Comparative Study of Steel Angles as Tension Members Designed by Working Stress Method and Limit State Method

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Abstract- The latest version of the Code of Practice for general construction in steel IS 800:2007 is based on Limit State Method of design. The design concept is totally changed in comparison to earlier IS 800:1984 which is based on elastic method. In the present work, the detailed study of structural components as tension members by designing using Limit State Method and Working Stress Method has been carried out and submitted the comparative study of the same in the form of graphs and charts, which highlights the actual economy achieved by Limit State Method over Working Stress Method for different structural sections. The observations made based on this study are very much useful to the practicing structural engineers.

Keywords- IS 800:1984, IS 800: 2007, Limit state method, Working stress method

1 INTRODUCTION

Structural steel has several advantages over other competing materials such as concrete and wood, such as high strength to weight ratio, high ductility, uniformity, and its ability to be fully recyclable. Ductility and toughness are very important when steel is subjected to earthquake loads or impact loads. It offers much better compressive and tensile strength than concrete.

A civil engineering designer has to ensure following requirements that govern the structural design:

- It should have adequate strength
- It should have adequate stability and rigidity
- It should be durable
- It should not interfere with the functional requirements
- It should be economical
- It should be readily adaptable to future extension

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Thus safety is one of the paramount responsibilities of the designer. However, it is difficult to assess at the design stage how safe a proposed design will actually be consistent with economy.

The codes published by the Bureau of Indian Standards for design of steel structures are IS800:1984 and IS800:2007. Earlier for designing steel structures Working Stress Method is used (IS800:1984). Now designing is done using Limit State Method (IS800:2007).

In view of this an effort has been made to high light the actual economy may be achieved by adopting Limit state method in the design of tension members based on IS800:2007.

2 DESIGN OF TENSION MEMBER BY LIMIT STATE METHOD (IS 800:2007)

Tension members are linear members in which axial forces act to cause elongation (stretch). Such members can sustain loads upto the ultimate load, at which stage they may fail by rupture at a critical section.

The design strength of the tension member shall be minimum of T_{dg}, T_{dn} and T_{db}.

2.1 Strength Due To Yielding Of Gross Section

The design strength in the member under axial tension is given by

$$T_{dg} = f_y A_g / \gamma_{mo} \quad (1)$$

where

γ_{mo} = the partial safety factor for failure in tension by yielding. The value of γ_{mo} according to IS800:2007 is 1.10.

2.2 Design Strength Due To Rupture Of Critical Section

Tension rupture of the plate at the net cross-section is given by

$$T_{dn} = 0.9 f_u A_n / \gamma_{ml} \quad (2)$$

where

γ_{ml} = the partial safety factor against ultimate tension failure by rupture (γ_{ml} = 1.25)

Single Angle Tension Member

The strength of an angle connected by one leg as governed by tearing at the net section is given by

$$T_{dn} = 0.9 f_u A_{nc} / \gamma_{ml} + \beta A_{go} f_y / \gamma_{m0} \quad (3)$$

where

β accounts for the end fastener restraint effect and is given by

$$\beta = 1.4 - 0.076 (w/t)(f_u/f_y)(b_s/L) \quad [\approx 1.4 - 0.52(b_s/L)] \quad (4)$$

$$= (f_u \gamma_{m0} / f_y \gamma_{m1}) \geq 0.7$$

2.3 Design Strength Due To Block Shear

A tension member may fail along end connection due to block shear. The corresponding design strength can be evaluated using the following equations. The block shear strength T_{db}, at an end connection is taken as the smaller of

$$T_{db1} = (A_{vg} f_y / (\sqrt{3} \gamma_{m0}) + 0.9 f_u A_{tn} / \gamma_{m1}) \quad (5)$$

Or

$$T_{db2} = (0.9 f_u A_{vn} / (\sqrt{3} \gamma_{m1}) + f_y A_{tg} / \gamma_{m0}) \quad (6)$$

3 Design Of Tension Member By Working Stress Method (IS 800:1984)

3.1Axial Stress:

The permissible stress in axial tension, σ_{at} (MPa) on the net effective area of the sections shall not exceed:

$$\sigma_{at} = 0.6 f_y \quad (7)$$

3.2 Design Details:

Net Effective Areas for Angles and Tees in Tension In the case of single angle connected through one leg the net effective sectional area shall be taken as:

$$A_{net} = A_1 + A_2 k \quad (8)$$

where

$$k = 3A_1 / (3A_1 + A_2) \quad (9)$$

4 Design Charts

4.1 Design Charts For Tension Member By Limit State Method

The Charts have been prepared based on IS: 800-2007 for Tension member. The procedure adopted is demonstrated with the design examples given below.

