Design of Steel Connections as per IS 800:2007 and Comparison with other Codal Provisions

Dr. Ghanshyam M. Savaliya
Assistant Professor, Government Engineering College Palanpur, Palanpur, Banaskantha, Gujarat, INDIA. 385001

Abstract-- **Advancement in design, fabrication and erection of steel structures has taken place with edification of technology and globalization. Limit state design method (LSM) philosophy for steel structures represents advantages in terms of more accuracy and economy over traditional design methods. Steel connection parameters such as specifications, assumptions, and design methodology based on provisions of IS 800:2007 have been presented in this paper. Extent of discussion has been particularly focused on important connections like web angle connections.**
Design steps for steel connections have been summarized based on codal provisions of different countries. A typical design example of double web angle connections has been computed using corresponding design stipulations of BS5950, AISC-LRFD and IS 800. Analytical calculations of the solved example have been presented and the results are compared using different countries code.
Key Words-- Limit State Design, Steel Connections, IS 800, AISC LRFD, BS5950

I. INTRODUCTION

Steel structures are assemblages of different elements joined together using various types of steel connections. The steel connections are important elements in controlling the behavior of the whole steel structure. The behavior of connections is complex due to the influence of factors like geometric imperfections, lack of fit, residual stress, connection flexibility, geometric complexity, slipping, nonlinear load-deformation characteristics etc. A variety of components such as angle cleats, end plates, stiffeners and bolts are used to transfer disperse loads from one member to other. Uses of bolts for discrete load paths are employed to transfer loads. Understanding of different types of connections is very essential for safe and economical design of the steel structure. It is vital for the connectors to develop full strength or a little higher strength compared to the members being joined for achieving an economical design.

The structural design of steel structure is based on provisions of a standard code. A standard code serves as a reference document consisting of important guidelines related to different philosophies of connection design. Standard codes incorporate comprehensive details for the design of different structural components. These details include, concept of design, design specifications, design methods, safety factors and loading values etc. Here, in this article these details are discussed in brief for different countries codal provision.

II. LITERATURE SURVEY:

Many countries have published their own standards, these codes are a product of constant research, development and past experiences of experts corresponding to respective fields. The philosophy of the limit state method (LSM) was introduced in British Code CP 110(1972) (now BS 8110) and Indian concrete code IS 456:1978. Limit states design was first adopted for steel structures in the Canadian code in 1974, this was followed by the British codes BS 5950 and BS 5400. In USA, the American Institute of Steel in Construction introduced LSM in the form of load-resistant factor design (LRFD) in 1993. N. Subramanian (2008).

IS 800 (2007):

Due to globalization, engineering practice has not remained confined to a particular area therefore practicing engineers before 2007 were facing difficulties with existing code in India. Realizing these difficulties Bureau of Indian Standards, New Delhi with the faculty of Civil Engineering, Indian Institute of Technology, Madras to help and prepare a draft for revision of IS 800 (2007). This work was carried out in a project mode with financial support from the Institute for Steel Development and Growth (INSDAG), Kolkatta.

IS 800(2007) is based on international practice which is an improvement over the previous code IS 800 (1984), with new provisions on partial safety factor-based limit state method of design including design against fatigue, design for fire load, design for durability, design by experimental data etc. It includes parameters like fatigue, ultimate strength, member end connections, restrains and many more having greater influence on the design considerations which makes IS 800 (2007) more complex and time consuming for new users. The philosophy of the limit state design method incorporates a multiple safety factor format that to provides adequate serviceability at service loads, by considering all possible ‘limit states’.

Design assumptions and specifications for steel connections have been summarized on the basis of codal provisions used in different countries. The design provisions of connections are compared with different countries codes. Design stipulations towards different types of steel connections pertinent to AISC ‘Load and Resistance Factor Design’ (LRFD) (2005) and BS 5950 (2000) specifications have been compared with the relevant parameters of IS 800 (LSM)(2007).

