20	8.74	3.47	1.67	0.69	0.53	0.33	0.10	0.07	0.04	0.02
ISMB350	32	321.60	6.25	2.56	1.23	0.51	0.39	0.24	0.08	0.05	0.03	0.02
ISMB400	32	368.00	4.81	1.97	0.95	0.39	0.30	0.19	0.06	0.04	0.02	0.01
ISMB450	32	415.20	3.81	1.56	0.75	0.31	0.24	0.15	0.05	0.03	0.02	0.01
ISMB500	32	465.60	3.08	1.26	0.61	0.25	0.19	0.12	0.04	0.02	0.02	0.01
ISMB550	32	511.40	3.08	1.05	0.51	0.21	0.16	0.10	0.03	0.02	0.01	0.01
ISMB600	32	558.40	2.17	0.89	0.43	0.18	0.14	0.08	0.03	0.02	0.01	0.01
ISHB300	32	278.80	8.41	3.44	1.66	0.68	0.53	0.33	0.10	0.06	0.04	0.02
ISHB350	32	326.80	6.19	2.53	1.22	0.50	0.39	0.24	0.08	0.05	0.03	0.02
ISHB400	32	374.60	4.75	1.95	0.94	0.38	0.30	0.19	0.06	0.04	0.02	0.01
ISHB450	32	422.60	3.77	1.54	0.74	0.30	0.24	0.15	0.05	0.03	0.02	0.01

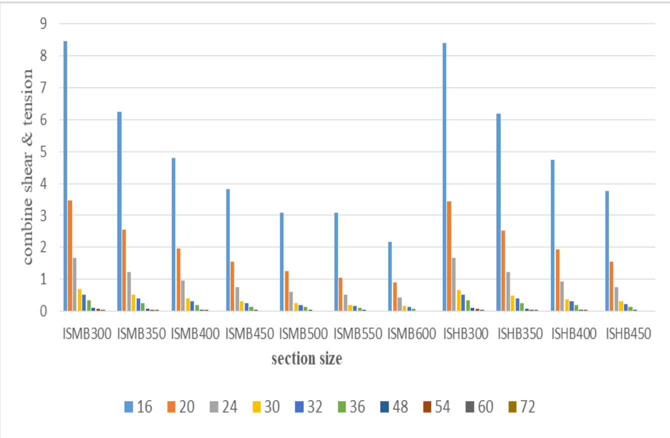

Chart -1: combine shear and tension for 32 mm thick plate of 8.8 grade bolt

6. CONCLUSIONS

•The design of different types of moment end plate connection and shear connection has been done as per IS code specifications.
•A simplified method is introduced to choose the proper thickness of the end plate for certain diameters of bolt.
•The suggested thickness of the plate is minimal to obtain failure of the bolt with the certain diameter in any case.
•Bolts of diameter 30 and above should be used to minimal the failure of bolt as well as structure.
•This method is only for determining the proper thickness of the end plate; all the other components of the connection must be verified.
•Bolted beam-column connections are widely utilized in steel construction. Various connections might be chosen to satisfy a task while all of them have advantages and drawbacks. The designer should consider certain parameters like cost, shop fabrication, shipping and installation to settle on a correct one. .
•Well-developed spreadsheets are good tools for connection design and price estimation.
•HSFG bolted connections are very stiff and hence they have good performance under fatigue loading.

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BIOGRAPHIES

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