4.1.1 Design Example

Tensile Strength of Single Angle ISA 200 X 200 X 12 (As per IS 800:2007) with single row bolted connection (27nos 8mm dia.)

The no of bolts considered for the design of tension members for end connections is based on minimum no. of bolts required for the full strength of the angle for Block shear.

Solution:

1. Design strength due to yielding of gross section

$T_{dg} = f_y A / \gamma_{m0}$

A = {(200 -12/2) + (200-12/2)} x 12 = 4656mm.

γ_{m0} =1.1

T_{dg} = 250 x 4656 / 1.1 = 1058.182kN.

2. Design strength due to rupture of critical section

e = 40mm

p = 60mm

$T_{dn} = 0.9 f_u A_{nc} / \gamma_{m1} + \beta A_{go} f_y / \gamma_{m0}$

A_{nc} = (200 -12/2-12) x 12 = 2184mm^2

A_{go} = (200 -12/2) x 12 = 2328mm^2

$\beta = 1.4 - 0.076 (w/t)(f_u/f_y)(b_s/L)$

$= (f_u \gamma_{m0} / f_y \gamma_{m1}) \geq 0.7$

where

w= 200

b_s= 200+g-t = 200+115- 12 = 303mm

(g = 115mm if 200 mm leg is connected)

L=40 + (60 x 26) – (10 x 22) = 1380mm

β = 1.4 – 0.076 (150/10) (410/250) (303/1380) = 1.23

= (410/250)x(1.1/1.25) =1.4432 ≥ 0.7

Therefore, $\beta = 1.23$

$T_{dn} =$ (0.9x410 x 2184 /1.25) +(1.23 x 2328 x 250 /1.1)

= 1295.50 kN

3. Design strength due to block shear

The block shear strength T_{db}, at an end connection is taken as the smaller of

$T_{db1} = (A_{vg} f_y /(\sqrt{3}\,\gamma_{m0}) + f_u\, A_{tn} /\gamma_{m1})$

or

$T_{db2} = (f_u A_{vn} /(\sqrt{3}\,\gamma_{m1}) + f_y A_{tg} /\gamma_{m0})$

Do = D + 2 = 8 + 2 = 10mm.

Tearing length in tension = 200 -115=85mm

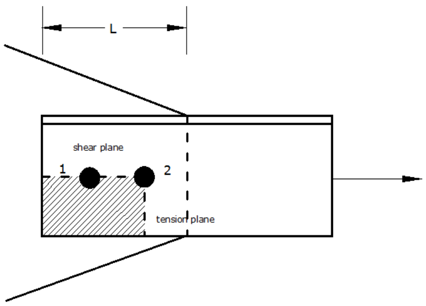


Fig.4.1 Shear plane and tension plane

A_{vg} = [(27-1) 60+40] 12 = 19200 mm²

A_{vn} = [(27-1) 60+40-(27-(1/2))22] = 16020 mm²

A_{tg} = [85 x 12] =1020 mm²

A_{tn} = [85-(0.5)10]12 = 960 mm²

T_{db1} = [{19200x250/(√3 x 1.1)}+{ 0.9 x 410 x 960 /1.25}]/1000

= 2802.81kN or

T_{db2} = [{0.9x 410 x 16020/ (√3x 1.25)} + { 250 x1020 /1.1 }]/1000

= 2962.25kN

The block shear strength is T_{db} = 2802.81kN

Strength of Single Angle is least of above three values, 1058.18KN.

4.2 Design Charts For Tension Member By Working Stress Method

The Charts have been prepared based on IS: 800-1984 for Tension member. The procedure adopted is demonstrated with the design examples given below.

4.2.1 Design Example

Tensile Strength of single angle ISA 200 X 200 X 12 (As per IS 800:1984) with single row bolted connection (27nos 8mm dia.)

