ANALYSIS AND DESIGN OF INDUSTRIAL SHED USING HOLLOW STEEL SECTIONS

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Abstract— As there is rapid growth in industrialization, it is necessary to minimize the use of steel along with a gain of desired strength; use of tubular steel sections can satisfy this condition. So this study is focused on using various hollow steel sections for designing the industrial shed. Various aspects like bending properties of hollow beam sections, buckling properties of hollow column sections, torsional properties, and study of tubular trusses are included. Basically, this thesis aims in making use of tubular or hollow sections instead of conventional steel sections so as to minimize the steel quantity with gain of high strength to weight ratio. This project mainly focuses on determining the cross section behaviour and utilization ratio of various hollow sections such as square hollow section, rectangular hollow section and circular hollow sections for static loading. Further the design and parametric study is done using Eurocode method.

Keywords— Hollow Sections, Tubular Beam, Tubular Column, Tubular Truss, Joints, Connections, Warehouse

I. INTRODUCTION

Steel as a construction material is significant and widely used in industrial warehouses, commercial buildings, pedestrian bridges and highway signboards and the list goes on. Steel has high strength to weight ratio but as steel usage is rapidly increasing due to growth of industrialization it is very important to optimize use of steel and to use various alternatives one of which is using tubular steel sections. Numerous models in nature show amazing properties of the hollow or tubular shape concerning stacking in compression, twist and bowing example the hollow bamboo sections and many more. The properties of hollow steel sections are proving better strength wise as well as aesthetically. Something that's taking a rapid growth towards development in the construction atmosphere is use of hollow steel structures. This is because they are strong, long-lasting, and most importantly adjustable. They have many applications for an instance hollow sections can be used in design of highway sign trusses, towers, offshore structures, industrial sheds, metro stations and list goes on. What tubular structures actually are? Tubular structures are structures constructed using hollow sections like hollow circular section (CHS), Hollow Square or rectangular sections (SHS or RHS). The hollow area in these steel sections has many benefits when compared with solid steel sections; one of the benefits is that this hollow area allows releasing stress or vibrations and hence they do not bend or twist easily. These hollow or tubular sections can be manufactured either from stainless steel or high strength steels by hot-rolling process or cold-forming process.

Jeffrey A. Packer, Peter C. Birkemoe and William J, Tucker [1] discussed design aids and design procedures for welded connections of Pratt and Warren type trusses subjected to static loading. It was concluded that SHS or CHS web members welded/connected to SHS or RHS members can be accommodated. B. Kozy and C. J. Earls [2] revealed that that the limit state of bearing failure in long-span tubular trusses is influenced by the geometry of the connection including the adjacent intermediate truss member, the nature of loading, and the material properties. Ben young, et.al [3] first validated numerical modeling methodology for beams and conducted parametric study on the cold-formed high strength steel tubular beams to obtain cross-sectional bending resistances whereas Xiang Yun, Leroy Gardner[4] developed finite element models and based on numerical investigation it was found that European code EN 1993-1-1 proved to be conservative in finding the ultimate capacity of hot rolled and cold formed steel continuous beams especially for class3 sections so continuous strength method was used to determine the strength of stocky and class 3 sections. Xiaoyi Lan, Junbo Chen, et.al [5] proposed base curves and resistance functions for CHS, EHS, SHS and RHS under bending by using CSM. It was found that compared to DSM and codified methods, CSM provided more accurate predictions for resistance functions. Merih Kucukler, Leroy Gardner [6] proposed a SRM for design of hot-finished tubular steel members. Omar A.Sediek, Jason McCormick; et.al [7] studied the collapse behaviour of seventeen hollow structural steel columns and performed a detailed finite element study which shows that behavior of hollow steel columns is highly dependent on the local slenderness ratios and the level of initial applied axial load. Two failure modes were observed global and local failure mode.

II. OBJECTIVES OF RESEARCH WORK

- To study various properties and concepts of tubular or hollow steel sections and use it in analysis and design of industrial warehouse
- To find the average utilization ratio of hollow structural member and compare it with conventional structural members.

