COMPUTER AIDED ANALYSIS AND DESIGN OF COLD FORMED STEEL PRATT TRUSS IN CYCLONIC REGION

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ABSTRACT : Cold Formed Steel Sections are used widely in buildings, automobile equipment, railway coaches, storage racks, transmission poles, etc. It is used for construction mainly for its ease in mass production and fabrication, uniform quality, light weight with quick and simple erection and installation. Main objective of this paper is to analyze and design a Pratt Truss made of Cold Formed Section in a cyclonic region. Provisions from IS 875 (Part III): 2015 were considered for the analysis of wind load in cyclone prone region. The truss was analyzed using STAAD.Pro and the axial forces were validated using Joint Method approach of truss analysis. Load Combinations from Working Stress Method and Limit State Method was considered for the design of truss. Provisions from IS 801:1987 was considered for the design of Cold Formed Steel Truss and the section properties were considered from IS 811:1975. Utility ratio calculated using manual calculations and obtained from STAAD results were compared and found to be approximate.

***Index Terms* - Cold Formed Steel, Pratt Truss, Cyclone Prone Region, Working Stress Method, Limit Stress Method.**

I. INTRODUCTION

India is one of the country which is highly vulnerable to the natural hazards like earthquakes, floods, cyclones, etc. Considering severity, duration and areas of destruction cyclones are most destructive among all natural hazards. India has a coastline of 7516 km, where main land has covered 5400 km, while 132 km by Lakshadweep and 1900 km in Andaman and Nicobar Island. A study shows that during the year 1891-2000, around 308 cyclones struck the Eastern Coast out of which 103 were severe, while during the same period 48 cyclones crossed West Coast out of which 24 were severe.

Fig. 1 clearly shows that the East coast of India i.e. the coastal regions in Tamil Nadu, Andra Pradesh, Odisha, West Bengal is more affected by cyclonic storm compared to that of the west coast where Gujrat is more cyclone affected.

Steel frames are considered to be preferred in geographic locations, with high wind speed as steel has higher tensile strength and greater bending moment strength. In comparison to Hot Rolled Sections, Cold Formed Steel is easy to mass production and fabrication, they possess uniform quality and they are light in weight. Its erection and installation is quick and simple. Cold Formed Sections are manufactured using steel sheets, strips, plates or flat bars by roll-forming machines or by press braking or bending brake operations. IS 801:1975, has stated that the Cold Formed Steel structural members are cold formed from steel sheets or strips not thicker than 12.5 mm, whereas IS 811:1987 states that the steel sheets or strips should not be thicker than 10 mm. It is essential to have proper knowledge about the properties of the material of the steel sheets, strips, plates or flat bars as it plays a vital role in the performance of the structural members.

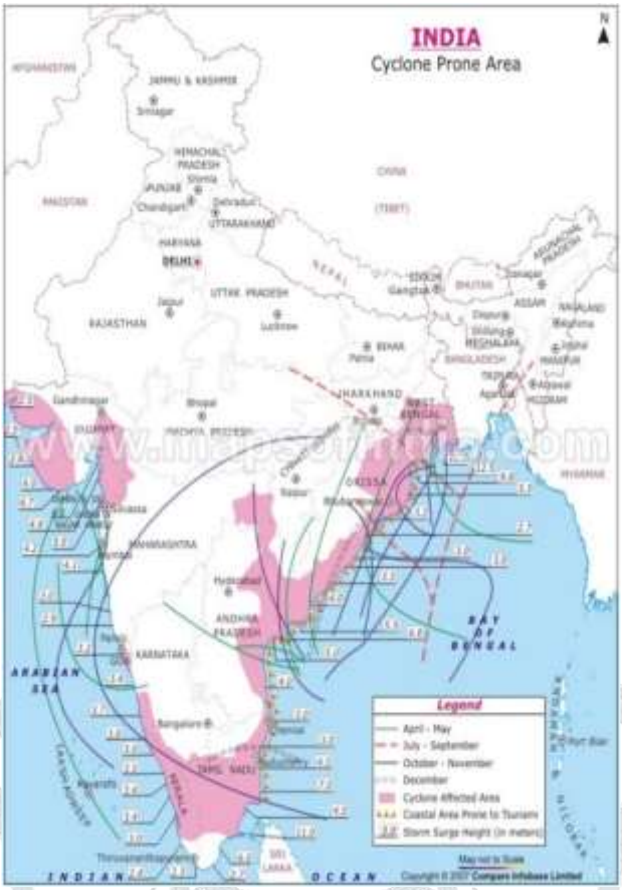

Figure 1. Map showing Coastal Areas of India affected by Cyclones

In past few decades the use of cold formed steel has increased considerably. The Cold Formed steel is also used as car bodies, railway coaches, various types of equipment, transmission poles, bridge construction, etc. It is also used in the form of corrugated sheet to serve as a roof covering.