Solution:

1. Axial Stress

f_y = 250 N/mm² (Mild steel)

$\sigma_{at} = 0.6\, f_y$ = 0.6 x 250 = 150 N/mm²

2. Design Details

A_1 = {(200 - 12/2 - 9.5} x 12 = 2214mm²

A_2 = {(200 -12/2} x 12 = 2328mm²

k = $3A_1/(3A_1 + A_2)$ = 3 x 2070 / (3 x 2214 + 2328) = 0.74

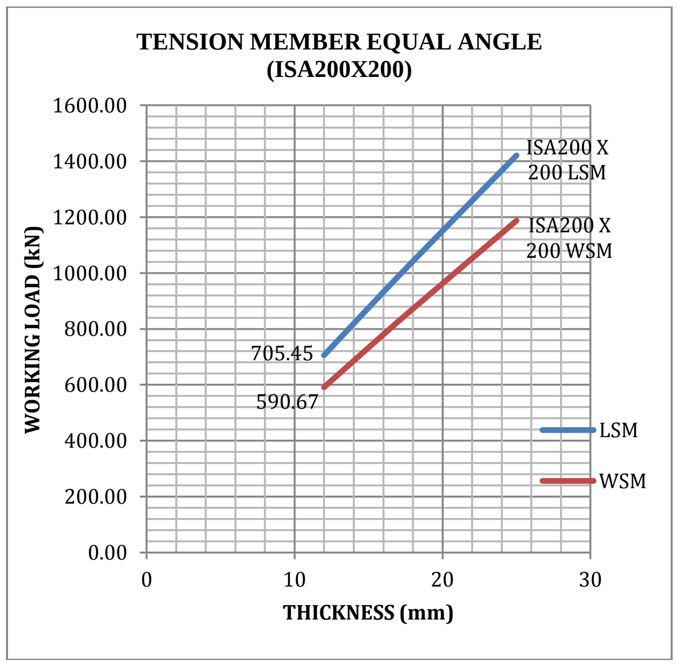
Anet = $A_1 + A_2$ k = 2214 + 2328 x 0.72 = 3937.81 mm²

P = $\sigma_{at} A_{net}$ = 150 x 3937.81 = 590.67 kN

Strength of Single Angle is, 590.67 kN

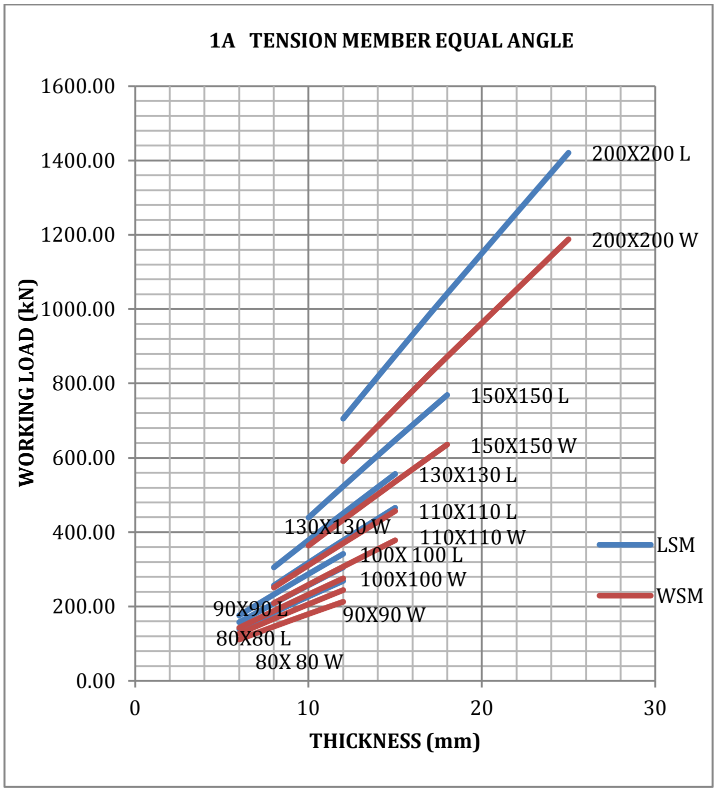
Table no.4.1 Working loads for Equal Angle (ISA200x200) as Tension member for varying thicknesses designed by Limit State Method and Working Stress Method.

a(mm)	Thickness (mm)	No.	Dia.	P LSM (kN)	P LSM/1.5 (kN)	P WSM (kN)
200	12	27	8	1058.18	705.45	590.67
200	15	27	8	1312.50	875.00	732.43
200	18	27	8	1562.73	1041.82	871.83
200	25	27	8	2130.68	1420.45	1187.90