III. COMPARISON OF SPECIFICATIONS

Here, general specifications for design of connections are presented here with different countries code. Specifications for connections include spacing, design strength of bolts in shear, bearing and tension force, Bolt Subjected to Combined Shear and Tension stresses are compared as presented in Table 1 and some notations of Table are as follows.

n_n =number of shear planes with threads intercepting shear plane

n_s =number of shear planes without threads intercepting shear plane

A_{sb} =nominal plain shank area of bolt

β_{lg} =Reduction factor that allows for effect of large grip length

β_{lj} =Reduction factor which allows for overloading of end bolts that occur in long connection

β_{pkg}=Reduction factor to account for packing plates in excess of 6mm

A_{nb}=net tensile area at threads, may be taken as area corresponding to root diameter at thread

For ISO thread profile, as $A_{nb} = (A/4)(d\text{-}0.9382p)^2$

TABLE I

COMPARISON OF GENERAL SPECIFICATIONS

	IS:800 (2007)	BS:5950-I (2000)	AISC LRFD (2005)
Bolt Holes (d=bolts dia.)	d+1mm;d≤14mm d+2mm;d>16mm d+3mm;d>24mm d=dia. of bolts	- d+2mm;d≤24mm d+3mm;d>24mm d +6mm; Holding down bolts:	- d+2mm;d≤24mm; d+3mm;d>24mm d=dia. of rivet/bolts
Minimum Spacing	≥ 2.5 × d d=dia. of rivet/bolt	≥ 2.5 × d d=dia. of rivet/bolt	2.66 × d in direction of force
Maximum Spacing in Direction of stresses exposed. Any direction connection in exposed condition	<32*t* or 300 mm, - t= thickness of thinner plate	In the direction of stress should not exceed 14 × t Maximum spacing <16 × t ≤ 200mm t=thickness of thinner plate	12 t < 6 in. (150 mm) T=thickness of the connected part
Pitch, in Tension member, Compression member, Connecting to face of Rolled hot sections (RHS)	<16*t* or 200 mm, <12*t* or 200 mm t = thickness of thinner plate	Vertical = 70mm; bolt gauge or cross centres = 90mm or 140mm for end plates & 100mm+ beam web thickness ≥0.3 × RHS face width	Min. of 12*t* or 150 mm t = thickness of thinner plate
Min. Edge dist. Sheared or Hand Flame Cut, Rolled, Machine Flame Cut	1.7 × Hole Diameter 1.5 × Hole Diameter	1.40 x Hole Diameter 1.25 x Hole Diameter	1.75 × Hole Diameter 1.25 × Hole Diameter

Max. Edge distance to nearest line of fasteners from an edge of any unstiffened part, Exposed to corrosive influences	$< 12 \times t\varepsilon$; Yield stress ratio $\varepsilon=(250/f_y)^{1/2}$ and t is thickness of thinner outer plate < 40 mm $+ 4t$,	$11 \times t\varepsilon$; $\varepsilon = (275/f_y)^{1/2}$ t is thickness of thinner outer plate < 40 mm $+ 4t$,	$<24t$ or 305 mm, t is thickness of thinner outer plate $<14t$ or 180 mm,
Effective Areas of Bolts	A_n net tensile stress area at root ofthe threads	A_s , Area at root of threads	Area at threads, A_{nt}
Factored shear force (V_{sb})	$V_{sb} = V_{db}$; V_{db}=design strength =smaller of shear, V_{dsb} and bearing, V_{dpb}	shear capacity Ps of a bolt should be taken as: $P_s=p_s\times A_s$	The design tension or shear strength, $\Phi \times F_n \times A_b$, Φ= 0.75 (LRFD);
Shear Capacity of Bolt (V_{dsb})	$V_{dsb} \leq V_{nsb} / \gamma_{mb}$	$P_s=p_s \times A_s$ p_s=Shear strength of bolt, A_s=Shear area	$V_u=\Phi\times A_b \times F_v$ Φ=resistance factor $F_{v=}$ Nominal strength $A_{b=}$ Nomi. area
nominal shear capacity of a bolt (V_{nsb})	$V_{nsb} = \frac{f_u}{\sqrt{3}}(n_n A_{nb} + n_s A_{sb})$ $\beta_{lj}\beta_{lg}\beta_{pkg}$	$V_{nsb} = p_s \times A_s \times$ Reduction factors p_s=Shear strength of bolt, A_s =Shear area	$F_v = 0.6 \times$ nominal Tension capacity of A307 =0.65 for A325& A490 $A_{nt} = 0.785\left(d - \frac{0.9743}{n}\right)$
Net tensile area at thread A_{nb}	$A_{nb} = (A/4) \times (d-0.9382p)^2$ A_{nb} =78-80% of gross area	A_t=tensile area of bolt	n=no of threads per inch ,
Reduction factor for *Long Joints* (β_{lj}); element containing more than two bolts	$\beta_{lj} = 1.075 - l_j / (200\, d)$ but $0.75 \leq \beta_{lj} \leq 1.0$	$L_j > 500$mm $(5500-L_j)/5000$ L_j =Length of joints	$\beta_{lj} = 1.2 - 0.002 (L/w)\leq 1.0$ L=actual length of end loaded weld
Reduction factorfor *Large Grip Lengths* $l_g > 5\times d$ of bolts	$\beta_{lg} = 8\, d /(3\, d+l_g)$; Where $l_g<8\times d$ & $\beta_{lg}<\beta_{lj}$,	$(8d)/(3d+T_g)$ T_g=thickness of grip	No. increased by 1% for each 2mm increased in grip
Reduction factor for Packing Plates(β_{pkg})	β_{pkg} =(1-0.0125t_{pkg}) where , t_{pkg} = thickness of thicker packing in mm	$(9d)/(8d+3*t_{pa})$ t_{pa}=thickness of pack	[1-0.0154(t-6)]; t=total thickness of filler plates≤19mm