• To compare weight of structure using hollow steel sections (RHS, CHS and SHS) with conventional steel sections (IPE, HEA, angle sections)
• To design connections for hollow roof truss

III. PROBLEM STATEMENT

The present study involves analysis and design of industrial warehouse located at Aachen, Germany with flat terrain category in industrial or commercial areas using tubular or hollow steel sections. An industrial shed/warehouse with 22.5m x 60m plan dimensions, eave height of 5m, total height of structure 9m, with duo-pitched roof profile and having pitch angle of 19.57° is modelled and analyzed in STAAD pro v8i. The limit state design is performed using Eurocode EN 1993-1-1. The study also involves design of connection and selection of type of joint for connection of tubular/hollow roof truss using the guidelines given by CIDECT and IIW. The results are compared with conventional steel sections.

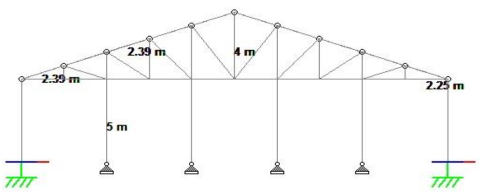

Figure 1: Elevation of structure

A. Analysis

For the safe design of structure, it is essential to have infor- mation of different types of loads and their worst combinations to which the structure might be subjected during its life span. The loads on structure or structural member would depend upon the application for which the structure is used. In the present application, the loads under consideration are dead load, live load and wind load. A Linear Static Analysis is per- formed for the given problem statement using a Finite Element based software STAAD pro v8i which uses stiffness matrix method for finding loads in members, displacements, forces, support reactions, etc. fig:1 shows the 3D view of model from STAAD pro for given problem statement. European code EN- 1993-1-1, Eurocode 3: Design of Steel Structures – Part 1–1: General Rules and Rules for Building, European Committee for Standardization (CEN) is used for design. And member selection is done by using Eurocode EN 10210-1 for hot finished structural hollow sections of non-alloy and fine grain structural steels and Eurocode EN 10210-2 for hot finished structural hollow section of non-alloy and fine grain structural steels part-2 tolerances, dimensions and sectional properties.

1. *Material Properties*: As per European standard EN-10210-1, S355 H grade of steel is used which has following properties. Where S355 H indicates hollow structural steel of yield strength of fy = 355N/mm2 with tensile strength fu = 510 N/mm2 for thickness of sections t ≤ 40mm.
2. *Loads:* Loads under consideration are dead load, live load and wind load. Dead load and live loads are calculated based on EN 1991-1-1 Eurocode 1 Action on structures part1-1 General actions- Densities, self weight, imposed load for building. Whereas wind load is calculated based on EN 1991-1-4 Eurocode 1 Action on structures part 1-4 General actions- Wind actions.
• Dead load = 1.5kN/m + self weight
• Imposed load = 1.6875kN/m= 0.75kN/m^2 x 2.25
• Basic wind characteristics are stated below from European code EN 1991-1-4:
a) Location: Aachen, Germany
b) Basic wind speed (vb):25 m/s
c) Peak velocity pressure [qp(z)] = 604.916 Pa as per Section 4.5
d) Internal pressure coefficient [Cpi] =0.2 and -0.3 as per section 7.2
e) External pressure coefficient [Cpe] calculated for various zones based on section7.2
f) External and internal wind pressures are calculated based on section 5