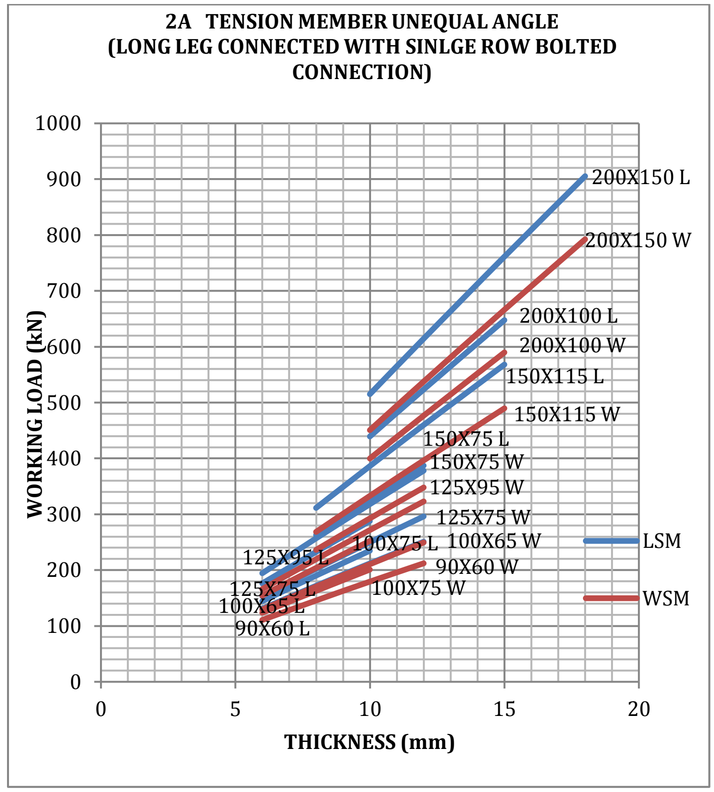


Graph no.1Graph is plotted Working load Vs Thickness.

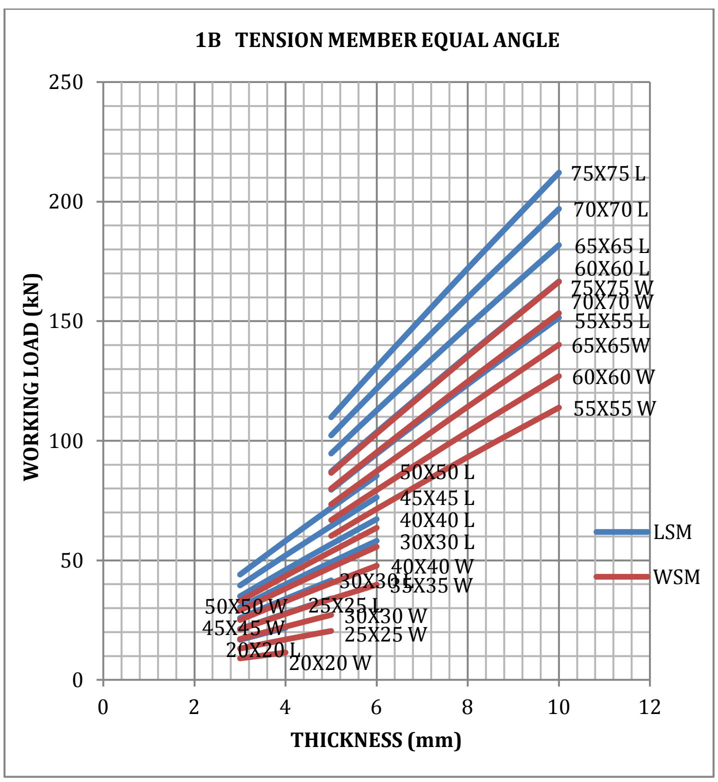
Similarly, working loads for tension member for all equal angles of all thicknesses for 8mm diameter bolts are calculated. Related all design tables and graphs plotted for working load Vs thickness are given below.