IV. DOUBLE ANGLE WEB CLEAT CONNECTION

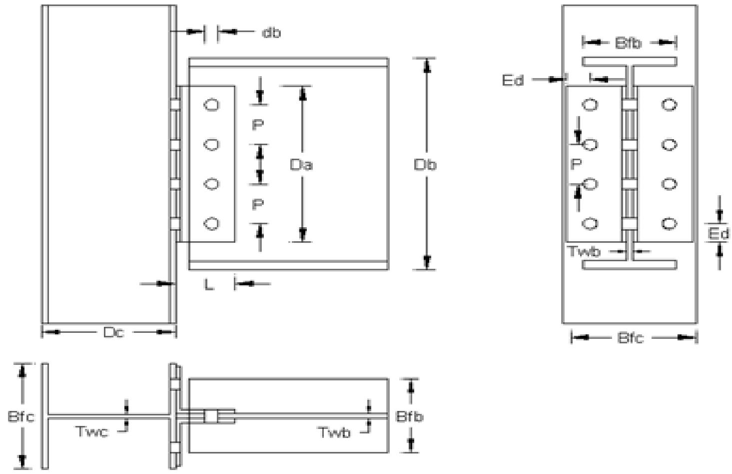

Fig. 1 DETAILS OF DOUBLE WEB ANGLE CONNECTION

Connection consists of a pair of angle cleats that are usually bolted to supported beam web in shop and beam assembly is then bolted to supporting member on site. Double web angle connection as shown in Fig. 1 the step wise procedure and design codal provision using different countries code are presented as shown in Table 2.