II. LITERATURE REVIEW

Many studies have done related to the Cold Formed Steel. The literature points out considerable work in this field. Some of related work are, A. Jayaraman, (2015)[3] studied behavior of Cold Formed Steel Channel Section and built-up channel section and examined them theoretically and numerically, where they were designed for all the internal forces, to evaluate the co-existing moment and shear force at the critical cross section. S. A. Kakde, (1987)[8] performed an experimental investigation to determine the compressive strength of Cold Formed Steel Plain Tubular Section, where the experimental results were compared with manually calculated design strength using Indian Standards and North American Specification for Cold Formed Steel Structures. Bruce Bateman (1997)[4], examined Cold Formed Steel by particularly looking into the economic differences and implications of its use in comparison with wood frame construction. He also made a remark that the steel frame can be considered in geographical location experiencing natural disasters like hurricanes and earthquake, because of its high tensile strength and bending strength compared to lumber. J. Yan and B. Young (2002)[6], performed an experimental analysis with Cold Formed Steel Channels as its experimental subject, subjected to pure axial compression for fixed end columns and compared the results with the results calculated with the help of Australian/ New Zeeland Standards for Cold Formed Steel. J. Shanmugasundaram (2000)[5], illustrated the damages caused by cyclone on different types of structures by conducting a survey of a cyclone affected region. Kishor Mehta (1984)[7], studied wind induced damages, along which he commented on the damage to the structures and gave some remarks on design implications..

III. OBJECTIVE

Main objective of this paper is to analyse and design a Pratt Truss made of Cold Formed Channel Section for cyclonic region. The truss is modelled using STAAD.Pro and analyzed for Dead, Live and Wind Loa, along with Load Combinations from Working Stress Method and Limit State Method. For wind load, the truss is considered in a cyclonic region and provisions from IS 875 (Part III):2015 is consider for wind analysis..

IV. ANALYSIS

A truss as shown in Figure 2 has been considered for analysis and design with span of truss as 16 m with spacing of truss is 2 m to be built near Bhubaneshwar. Class of Building is considered as general with life of 50 years and terrain category 2 with width of Building 20 m and height of eve level is considered as 12 m with topography less than 3°. Considering medium openings between 5-20% of wall area.

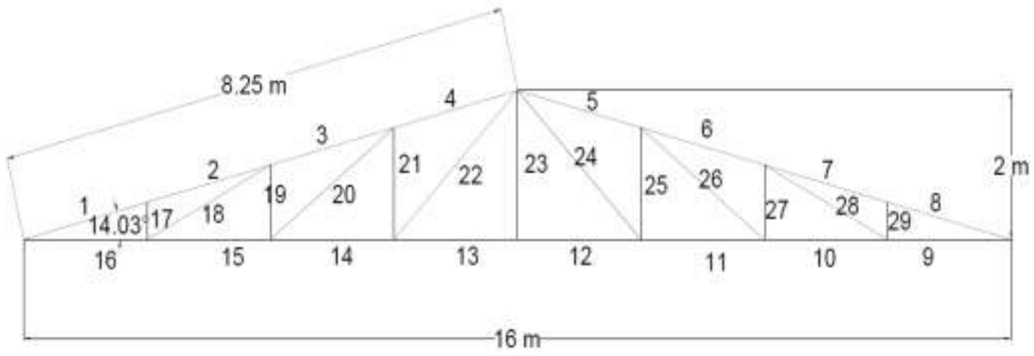

Figure 2. Pratt Truss

4.1. Truss dimensions

Height of truss $= 2\ m$

Spacing of truss $= 3.2\ m$

Slope of truss $= 14.03°$

Top Chord Length $= 8.25\ m$

Spacing of purlin $= 2.06$

Sloping area of roof $= 2[Sloping\ lenght \times Spacing\ of\ truss] = 52.8\ m^2$

Plan area of roof $= Span \times Spacing = 51.2\ m^2$

4.2. Load calculation

1) Dead Load

Considering;