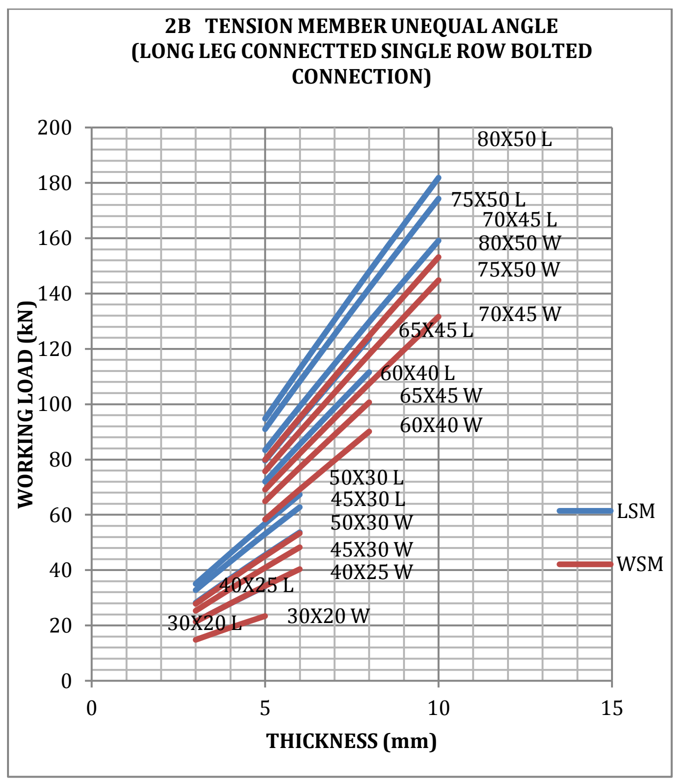
Graph no.1A Graph is plotted Working load Vs Thickness.



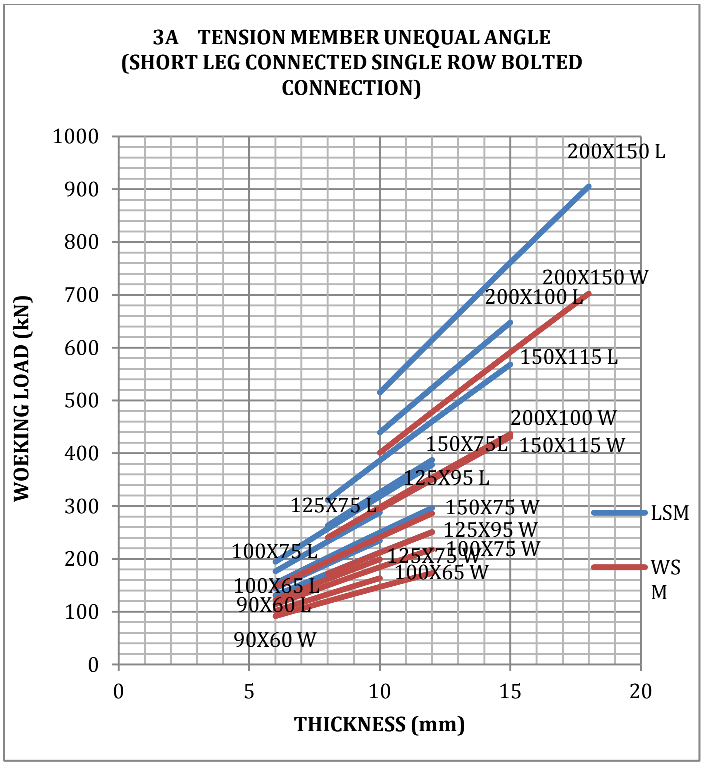
Graph no.2A Graph is plotted Working load Vs Thickness.



