Design of steel structures

Design of tension members by working stress method and limit stage method

INTRODUCTION

In a steel structure, there are many important structural components, which govern the satisfactory performance of the entire structure like the bracing systems, both vertical column bracings and also the horizontal floor bracings and most of all the connections between structural components. Beams are generally subjected only to flexure about the horizontal axis whereas columns are subjected to axial load along with bending moment about the major axis. The minor axis moment in columns are generally nil or very nominal since in a standard structural system, the columns are so oriented that the frames along the major axis of the columns are moment resistant frames, and column bracings are provided in the frames along the other perpendicular direction.

Few important problems have been solved using WSM as per the existing IS: 800 – 1984 and as well as the LSM based on IS:800-2007

LOADS AND LOAD COMBINATIONS (Refer IS:800)

To design a structure, it is analyzed first for its intended structural configuration and assumed sectional properties against various loads individually and in combination with each other in a way by which the structure may be subjected any time or at all time during the life of the structure for which it is to be built.

The various primary loads and other secondary effects required to be considered for Indian conditions while computing the maximum stresses in a structure or structural components are mainly as follows:

a) Dead Loads as per IS: 875 – 1987 (Part – 1).
b) Imposed or Live Loads as per IS: 875 – 1987 (Part – 2).
c) Wind Loads as per IS: 875 – 1987 (Part – 3).
d) Seismic or Earthquake loads as per IS: 1893 – 2002.
e) Erection loads.
f) Secondary effects due to contraction or expansion resulting from temperature changes, shrinkage, creep in compression members, differential settlements of the structure as a whole and its components.

As a general approach, a structure is analyzed for all the probable primary load cases and their combinations as mentioned above. Only for special structures or under stringent conditions, the secondary effects are considered in the overall analysis and in the design of connections of the structural components.

The Load combinations which are applicable for a standard structure as per Indian codes are as given below:

a) Dead Load (DL)
b) Dead Load (DL) + Live Load (LL)
c) Dead Load (DL) + Wind Load (WL) / Earthquake Load (EL)

d) Dead Load (DL) + Live Load (LL) + Wind Load (WL) / Earthquake Load (EL)

While designing a structure using the popular "Allowable stress Design method", the above load combinations are considered with an individual load factor of unity. As per existing IS: 800 -1984, the permissible stress limit as calculated is allowed to be increased by 33% in case of load combinations, which considers wind or seismic load.

In the proposed Limit State Method of design also the above load combinations are considered, but with variable load factors called the "Partial Safety Factor for Loads as described in Table – 1 below. This variable load factors basically ensures a rational approach to account for the variable nature of the loadings and thus enable to use steel efficiently and economically in different structural systems.

Similarly, to determine the strength of the member to be designed against the factored load as described above, a reduction factor for strength called "Partial Safety Factor for Material" is taken into consideration, which accounts for uncertainty in material strength and quality as well as manufacturing tolerances. Various material safety factors as have been adopted in IS: 800 (LSM) to cater to the Indian conditions are as given in Table – 2.

Table 1: Partial Safety Factors for Loads γ_f for Limit States

Combination	Limit State of Strength					Limit State of Serviceability			
	DL	LL		WL /EL	AL	DL	LL		WL / EL
		Main	Accompanying (CL, SL**, etc.)				Main	Accompanying (CL, SL**, etc.)	
DL+LL+CL	1.5	1.5	1.05	-	-	1.0	1.0	1.0	-
DL+LL+CL +WL/EL	1.2 1.2	1.2 1.2	1.05 0.55	0.6 1.2	-	1.0	0.8	0.8	0.8
DL+WL/EL	1.5 0.9*	-	-	1.5	-	1.0	-	-	1.0
DL + Erection Load	1.2 0.9*	1.2	-	-	-	-	-	-	-
DL + LL + Accident Load	1.0	0.35	0.35	-	1.0	-	-	-	-

* This value is to be considered when stability against overturning or stress reversal is critical
** SL is Snow Loads