Self-Weight of C.G.I. $= 150\ N/m^2$

Self-Weight of Purlin $= 90\ N/m^2$

Self-weight of truss $= \left[\frac{span}{3} + 5\right] \times 10 = 103.33\ N/m^2$

Total Weight of Truss on Plan Area $= 5290.67\ N$

Total Weight of C.G.I. sheet and wind bracings on slopping area $= 8976\ N$

Self-Weight of Purlin $= No.Purlin \times spacing\ of\ truss \times weight\ per\ m^2$

$= 2880\ N$

Total Dead Load $= 17146.67\ N$

Dead Load on each panel $= 2143.33\ N = 2.14\ kN$

Dead Load on End Panels $= 1071.67\ N = 1.07\ kN$

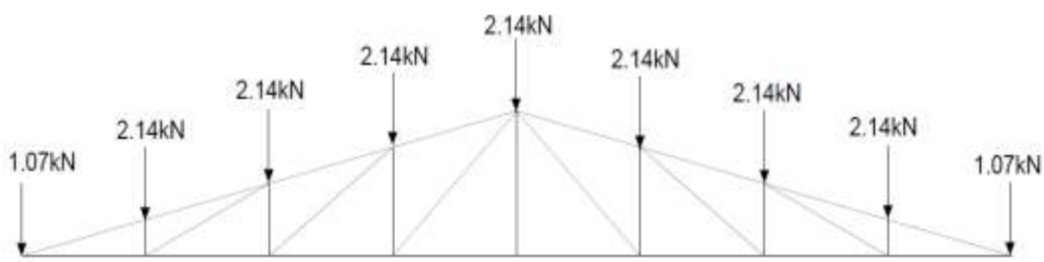

Figure 3. Dead Load

2) Live Load

As Slope is greater than 10°;

∴ Imposed Load on truss $= 750 - 20(\theta - 10) = 669.4\ N/m^2$

Live Load on roof truss $= \frac{2}{3} \times imposed\ load \times plan\ area = 22848.85\ N$

Live Load on each panel $= 2856.11\ N = 2.86\ kN$

Live Load on end panels $= 1428.05\ N = 1.43\ kN$

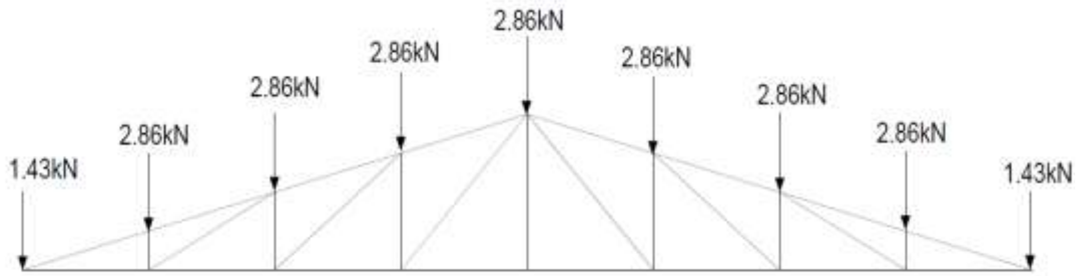

Figure 4. Live Load

3) Wind Load

For analysis of wind in cyclonic region, provisions from IS 875 (Part III): 2015 were considered. When compared with IS 875 (Part III): 1987, IS 875 (Part III): 2015 introduced an importance factor for cyclonic region (k_4), determined as per Clause 6.3.4, to determine the design wind speed. The value of k_4 is considered depending on the importance of the structure recommended in IS 15498: 2004.

a. Design Wind Speed:

From Clause No. 6.3[15]

$$V_z = V_b \times k_1 \times k_2 \times k_3 \times k_4$$

Where,

V_b = Basic Wind speed for Bhubaneshwar = $50\ m/s$ (Annex A)[15]

k_1 = Probability factor for class of structure as general and life of building as 50 years (Table 1, Cl.6.3.1)[15] = 1

k_2 = Terrain roughness and height factor for terrain Category 2 and Class A for 12 m height (Table 2, Cl. 6.3.2.2)[15] = 1.02

k_3 =Topography Factor for upwind slope less than 3° (Cl. 6.3.3)[15] = 1

k_4 =Importance Factor for Cyclonic region for Industrial structure (Cl.6.3.4)[15] = 1.15

$$\therefore\ V_z = 58.65\ m/s$$

b. Design Wind Pressure (Cl.7.2) [15]

$$p_z = 0.6 \times {V_z}^2 = 2063.89\ N/m^2 \qquad = 2.06\ kN/m^2$$

Where,

p_z = Wind pressure at height z

In addition to $p_z = 0.6 \times {V_z}^2$, IS 875 (Part III):2015, introduced design win pressure(p_d).