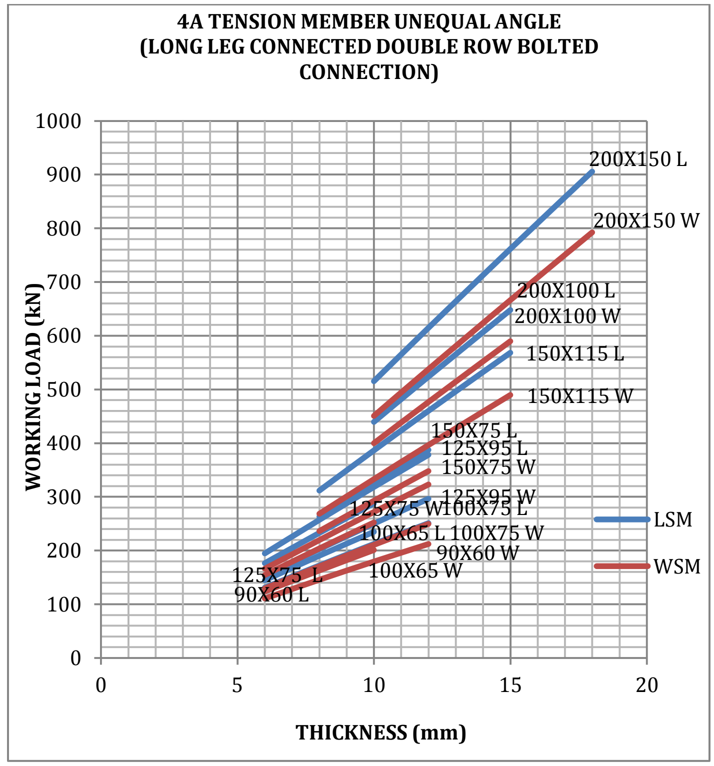
Graph no.1B Graph is plotted Working load Vs Thickness.



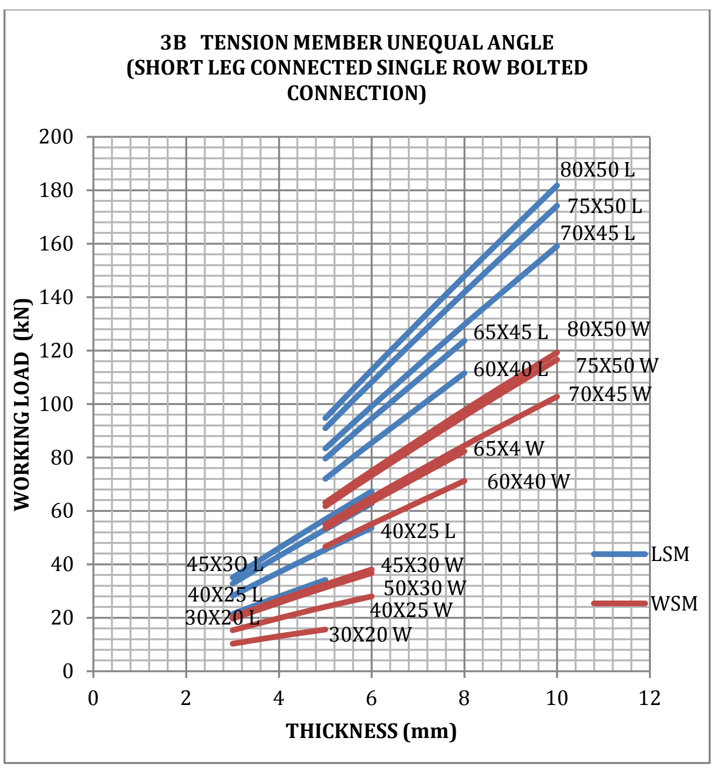
Graph no.2B Graph is plotted Working load Vs Thickness.



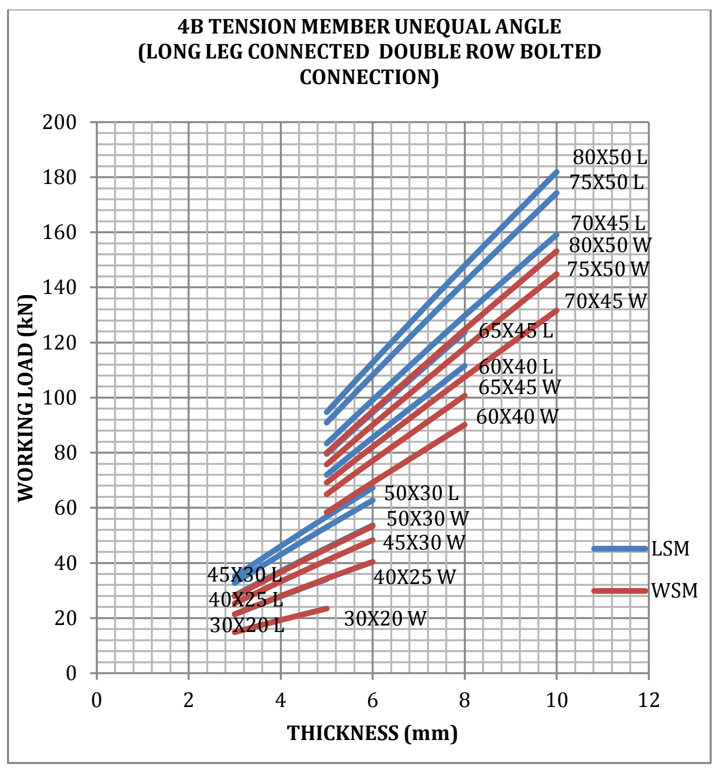
Graph no.3A Graph is plotted Working load Vs Thickness.