Table – 2 Partial Safety Factor for Materials, γ_m

Sl. No.	Definition	Partial Safety Factor	
1	Resistance, governed by yielding γ_{mo}	1.10	
2	Resistance of member to buckling γ_{mo}	1.10	
3	Resistance, governed by ultimate stress γ_{m1}	1.25	
4	Resistance of connection γ_{m1}	Shop	Field

			Fabrication	fabrication
	(i)	Bolts – Friction Type, γ_{mf}	1.25	1.25
	(ii)	Bolts – Bearing Type, γ_{mb}	1.25	1.25
	(iii)	Rivets	1.25	1.25
	(iv)	Welds	1.25	1.50

3.0 DESIGN PROCEDURES

3.1 DESIGN OF TENSION MEMBER

3.1.1 <u>Ex. 1</u> Comparison of strength of a standard angle say ISA 50x50x6 for WSM and LSM subjected to load combination of dead load and live load.

{Note: 1cm =10 mm, 1 ton = 10kN = 1000N, 1MPa = 1 N/mm^2, 1 N/mm^2 =10 kg/mm^2, working stress 1500kg/cm^2 =150 MPa}

Gross area of ISA 50x50x6, A_g = 5.68 cm^2

Working stress method

(a) WSM (Welded) (Clause: 4.2.1 of Page –37 0f IS: 800 –1984)

$A_n = A_1+A_2.k = (1+k)\ A_g/2 = 1.75 \times 5.68/2 = 4.97$ cm^2 ($A_1=A_2=Ag/2$)

$k = \dfrac{3A_1}{3A_1 + A_2} = 0.75$, where A_1, A_2 are connected and out standing legs

Strength of section = 150 x 4.97 / 1000 = 74660 kN, 74.66kN

(b) WSM (Connected with 5 nos. 12 mm bolts)

$A_1 =$ 5.68/2 - 1.35 x 0.6 = 2.03 cm^2; A_2 = 5.68/2 =2.84 cm^2

$k = \dfrac{3x2.03}{3x2.03 + 2.84} = 0.682$

$\therefore\ T_d = (2.03 + 0.682 \times 2.84)\ 150 = 59500$ kN, 79.5 kN

Limit state method

(Permissible load is governed by smaller of strength obtained by (i) yielding of gross section, (ii) tearing at net section and (iii) block shear failure for bolted connection])

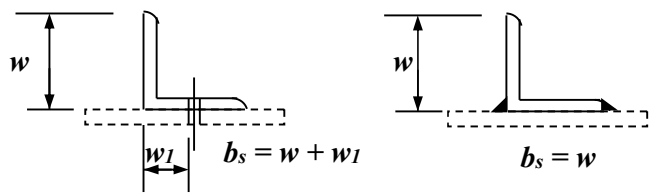
(i) Strength as governed by yielding of gross section (Clause 6.2) –
$T_{dg} = A_g.f_y/\gamma_{mo} = 5.68x250/1.10 = 129.09$kN
(γ_{mo} = safety factor for material against yield stress = 1.10)

(ii) Strength as governed by tearing at net section (Clause 6.3.3.)-

The tearing strength of an angle connected through one leg is affected by shear lag. The design strength as governed by tearing at net section is given by

$T_{dn} = 0.9A_{nc}\, f_u / \gamma_{m1} + \beta\, A_{go}\, f_y / \gamma_{mo}$.

(γ_{mo} = as discussed earlier)
(γ_{m1} = safety factor for material against ultimate stress = 1.25)
$\beta = 1.4 - 0.076\,(w/t)\,(f_y/f_u)\,(b_s/L_c)$
$= 1.4 - 0.076x\,(50/6)\,x\,(250/410)\,x\,(50/140) = 1.262$
L= length of 6mm weld = 140 mm, b_s = w =50 mm]



$$T_{dn} = 0.9x\frac{5.68}{2}x\frac{410}{1.25} + 1.262x\frac{5.68}{2}x\frac{250}{1.10} = 165.29kN$$

Therefore, design strength is T_{dn} = 129.09 kN

<u>Comparison of LSM and WSM for Welded Connection:-</u>

Now, comparing (a) with (a_1). We find that for WSM, T_d = 74.7 kN
Equivalent load in LSM with load factors of 1.5 for DL & LL in DL+LL combination is T_d = 74.7 x 1.5 = 112.05kN