Design Wind Pressure (p_d),

$$p_d = K_d \times K_a \times K_c \times p_z$$

Where,

K_d = Wind Directionality Factor for cyclone affected region (Cl.7.2.1)[15]

= 1

K_a =Area Averaging Factor for rafter tributary area (Cl.7.2.2)[15] = 0.8

K_c =Combination Factor (Cl.7.3.3.13)[15] $= 0.9$

$$\therefore p_d = 1486\, N/m^2 = 1.49\, kN/m^2$$

From Cl.7.2[15]

$$p_d > 0.70 p_z, \text{Safe}$$

c. Wind Load on Individual member (F):

From Cl. 7.3.1[15]

$$F = \left(C_{pe} \pm C_{pi}\right) A p_d$$

Where,

C_{pe} = External Pressure Coefficient (Cl. 7.3.3) [15]

C_{pi} = Internal Pressure Coefficient (Cl. 7.3.2) [15]

A =Surface area of structural element or cladding unit

As we are considering medium openings between 5-20% of wall area,

$$C_{pi} = \pm 0.5$$

For C_{pe}, from Table 6, Cl. 7.3.3.2[15]

For Wind Normal to Ridge, using interpolation

For Windward Slope, $C_{pe} = -0.94$

For Leeward Slope, $C_{pe} = -0.56$

Similarly, for Wind Parallel to Ridge, using interpolation

For Windward Slope, $C_{pe} = -0.8$

For Leeward Slope, $C_{pe} = -0.6$

∴ From the above values, the maximum value of F from both windward and leeward for normal to ridge and parallel to ridge should be considered.

$$\therefore F = -1.44 A p_d$$

d. Total Wind Load: $F = -113.29\ kN$

e. Wind Load on each panel= $14.16\ kN$

f. Wind Load on end panels= $7.08\ kN$

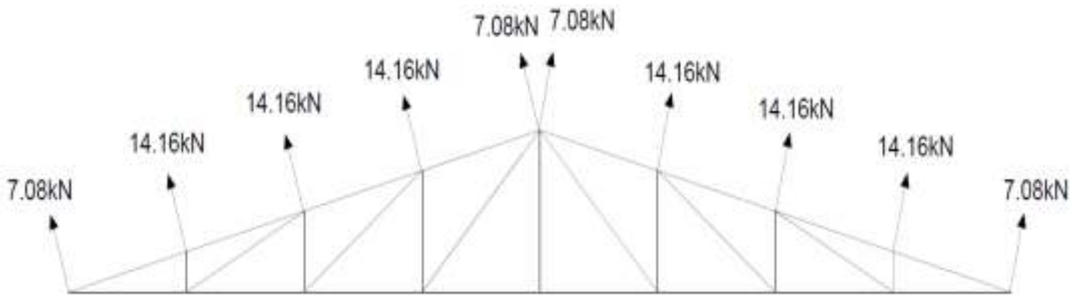

Figure 5. Wind Load

From above calculations, dead load, live load and wind load acting on the panel points are tabulated below.

Table 1. Loads at panel points

Loads	Loads on intermediate points	Loads on end points
Dead Load (DL)	1.07 kN	2.14 kN
Live Load (LL)	1.43 kN	2.86 kN
Wind Load (WL)	7.08 kN	14.16 kN

4.3. Internal forces

For Design of Cold Formed Sections, IS 801 has recommended to consider the load combinations from, IS 800:1962, which are given in following Table 4, for the load obtained from STAAD Analysis.

Truss members were analyzed for the above calculated loadings by using joint method and STAAD. Table 2 and Table 3 displays the results of the analysis for both the methods.

Truss was analyzed manually using Joint Method. The axial forces acting on truss members is as shown in the following table.