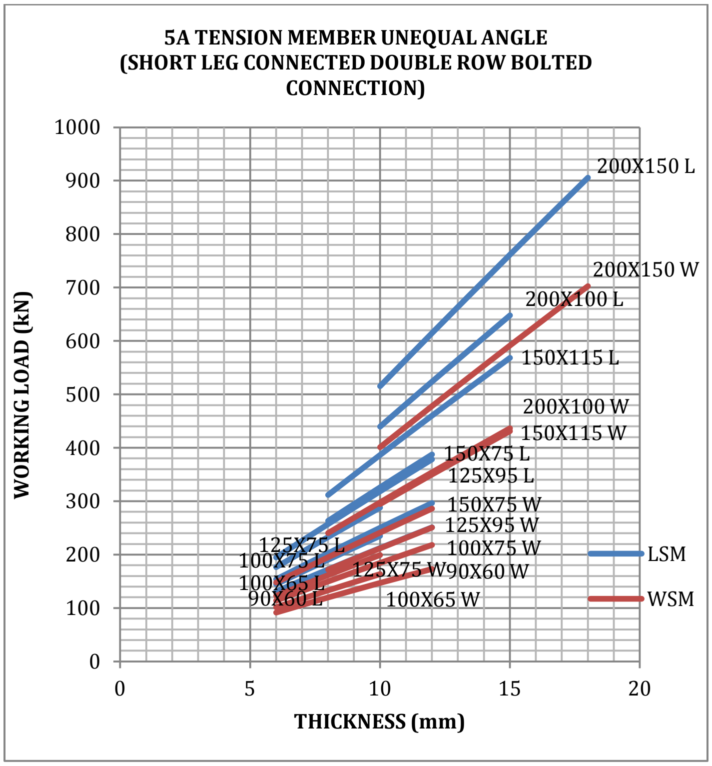
Graph no.4A Graph is plotted Working load Vs Thickness.



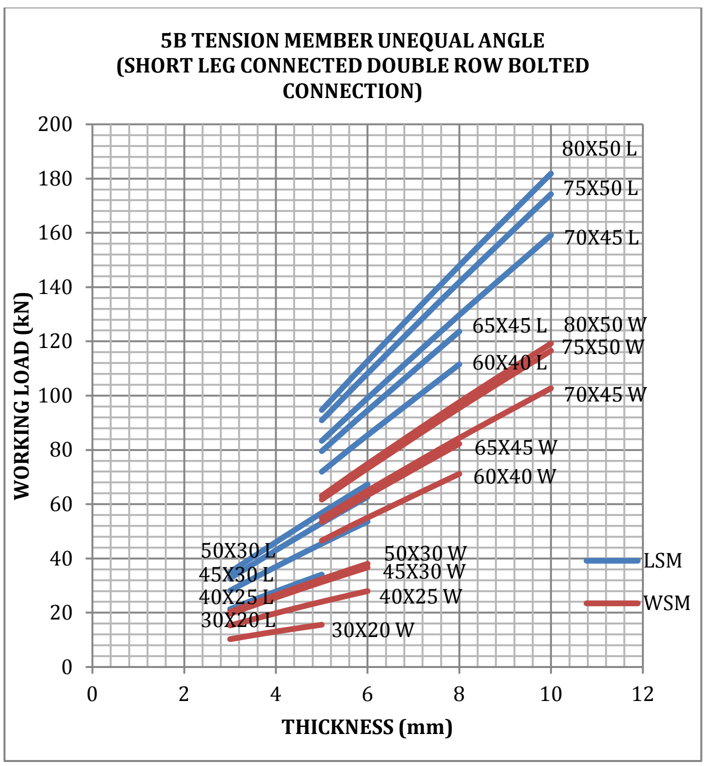
Graph no.3B Graph is plotted Working load Vs Thickness.