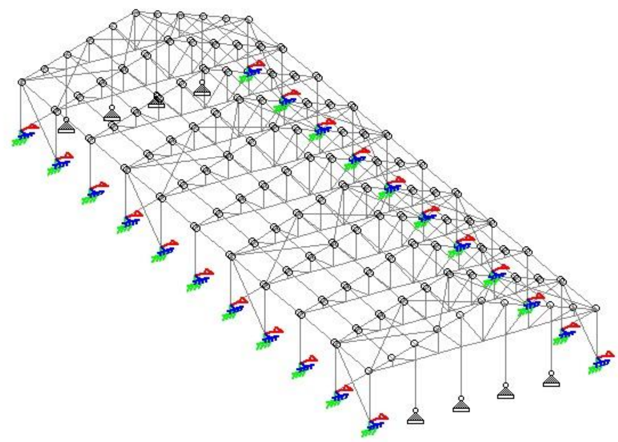

Figure 2: 3D view of model for given problem statement

3. *Load Cases:* Two methods for determining the combination of actions to be used for the persistent or transient ultimate limit state (ULS) are presented in BS EN 1990. Load cases are selected for ultimate limit state (ULS) based on EN 1990(2002) from equation 6.10, equation 6.10(a), equation 6.10(b) and that for serviceability limit state (SLS) from equation 6.14 based on EN 1990(2002). The permanent action i.e. dead load is considered as (Gk). When multiple independent variable actions occur simultaneously, the Eurocode considers one variable as leading variable action (Qk, ı) and the other to be accompanying variable actions (Qk, i). A leading variable action is one that has the most significant effect on the structure or member. Total 21 load

combinations are formed for given structure based on EN 1990:2002.

4. *Sections Assigned:* Hollow sections are selected from EN 10210-2 hot finished structural hollow sections of non-alloy and fine grain steels — Part 2: Tolerances, dimensions and sectional properties.

Table I: Sections Assigned for Members

Member	Hot-rolled hollow section assigned (all units in mm)	Conventional steel section assigned
Column	150x100x12.5 RHS	HE 200 A
Top chord	200 x10 SHS	IPE 600
Bottom chord	250 x 150 x 10 RHS	IPE 600
Web or bracing member	120 x 5 SHS	L 200 x 200 x 12
Gable column	120 x 80 x10 RHS	HE 180A
Rafter member	139.7 x 10 CHS	L 200 x 200 x 16

B. NUMERICAL ANALYSIS RESULT

Below are summarized results from STAAD pro v8i software for considered problem statement

- Result for maximum forces in members: The table I below gives summary of maximum axial forces, shear forces and bending moments for the sections assigned.

Table II: Section Wise Maximum Forces and Moments

Section properties	Maximum axial force (kN)	Maximum shear force (kN)	Maximum bending moment(kN-m)
250 X 150X10 RHS	465.351	20.091	76.6
200X10 SHS	464.10	31.34	64
150X100X12.5 RHS	182.93	0.87	33.14
139.7X10 CHS	104.22	18.59	27.56

- Maximum lateral deflection observed in column: The Maximum lateral deflection in x-direction, 14.53 mm is observed for column number 280 with section properties 150x100x12.5 RHS.

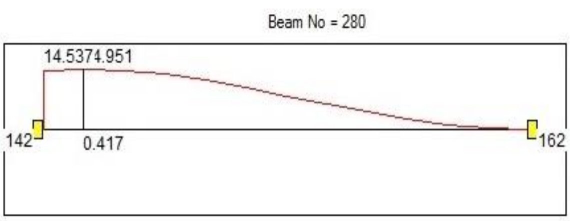

Fig 3: Lateral deflection in column in X-direction

- Nodal displacements: Maximum nodal displacements observed in x,y,z directions are summarized as shown in figure 4 below.

Table III: Maximum Nodal Displacements

Node no.	Displacement in X-direction (mm)	Displacement in Y-direction (mm)	Displacement in Z-direction (mm)
142	+14.537	-0.376	-0.077
104	12.834	-10.2	0.775
3	0	-0.29	+105.346