Table 2. Axial force (Joint method)

Truss Member	Member	DL (kN)	LL (kN)	WL (kN)
Principal Rafter	1	-30.90	-41.29	198.37
	2	-30.90	-41.29	212.52
	3	-26.49	-35.40	180.66
	4	-22.08	-30.98	152.32
Main Tie	13	17.14	25.05	-95.41
	14	21.42	30.05	-125.47
	15	25.70	34.34	-156.39
	16	29.98	40.60	-190.73
Vertical Tie	17	-2.14	-2.86	17.17
	19	-3.21	-4.29	23.19
	21	-4.28	-5	30.06
	23	0.001	0.34	0.002
Inclined Tie	18	4.78	6.39	-38.39
	20	5.35	5.36	-38.65
	22	6.05	7.07	-42.51

Similar model was analyzed is STAAD too. The axial forces from STAAD analysis is shown in the given table.

Table 3. Axial force (STAAD)

Truss Member	Member	DL (kN)	LL (kN)	WL (kN)
Principal Rafter	1	30.88	41.27	-198.24
	2	30.88	41.27	-201.78
	3	26.47	35.38	-175.23
	4	22.06	29.48	-148.68
Main Tie	13	-17.12	-22.88	103.03
	14	-21.4	-28.60	132.22
	15	-25.68	-34.32	161.41
	16	-29.96	-40.04	190.60

Vertical Tie	17	2.14	2.86	-14.60
	19	3.21	4.29	-21.89
	21	4.28	5.72	-29.19
	23	0	0	0
Inclined Tie	18	-4.79	-6.40	32.64
	20	-5.35	-7.15	36.49
	22	-6.05	-8.08	41.28

In the above Table 3, the compressive axial stress is considered as positive and tensile axial stress is considered as negative as per the sign conventions given in STAAD.

4.4. Load combinations

For Design of Cold Formed Sections, IS 801 has recommended to consider the load combinations from, IS 800:1962, which are given in following Table 4, for the load obtained from STAAD Analysis.

Table 4. Load combinations (WSM)

Truss Member	Member	DL+LL	DL+LL+WL	DL+WL
Principal Rafter	1	72.15	-126.09	-167.36
	2	72.15	-129.67	-170.90
	3	61.85	-113.38	-148.76
	4	51.54	-97.14	-126.62
Main Tie	13	-40	63.03	85.91
	14	-50	82.22	110.82
	15	-60	101.41	135.73
	16	-70	120.60	160.64
Vertical Tie	17	5	-9.57	-12.46
	19	7.5	-14.39	-18.68
	21	10	-19.19	-24.91
	23	0	0	0
Inclined Tie	18	-11.18	21.56	27.85
	20	-12.5	23.99	31.14
	22	-14.14	27.14	35.23

Combinations from IS 800:2007 were also consider for the design of truss, given in the following Table 5, for the loads obtained from STAAD.

Table 5. Load combinations (LSM)

Truss Member	Member	1.5(DL+LL)	1.2(DL+LL+ WL)	1.5(DL+WL)
Principal Rafter	1	108.23	-151.30	-251.04
	2	108.23	-155.55	-256.35
	3	92.77	-136.06	-223.14
	4	77.31	-116.57	-189.93
Main Tie	13	-60	75.64	128.67

	14	-75	98.67	166.23
	15	-90	121.70	203.60
	16	-105	144.73	240.97
Vertical Tie	17	7.5	-11.52	-18.68
	19	11.25	-17.27	-28.03
	21	15	-23.03	-37.37
	23	0	0	0
Inclined Tie	18	-21.21	32.57	52.85
	20	-18.75	28.79	46.71
	22	-16.77	25.75	41.78

V. DESIGN

Rafter member "1", was considered for the design, consists of the C- Section of dimensions 100x100x25x5 mm.

5.1. Section properties

Section properties required for design are considered from IS 811:1987, shown in Fig. 5. Properties like dimensions, mass and sectional properties can be obtained from the code. Also, some requirements for corrosion protections are also given in the code.