Graph no.4B Graph is plotted Working load Vs Thickness.



Graph no.5A Graph is plotted Working load Vs Thickness.



Graph no.5B Graph is plotted Working load Vs Thickness.

5 Design using Charts

A beam carries working Load of 1000 kN, design the suitable angle section.

Select the suitable sections for the above load are

Using Limit state method ISA 200X200X18
or

Using Working stress method ISA 200X200X25

This shows that the Limit state method is economical.

6 Observations

The observation made from the design graphs are as under:

1. Tension member for equal and unequal angles: The Limit State Method (LSM) gives higher values than Working Stress Method (WSM).

a) Equal angle: It varies from 16% to 47% for higher sections to smaller sections.

b) Unequal angle long leg connected with single row bolted and double row bolted: It varies from 12% to 31% for higher sections to smaller sections.

a) Unequal angle short leg connected with single row bolted and double row bolted: It varies from 22% to 54% for higher sections to smaller sections.

7 Conclusion

The design of tension member using Angles by Limit state method is economical over the working stress method which values for 12% to 54%.

Notations

a connecting leg

A section area

A_1 effective cross-sectional area of the connected leg

A_2 the gross cross-sectional area of the unconnected leg

A_e effective sectional area

A_g gross area of cross section

A_{go} gross area of outstanding leg

A_n net area of the total cross section

A_{nc} net area of connected leg of the member

A_{tg} minimum gross 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

A_{tn} 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

A_{vg} minimum gross area in shear along a line of transmitted force

A_{vn} net area in shear along a line of transmitted force

b_s shear lag width

E modulus of elasticity

f_{cc} critical buckling stress

f_u characteristic ultimate stress

f_y characteristic yield strength

σ_{ac} axial compressive stress

σ_{at} axial tensile stress

L Length of the end connection, i.e. distance between the outermost bolts in the joint along the length direction or length of the weld along the length direction

Lc length of the end connection, i.e. the distance between the outermost bolts in the end joint measured along the load direction or length of the weld along the load direction

t thickness of the leg

w outstand leg width

γ_{mo} the partial safety factor for failure in tension by yielding

γ_{m1} partial safety factor for failure at ultimate stress

REFERENCE

[1] Dr. Vinod I. Hosur and Anand N. Shetty “Design chart for steel compression member as per IS800:1984 AND AISC-LRFD”, Journal Of Structural Engineering, VOL .30, NO. 4, pp. 281-291, January-March 2003.
[2] J. Daniel Ronald Joseph and K. Balaji Rao and M. B. Annop, “Probabilistic analysis of steel columns designed based on IS 800-2007”, CSIR-Structural Engineering Research Centre, SIR Campus, Taramani, Chennai -600113, India, Journal Of Structural Engineering, VOL .37, NO. 2, pp. 96-100, June-July 2010.
[3] Mohan Gupta and L.M. Gupta, “Net Section Efficiency of Bolted Steel Angles under Tension”.
[4] Mohan Gupta, L. M. Gupta, “Evaluation of stress distribution in bolted steel angles under tension”, Journal of Structural Engineering, 2004.
[5] Wu, Y. and Kulak, G.L. “Shear Lag in Bolted Single and Double Angle Tension Members”, Structural Engineering Report No. 187, 1993.
[6] C S Nair, Dr S Sreekumar, “Investigation on the Behaviour of Rolled Steel Tension Members”, Department of Civil Engineering, College of Engineering, Trivandrum, Volume 90, pp32-37, August 2009
[7] R.G. Driver, G.Y. Grondin, and G.L. Kulak, “A unified approach to design for block shear”, Department of Civil & Environmental Engineering, University of Alberta, Canada.
[8] Dr. N. Subramanian, “Code Of Practice On Steel Structures -A Review Of IS 800: 2007”, Computer Design Consultants, Gaithersburg, MD 20878, USA.
[9] IS 800:1984 ‘Indian Standard General Construction in Steel — Code of Practice’.
[10] IS 800:2007 ‘Indian Standard General Construction in Steel — Code of Practice’.
[11] Dr. N. Subramanian; “Design of Steel Structures”; Oxford University Press, New Delhi.
[12] Teaching Resource in Design of Steel Structures IIT Madras, SERC Madras, Anna Univ., INSDAG