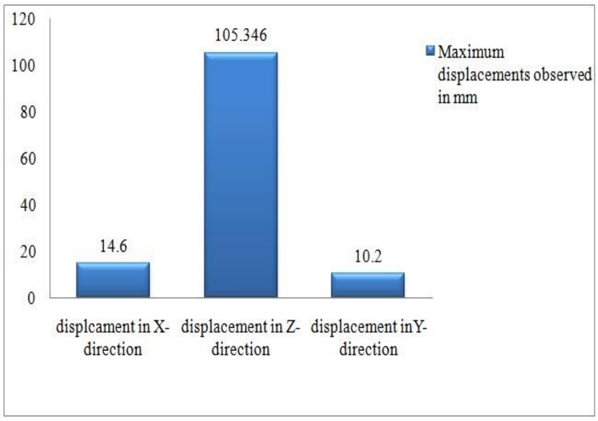

Fig.4: Maximum displacement observed at nodes

IV. DESIGN

Limit state design is done based on definition given by EN 1990 for static loading only. The design parameters are assigned for members in STAAD pro based on EN 1993-1-1. The buckling length Lcr of a hollow section used as a chord member is taken as 0.9L for both in-plane and out-of-plane buckling, where L is the system length for the particular plane. The buckling length Lcr of a hollow section used as brace member welded around its perimeter to hollow section chords is generally taken as 0.75L for both in-plane and out-of- plane buckling.[11]

A. Design of bottom chord member

Bottom chord members (250 x 150 x 10 RHS) are subjected to combined axial tensile force and bending moment so design is done based on EN 1993-1-1 clause 6.2.9. Beam no. 446 is designed for critical load combination 1.35DL + 1.5LL + 1.5WLx.

1. *Section classification:* From EN1993-1-1 table 5.2 [11] c/t= 250/10 = 25 ≤ 72 ε where ε = 0.81 for S355 grade steel. Hence section is classified as class 1 section.

2. *Design checks:* Where an axial force is present, allowance is to be made for its effect on the plastic moment resistance. Based on equation 6.2.9 from EN 1993-1-1 combined tension and bending the check is given as follows:

MEd/ (MN, y, Rd) ≤ (1)

As per clause 6.2.3 EN 1993-1-1 tensile resistance capacity is equal to plastic resistance capacity and is given as follows:

$$N_{t,Rd} = (A.f_y)/\gamma \quad (2)$$

Table IV: Design Properties for Bottom Chord Member

Sr.No.	Design properties	Calculated values
1.	Maximum or design axial force in member (NEd)	465.34 kN (Tension)
2.	Maximum bending moment in y-y axis (MEd)	75.47kN-m
3.	Design capacity or resistance force (Nt,Rd =Npl,Rd)	2658 kN
4.	Design moment capacity MN,y,Rd ≤ Mpl,Rd	151.2 kN-m

From above values equation (1) is satisfied.

$$M_{Ed}/(M_{N,y,Rd}) = 0.499 \le 1$$

Hence section 250 x 150 x 10 RHS can be used as bottom chord member.

B. Design of compression/ top chord member

Design of top chord member is performed for combined biaxial bending and axial compression

1. *Section classification:* 200 x 10 SHS section is selected as top chord member to resist a compressive force of 464.101 kN so based on table 5.2 EN 1993-1-1 c/t = 200/10=20 ≤ 33ε, where ε= 0.81 for fy=355 N/mm^2 So the section is classified as plastic section.

2. *Design checks:* The design properties and considerations are given in Table V below. The top chord must satisfy the condition based on clause 6.3.3 from EN 1993-1-1 as shown in equation (3)

$$\frac{N_{Ed}}{(\chi N_{Rk}/\gamma_{M1})} + \frac{(k_{yy}.M_{y,Ed})}{\chi_{LT}\frac{M_{y,Rk}}{\gamma_{M1}}} + \frac{k_{yz}.M_{z,Ed}}{\frac{M_{z,Rk}}{\gamma_{M1}}} \le 1$$

Table V: Design Capacities for Top Chord Member

Sr.no.	Design properties	Calculated values
1.	Maximum applied load or design load (NEd)	464.101 kN (Compression)
2.	Maximum design bending moment y-y axis (My,Ed)	64 kN-m
3.	Maximum design bending moment z-z axis (Mz,Ed)	14kN-m
4.	Resistance of member to uniform compression (Nc,rd)	2530.2 kN
5.	Buckling resistance of member (Nb,rd) from clause 6.3.1.1 EN 1993-1-1	2393.05kN
6.	χ= reduction factor for buckling from clause 6.3.1.2 EN1993-1-1	0.9

The values of kyy= 0.99 and kyz= 0.599 are interaction factors determined from Annex B table B.1 from EN 1993-1-1.