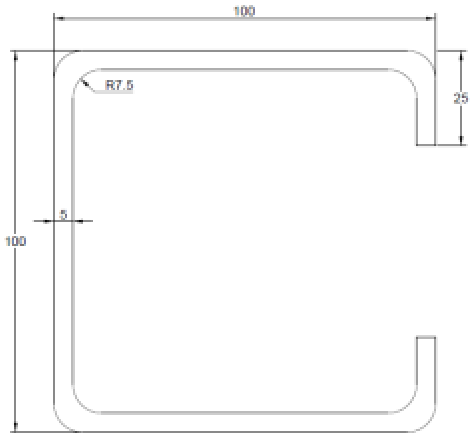

Figure 5. Cold Formed C-Section (100x100x25x5 mm)

Table 6. Section Properties

Web width	100 mm
Flange width	100 mm
Lip width	25 mm
Thickness	5 mm
Radius	7.5 mm
Area	1530 mm^2
r_{xx}	40.7 mm
r_{yy}	35.6 mm

5.2. Effective Width Calculation

Total force acting on a member is considered to be distributed over a reduced width. This reduced width is called as effective design width. The effective design width can be obtained using the formulae given as per Cl. 5.2[12].

Figure 5 shows the cross-sectional properties of the member '1' of the principal rafter. After calculation of the effective width of the considered section, Figure 6 indicates the effective width of the given cross-section.

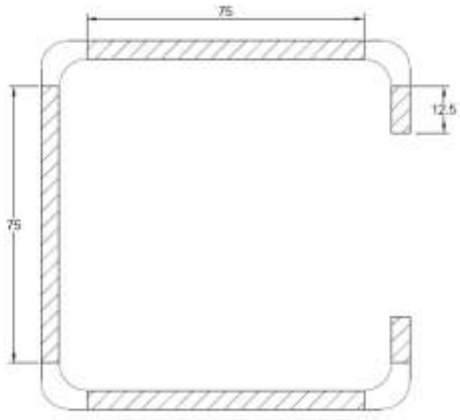

Figure 6. Effective Width of C-Section

5.2. Compression design

Compression Member was designed using, Cl. 6.6 [12].

$$\boldsymbol{F_{a1} = \frac{12}{23}QF_y - \frac{3}{23}\frac{(QF_y)^2}{\pi^2 E}\left(L/r\right)^2}$$

Where,

$$\frac{C_e}{\sqrt{Q}} = \sqrt{\frac{2\pi^2 E}{QF_y}} = 112.54 > \left(L/r\right)_{min}$$

F_{a1} = Allowable average compression stress under concentric loading

E = Modulus of Elasticity= $2.05 \times 10^5\ N/mm^2$

L = Unbraced Length of members= $2.062m$

r_{yy} = Radius of gyration= $35.6mm$

F_y = Yield point of steel= $355\ N/mm^2$

Q = Form factor

For member composed entirely of stiffened element

$$Q = \frac{A_{eff}}{A} = 0.90$$

A_{eff} = Effective design area = $1375\ mm^2$

A = Full or gross area of cross section= $1530\ mm^2$

$$\boldsymbol{F_{a1} = 144.62\ N/mm^2}$$

Permissible Compressive Load= $\boldsymbol{221.27kN}$

5.3. Tension design

Tension member was designed using Cl. 6.1[12].

Tensile Stress:

$$\boldsymbol{F = 0.6F_y = 213\ N/mm^2}$$

Permissible Tensile Load= $\boldsymbol{325.89\ \text{kN}}$

5.4. Permissible load

Table 6. Permissible Load

Truss Member	Member	Length (m)	Section (mm)	Permissible Load (kN)
Principal Rafter	1	2.062	100x100x25x5	-325.89
	2	2.062		
	3	2.062		
	4	2.062		
Main Tie	13	2	100x100x25x5	223.27
	14	2		
	15	2		
	16	2		
Vertical Tie	17	0.5	60x40x20x3.15	-102.67
	19	1		
	21	1.5		
	23	2		
Inclined Tie	18	2.36	100x60x25x5	96.45
	20	2.5		89.06
	22	2.83		70.78

VI. RESULTS AND DISCUSSION

When load combinations from working stress method are considered, Wind Load is observed to be the critical, so the truss is designed considering Wind Load as Critical Load. Also the utility ratio, a ratio of critical load to permissible load is calculated which is supposed to be less than 1, is calculated manually and using STAAD as shown in Table 8.