Therefore, corresponding to WSM design, percentage strength attained in LSM is = 112.05/129.09 =0.868 or 86.8%

(b_1) LSM (Connected with 5 x 12 mm bolt) Calculation in tons for the benefit of practising engineers

(i) Strength as governed by yielding of gross section (Clause 6.2) –
$T_{dg} = A_g.f_y/\gamma_{mo}$ = 5.68x2500/1.10 =12.909Tons

(ii) Strength as governed by tearing at net section (Clause 6.3.3) -
$T_{dn} = 0.9A_{nc}\, f_u / \gamma_{m1} + \beta\, A_{go}\, f_y / \gamma_{mo}$
$\beta = 1.4 - 0.076\,(w/t)\,(f_y/f_u)\,(b_s/L_c)$
$= 1.4 - 0.076x(50/6)x(250/410)x(72/120) = 1.168$,
L= length of connection = 30x4=120mm,
b_s = 50+28-6=72mm; w = 50mm]

$$T_{dn} = 0.9x2.03x\frac{4100}{1.25} + 1.168x2.84x\frac{2500}{1.10} = 13.53T$$

(iii) Strength as governed by block shear failure (Clause 6.4) -

(case – 1)

$T_{db} = (A_{vg} f_y / \sqrt{3}\gamma_{mo} + 0.9 f_u A_{tn} / \gamma_{m1})$

$T_{db} = (145x6x250/[\sqrt{3}x1.10] + 0.9x410x[22 - 13.5/2]x6/1.25)/10000 = 14.116T$

(case – 2

$T_{db} = (0.9 f_u A_{vn} / \sqrt{3}\gamma_{m1} + f_y A_{tg} / \gamma_{mo})$

$T_{db} = (0.9x410x[145 - 4.5x13.5]x6/\sqrt{3}x1.25 + 250x22x6/1.10)/10000 = 11.615^T$ (A_{vg} , A_{vn} = minimum gross and net area in shear along the line of transmitted force, respectively

A_{tg}, A_{tn} = minimum gross and net area in tension from the hole to the toe of the angle or next last row of bolt in plates, perpendicular to the line of force,

[Length of connection = 25(edge distance)+30x4=145mm]

A_{vg} = 145x6 mm^2: A_{vn} = (145-4.5x13.5) x 6 mm^2; A_{tg} = 22x6 mm^2;

A_{tn} = (22- 13.5/2) x 6 mm^2)

Therefore, design strength is T_{dn} = 11.615T

Comparison of LSM and WSM for Bolted Connection:-

Now comparing (b) with (b_1), we find that for WSM, T_d = 5.95T

Equivalent load in LSM with load factors of 1.5 for DL & LL in DL+LL combination is T_d = 5.95 x 1.5 = 8.925T^T

Therefore, corresponding to WSM design, percentage strength attained in LSM is = 8.925/11.615 =0.768 or 76.8%

Ex. 2: Comparison of strength of a standard angle say ISA 90x90x8 for WSM and LSM subjected to load combination of dead load, live load and wind load.

Calculations are in tons. {for students and practicing engineers}

Gross area of ISA 90x90x8, A_g = 13.79 cm^2

(a) WSM (Welded) (Clause: 4.2.1 of Page –37 of IS: 800 –1984)

$A_n = A_1 + A_2.k = (1+k) A_g/2$ = 1.75 x 13.79/2 = 12.066 cm^2 (A_1=A_2=Ag/2)

$k = \dfrac{3A_1}{3A_1 + A_2} = 0.75$

Strength of section = 1.33x1500 x 12.066 / 1000 = 24.072T

(b) WSM (Connected with 6 nos. 16 mm bolts)

A_1 = 13.79/2 -1.75 x 0.8 = 5.495 cm^2 ; A_2 = 13.79/2 =6.895 cm^2

$k = \dfrac{3x5.495}{3x5.495 + 6.895} = 0.705$

$\therefore$ T_d = (5.495 + 0.705 x 6.895) 1500/1000 = 15.535T

(a_1) LSM (connected with Weld) (Clause 6.1 of draft IS: 800) -

(i) Strength as governed by yielding of gross section (Clause 6.2)–
$T_{dg} = A_g.f_y/\gamma_{mo} = 13.79 \times 2500/1.10 = 31.34$ T