TABLE 2 COMPARISON OF DESIGN PROVISIONS FOR WEB ANGLE CONNECTIONS

	IS:800 (2007)	BS:5950-I (2000)	AISC LRFD (2005)
Design philosophy	Limit State design Method	Limit State design Method	Load and Resistance Factor Design
Steel Grade	Fy 250	S275	f_y=50ksi, f_u=65ksi f_y=36ksi, f_u=58ksi
Bolt class	M20 of 8.8 grade	M20 of 8.8 grade	¾ inch A325-N
1. Design of connection to Beam web			
Shear capacity of bolt connecting cleats to beam web	$V_{dsb} \le V_{nsb} / \gamma_{mb}$ $V_{nsb} = f_u/\sqrt{3}\,(n_n A_{nb} + n_s A_{sb})\beta_{lj}\,\beta_{lg}\,\beta_{pkg}$	The shear capacity of a single bolt $P_s = p_s\,A_s$ p_s=Strength of bolts A_s=Area of bolts	$V_u = \Phi.A_b.F_v$ Φ=resistance factor, F_v= Nominal strength, A_b =Nominal area at major thread dia
Pitch, in Tension member, Compression member,	<16*t* or 200 mm, <12*t* or 200 mm t = thickness of thinner plate	Vertical = 70mm; bolt gauge = 90mm or 140mm for end plates & 100mm+ beam web thickness (t_w);	Min. of 12*t* or 150 mm t = thickness of thinner plate
Horizontal Shear	$H=V_x e_x r_i/\Sigma r_i^2$	$F_{sm}=F_v\,a/Z_{bg}$	

force due to eccentricity	e_x=eccentricity of column face to bolt	$Z_{bg} = n(n+1)p/6$	-
Vertical Shear force per bolts	$v=V/n$ n=No of bolts	$F_{sv} = F_v/n$ n=No of bolts	$F_{sv} = R_u /n$ n=No of bolts
Resultant due to direct shear and moment	$R=\sqrt{(H^2+v^2)}$ < Bolt shear strength	$F_s = \sqrt{(F_{sv}^2+F_{sm}^2)}$ $< 2 P_s$	*From table [1]* t_w=web thick. of web $\Phi R_n > R_u$
2. Design of Connection to column flange			
Slip resistance per bolt	$V_{nsf} = \mu_f\ n_e\ K_h\ 0.8\ A_{sb}\ 0.70\ f_{ub}$	$P_{sL} = 1.1\ K_s\ \mu\ P_0$ P_0=min. shank tension μ= slip factor varies from 0.2 to 0.5	slip resistance, ΦR_n $Rn = \mu D_u h_{sc} T_b N_s$ (a) For standard size holes $h_{sc} = 1$
Horizontal Shear force due toeccentricity	$H=V_x g r_i/\Sigma r_i^2$ g=eccentricity due to guage dis.	$F_{sm}=F_v\ a/Z_{bg}$ $Z_{bg} = n(n+1)p/6$	-
Resultant force on outermost bolt due to direct shear and moment	$R=\sqrt{(H^2+v^2)}$ < Bolt capacity	$F_s = \sqrt{(F_{sv}^2 + F_{sm}^2)}$ $< 2 P_s$	*From table [1]* t_f=thickness of flange of beam $\Phi R_n > R_u$
3. Connecting element capacity			
Shear capacity of the leg of the angle cleat	$V/2\ t\ f_y/(\sqrt{3}\ \gamma_{m0})$ t=thickness of web angle, $f_y = 250 N/mm^2$ $\gamma_{m0} = 1.25$	P_v = min (0.6 p_y A_v , 0.7 $p_y K_e$ $A_{v.net}$) $A_v = 0.9\ (2e_1+(n-1)\ p)\ t_c$ $A_{v.net} = A_v - n\ D_h\ t_c$	$\Phi\ R_n = \Phi\ [0.6\ f_u\ A_{nv} + f_y\ A_{gt}]$ *design strength*, ΦR_n $R_n = 0.60 F_y\ A_g$ $\Phi = 1.00$
Bearing resistance on cleat	$V_{sb} \le V_{npb} / \gamma_{mb}$ $V_{npb} = 2.5\ d\ t\ f_u$	$P_{bs} = d\ t_c\ p_{bs}$ $< 0.5\ e\ t_c\ p_{bs}$ $p_{bs}=460\ N/mm^2$	-
Cleat Bending moment	$M_{req}=V/2\times g/2$ g=guage distance	$M_x= V/2\times g/2$ g=guage distance	$M_x= V/2\times e_1$ e_1=eccentricity
Moment capacity of cleat	$M_{obt}=1.2\times f_y\times Z/\gamma_{m0}$ $f_y=250\ \ \gamma_{m0}=1$ $M_{obt} > M_{req}$	$M_{obt}=1.2\times p_y\times Z_x$ $p_y=275$ $M_{obt} > M_x$	$M_c = p_y\times Z$ p_y=36 ksi $M_c > M_x$

Result Discussion on Design examples

Here, an effort is made to solve the problem using different countries' codal provisions for same geometry and component size of the connection. Double web angle connection is considered with configuration as shown in Fig 1. Capacity in a connection is found out with one vertical line of bolts. Here, in this problem connection configuration are predefined to resist a shear force of 120 kN.