χLT=1 For members not susceptible to torsional deformation

My,Rk and Mz,Rk=188.5 kN-m are resistances offered by section in y-y and z-z direction

Substituting the values in equation (3), the ratio = 0.478 ≤ 1 hence satisfactory.

Section 200x10 SHS is verified to use as top chord member.

C. Design of welded connection for N-type of joint configuration

All connection formulae used for design of N-type of joint using fillet weld are given in LRFD terms therefore the effect of factored load from bracing member should not exceed the factored resistance capacity of connection (N*)[9].

A fillet weld with throat thickness (a)=10.7mm is used based on equation given by IIW [9]

$$\text{Effective length} = \frac{2h_i}{\sin\theta i} + 2b_i \quad (4)$$

$$= 654.40\text{mm}$$

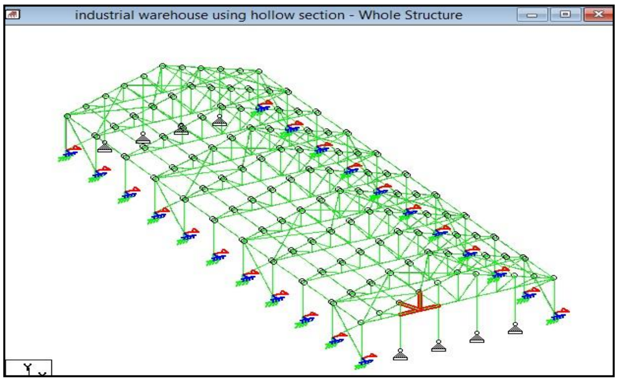

Figure 5: Location where N-type of joint is designed for welded connection

The gap (g) or overlap (q) is calculated based on eccentricity (e) by equation shown below. If the value of g is negative it is considered that the connection is to be overlapped and that negative value of g corresponds to overlap (q). Based on the equation given by J.A.Packer, J. Wardenier, D.Dutta, et.al [8] the calculated value of g= (-45.36) mm.

Which indicates that g is negative and connection is to be designed as overlapped connection for value of (q= -45.36).

Table VI: Design Properties and Calculations for Connection Resistance

Sr.No.	Design properties	Calculated values
1.	Chord face properties	b_o=250mm, h_o=150mm, t_o=10mm, A=7490mm^2
2.	Bracing member in tension (overlapping	b1= 120mm, h1=120mm, t1= 5mm, A= 2270mm^2

	member i=1)	
3.	Bracing member in compression(overlapped member j=2)	b2 = 120mm, h2= 120mm, t2=5mm, A= 2270mm^2
4.	Eccentricity	e = -0.20ho= 24mm
5.	Overlap (Ov)	Ov = (q x 100)/p = 53.45%
6.	Effective width (be)	be ≤ b1 or b2 = 100mm
7.	Overlap width (be(ov))	be (overlap) = 50 mm

Factored connection resistance (N_i*) for overlapped connection [for overlap 50% ≤ Ov ≤ 80%] of K or N type as per J.A.Packer, J. Wardenier, D.Dutta, et.al [8] is given by equation (5)

$$(N_i *) = fy_i \cdot t_i \, [2h_i - 4t_i + be + be(ov)] \qquad (5)$$

Where i=1, 2 bracing members.
Based on above values the factored design resistance (N_i*) = 600 KN ≥ 125.27 KN (the axial load in bracing member). Hence connection resistance is satisfactory.

V. VALIDATION OF ANALYSIS RESULTS

The analysis results and design ratios were validated for top and bottom chord truss members based on numerical analysis from STAAD pro and analytical analysis using Eurocode.