(ii) Strength as governed by tearing at net section(Clause 6.3.3) -
$T_{dn} = 0.9A_{nc}\, f_u / \gamma_{m1} + \beta\, A_{go}\, f_y \gamma_{mo}$

$$T_{dn} = 0.9x\frac{13.79}{2}x\frac{4100}{1.25} + 1.165x\frac{13.79}{2}x\frac{2500}{1.10} = 38.616T$$

$\beta = 1.4 - 0.076\,(w/t)\,(f_y/f_u)\,(b_s/L_c)$
$= 1.4 - 0.076x(90/8)x(250/410)x(90/200) = 1.165,$
L= length of 8 mm weld = 200mm, b_s =90mm]

Therefore, design strength is T_{dn} = 31.34T

<u>Comparison of LSM and WSM for Welded Connection:-</u>

Now, comparing (a) with (a_1). We find that for WSM, T_d = 24.072T
Equivalent load in LSM with load factors of 1.2 for DL, LL and WL in DL+LL+WL combination is T_d = 24.072 x 1.2 = 28.886T

Therefore, corresponding to WSM design, percentage strength attained in LSM is = 28.886/31.34 =0.92 or 92%.

(b_1) LSM (Connected with 6 x 16 mm bolt)

(i) Strength as governed by yielding of gross section Clause 6.2) –
$T_{dg} = A_g.f_y/\gamma_{mo} = 13.79 \times 2500/1.10 = 31.34$ T

(ii) Strength as governed by tearing at net section (Clause 6.3.3) -
$T_{dn} = 0.9A_{nc}\, f_u / \gamma_{m1} + \beta\, A_{go}\, f_y / \gamma_{mo}$

$$T_{dn} = 0.9x5.495x\frac{4100}{1.25} + 1.056x6.895x\frac{2500}{1.10} = 32767\,Kg \sim 32.767T$$

$\beta = 1.4 - 0.076\,(w/t)\,(f_y/f_u)\,(b_s/L_c)$
$= 1.4 - 0.076\,x(90/8)x(250/410)x(132/200) = 1.056,$
L= length of connection = 5 x 40 mm = 200 mm,
b_s=90+50 -8= 132mm; w = 90mm]

(iii) Strength as governed by block shear failure (Clause 6.4) -
<u>(Case – 1)</u>

$$T_{db} = (A_{vg} f_y / \sqrt{3}\gamma_{mo} + 0.9 f_u A_{tn} / \gamma_{m1})$$

$$T_{db} = (225x8x250/\sqrt{3}x1.10 + 0.9x410x[40 - 17.5/2]x8/1.25)/10000 = 31.00T$$

<u>(Case – 2)</u>

$$T_{db} = (0.9 f_u A_{vn} / \sqrt{3}\gamma_{m1} + f_y A_{tg} / \gamma_{mo})$$

$$T_{db} = (0.9x410x(225 - 5.5x17.5)x8/\sqrt{3}x1.25 + 250x40x8/1.10)/10000 = 24.8T$$

Therefore, design strength is T_{dn} = 24.83 T

Comparison of LSM and WSM for Welded Connection:-

Now comparing (b) with (b_1), we find that for WSM, T_d = 15.535Tons
Equivalent load in LSM with load factors of 1.2 for DL, LL and WL in DL+LL+WL combination is T_d = 15.535 x 1.2 = 18.642T

Therefore, corresponding to WSM design, percentage strength attained in LSM is = 18.64/24.83 =0.742 or 74.2%.
Therefore, LSM is advantageous over WSM.

CONCLUSIONS

The results are more or less same. Sometimes, LSM gives economical sections. What is important is that in LSM both strength and serviceability are given importance. In WSM only stress is considered (indirectly the strength). Serviceability behavior is not considered. Parametric analysis of a practical problem such as design of roof truss or a trussed building should be considered to get concrete conclusions.