Strengths of following component are checked for the design of double web angle connection.

1. Bolts group in beam web

2. Bolts group in column flange
3. Angle cleats in shear
4. Angle cleats in bending

Detailing of beam column connection configuration is shown in Fig. 1. and size parameters presented in Table 4 for all examples using different codes.

Table 3 DETAILS OF SECTION PROPERTIES AND CONNECTION CONFIGURATION PROVISION

	IS 800 (2007)	BS 5950 (2000)	AISC LRFD (2005)
Design philosophy	Limit State design Method	Limit State design Method	Load and Resistance Factor Design
Steel Grade	Fy 250	S275	f_y=50 ksi,f_u= 65 ksi f_y=36 ksi, f_u= 58 ksi
Bolt class	M20 8.8	M20 8.8	¾ inch A325-N
Beam	ISMB400	UB406 x 140 x 39	W16 x 31
Depth of D_b	400	406	15.88” (403 mm)
Width of flange B_{fb}	140	140	5.53” (140 mm)
Thick. of flange t_{fb}	16	8.6	0.44” (11 mm)
Thick. of web t_{wb}	8.9	6.4	0.28” (7.1 mm)
Column	ISHB200	UC203 x 203 x 46	W8 x 31
Depth of D_b	200	203	8” (203 mm)
Width of flange B_{fc}	200	203	8” (203 mm)
Thick. of flange t_{fc}	9	11	0.44” (11 mm)
Thick. of web t_{wc}	7.8	7.2	0.28” (7.1 mm)
Angle section	90 x 90 x 8mm	90 x 90 x 8mm	3½” x 3½” x 0.312”
Pitch	75	75	3.0” (76.2 mm)
Edge distance	35	35	1.3” (33.2 mm)

Table 4 COMPARISON OF COMPONENT STRENGTH WITH DIFFERENT CODES

Codal provision	IS 800		BS (2000)	AISC (2005)	
Component Strength	1984 (kN)	2007 (kN)	kN	kN	kips
Bolts group in beam web	230	146	177	565	127
Bolts group in column flange	290	305	589	687	154.4
Angle cleats in shear	315	545	701	395	88.74
Angle cleats in bending	357	536	700	647	145.4

Summary

The following conclusions are made from the comparative study of connections specification, provisions and analytical work conducted.

- Connection component strength varies with multiple safety factors.
- Design steps for steel connections have been summarized using different countries' codal provisions.
- In the Limit state design method, specifications for connections design are found likely similar in different countries' codal provision.
- Evaluated component strength of connection using different countries' codal provisions are as presented in Table 4.

V. References

[1] AISC-2005 Load and Resistance Factor Design (LRFD) Specification for Structural Steel Buildings, American Institute of Steel Construction, INC, Chicago, Illinois.

[2] AISC-LRFD-325(2001), AISC Manual of steel construction, American Institute of Steel Construction,3rd edition.

[3] BS 5950-2000: Part1 "Structural Use of Steelwork in Buildings" Code of practice for design in simple and continuous construction: hot rolled sections, British Standards Institution, London.

[4] IS 800-1984, "*Code of Practice for General Construction in Steel"*, First Revision, Bureau of Indian Standard, New-Delhi.

[5] IS 800-2007, "*Code of Practice for General Construction in Steel"*, Third Revision, Bureau of Indian Standard, New-Delhi.

[6] N. Subramanian, "*Design of Steel Structures"* based on the limit state method of design as per the latest Indian standard code IS800:2007, Oxford University Press, New Delhi, 2008.

Acknowledgment: Acknowledging Dr. U. V. Dave, Professor, Department of Civil Engineering, Institute of Technology, Nirma University, Ahmedabad, Gujarat, INDIA for providing valuable guidance during this research work.