A. *Member forces in truss based on analytical and numerical analysis*

Table VII: Member Forces for truss based on numerical and analytical analysis

Sr.No.	Members	Numerical analysis	Analytical analysis
1.	Top chord member	464.10kN (Compressive)	400.44kN (Compressive)
2.	Bottom chord member	465.35 kN (Tensile)	407.58 kN (Tensile)
3.	Diagonal web member	89.176kN (Compressive)	36.28kN (Compressive)
4.	Vertical web member	14.272kN (Tensile)	12.13 kN (Tensile)

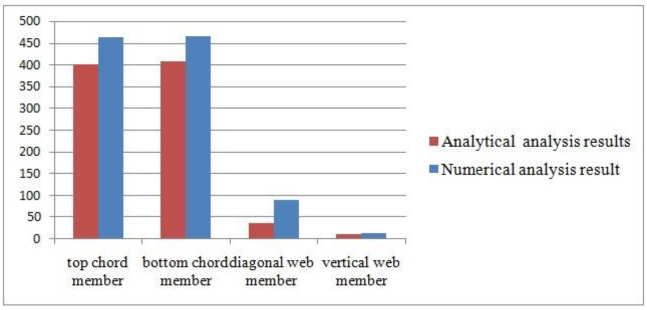

Figure 6: Validation of forces in truss members

B. *Design ratios for top and bottom chord members are compared based on result from STAAD pro v8i and EN 1993-1-1*

Table VIII: Comparison of Design Ratio for Top and Bottom chord members

Sr.No.	Member	Design ratio from STAAD pro v8i	Design ratio based on calculation from EN 1993-1-1
1.	200x10 SHS top chord member	0.29	0.478
2.	250x150x10 RHS bottom chord member	0.506	0.499

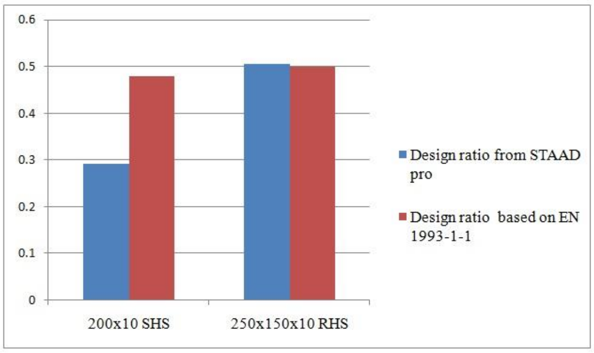

Figure 7: Validation of design ratios for top and bottom chord members

VI. RESULTS

1. Total weight of structure for same loading shows that hot-rolled hollow steel section weighs 829.60 kN whereas conventional steel section weighs 1026.094 kN which means that hollow steel sections weigh less for same loading as compared to conventional or open steel sections.
2. Allowable deflection criteria for lateral displacement for column is height/300= 17mm and maximum observed displacement from numerical analysis in X-direction is 14.537mm hence 14.537 < 17 so deflection check is satisfactory.

3. Utilization ratio for hollow and conventional section

Table IX: Utilization Ratios for Hollow and Conventional Sections

Member	Hollow section	Conventional section
Column	0.65	0.4
Top chord	0.35	0.2
Bottom chord	0.49	0.3
Web member	0.8	0.7
Gable column	0.68	0.18
Rafter	0.46	0.32

VII. CONCLUSIONS

Based on the work carried out on the hot-rolled hollow steel sections for considered problem statement following conclusions is made:
1. About 20% of steel is saved in the structure analyzed and designed using hollow steel sections.
2. Also the average utilization ratio of hollow steel members is more compared to conventional steel sections.
3. Usually hot rolled hollow sections fall under buckling curve 'a' which indicates that hollow sections are more effective in buckling resistance compared to other open sections.
4. While connections of tubular members it is necessary to consider the effective length of fillet welds. Joint strength increases with minimizing the variation between chord width and thickness.
5. Trusses made of hollow sections should be designed in such a way that the number of joints and thus fabrication is minimized.
6. RHS bracing members should not be of same width as that of RHS chord so as to ease the connection problems.

ABBREVATIONS

- SHS – Square Hollow Section
- RHS – Rectangular Hollow Section
- CHS – Circular Hollow Section
- EHS – Elliptical Hollow Section
- MTS machine – Material Testing Machine
- HSS - High Strength Steel
- DSM – Direct Strength Method
- CSM – Continuous Strength Method
- SRM – Stiffness Reduction Method

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