Table 8. Utility Ratio (WSM)

Truss Member	Member	Length (m)	Critical Load (WL) (kN)	Utility Ratio (Manual)	Utility Ratio (STAAD)
Principal Rafter (100x100x25x5)	1	2.062	-198.24	0.608	0.611
	2	2.062	-201.78	0.619	0.623
	3	2.062	-175.23	0.538	0.540
	4	2.062	-148.68	0.456	0.458
Main Tie (100x100x25x5)	13	2	103.03	0.461	0.532
	14	2	132.22	0.592	0.683
	15	2	161.41	0.723	0.834
	16	2	190.60	0.854	0.985

Vertical Tie (60x40x20x3.15)	17	0.5	-14.60	0.142	0.143
	19	1	-21.89	0.213	0.214
	21	1.5	-29.19	0.284	0.411
	23	2	0	0	0
Incline Tie (100x60x25x5)	18	2.36	32.64	0.338	0.339
	20	2.5	36.49	0.409	0.429
	22	2.83	41.28	0.583	0.584

Table 9 shows the weight of the truss members found using IS 801:1975.

Table 9. Weight of Truss (WSM)

Member	Principal Rafter	Main Tie	Vertical Tie	Inclined Tie
Section Required	100x100x25x5	100x100x25x5	60x40x20x3.15	100x60x25x5
Total Length	16.5	16	8	15.38
Weight per meter (kg/m)	12	12	3.78	8.91
Total Weight (kg)	198	192	30.24	137.04
	557.28 g			

Similarly, for limit state combinations, where 15(DL+WL) is observed to be the critical load and utility ratio is calculated, shown in Table 10. Also Table 11. Shows the calculated weight of the truss.

Table 10. Utility Ratio (LSM)

Truss Member	Member	Length (m)	Critical Load (WL) (kN)	Utility Ratio (Manual)	Utility Ratio (STAAD)
Principal Rafter (100x100x25x5)	1	2.062	-251.03	0.770	0.774
	2	2.062	-256.34	0.787	0.79
	3	2.062	-223.14	0.685	0.688
	4	2.062	-189.93	0.583	0.586
Main Tie (100x100x25x5)	13	2	128.86	0.577	0.666
	14	2	166.23	0.745	0.859
	15	2	203.60	0.912	1.053
	16	2	240.97	1.08	1.246
Vertical Tie (60x40x20x3.15)	17	0.5	-18.68	0.182	0.183
	19	1	-28.03	0.273	0.274
	21	1.5	-37.37	0.364	0.617
	23	2	0	0	0.774

Incline Tie (100x60x25 x5)	18	2.36	52.85	0.548	0.79
	20	2.5	46.71	0.524	0.688
	22	2.83	41.78	0.590	0.586

Table 11. Weight of Truss (LSM)

Member	Principal Rafter	Main Tie	Vertical Tie	Inclined Tie
Section Required	100x100x25x5	100x100x25x5	60x40x20x3.15	100x60x25x5
Total Length	16.5	16	8	15.38
Weight per meter (kg/m)	12	12	3.78	8.91
Total Weight (kg)	198	192	30.24	137.04
	557.28 g			

Truss is also designed for Hot Rolled Steel Sections using IS 800:2007 in STAAD and the design results is as shown in the table below.

Table 12. Weight of Truss (Hot Rolled Sections)

Member	Principal Rafter	Main Tie	Vertical Tie	Inclined Tie
Section Required	ISLC 225	ISLC 225	ISLC 225	ISLC 225
Total Length	16.5	16	8	15.38
Weight per meter (kg/m)	24	24	24	24
Total Weight (kg)	396	384	192	368.4
	1340.4 kg			

VII. CONCLUSION

- Internal forces in truss members due to dead load, live load and wind load calculated using Joint Method of Analysis and STAAD analysis were found to be approximately same.
- The combinations from working stress method and limit state method were considered, where for working stress design wind load is considered as critical load and for limit state design it is 1.5 (DL+WL).
- The utility ratio calculated manually and obtained from STAAD is approximately same for both the Working Stress Load Combinations and Limit State Load Combinations.
- The total weight of truss, designed for Working Stress Load Combinations and Limit State Load Combinations is found to be same, as safer sections for both the cases were same. Also when Hot Rolled Sections, were designed using IS 800:2007, the truss was found to be heavier than the Cold Formed Steel truss. Hence, Cold Formed Steel Sections are economical than Hot Rolled Steel Sections.
- As the Design of Cold Formed Steel is based on the principles of Working Stress Method, truss is found safe when the Working Stress load combinations are considered for cyclonic region.
- Compression failure was observed in the members' 9, 10, 15 and 16 with an unsupported length of 2m, when designed in STAAD for the critical load from Limit State Load Combinations, when considered in cyclone affected region.
- A future research can be done by considering C-Sections, greater than those given in IS 811:1987, for the design when combinations from Limit State is considered for cyclonic regions.

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