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The Economic and Structural Analysis of Hollow Structural Sections

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***Abstract*—**This study aims is to study the strength and economical comparison of hollow structural section (HSS) to the conventional sections in trusses. This also covers the advantages of hollow sections in its effectiveness to reduce corrosion, minimizing overall cost, and improvement in aesthetic value. The study involves the comparative analysis of a truss using hollow and conventional sections under the influence of usual loading values. It also covers comparative study of section properties and its attributes and wide application in architecture, industrial, infrastructural and general engineering. The Tool used for the analysis is STAAD Pro 2007.

Keywords: *Corrosion, Connection Details, Fabrication, Hollow Steel Sections, Open Sections.*

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I. INTRODUCTION

Steel members have high strength per unit weight. Therefore, a steel member of hollow section which has less unit weight is able to resist heavy weight. The study is oriented to determine the structural and economic efficiency of hollow sections over usual rolled sections in design of steel trusses in industrial complexes. Indian Standard Code IS 800:2007 was used to design the sample trusses and the tolerances were taken into regard from the standard guidelines. The study also covers various advantages of Hollow Steel Sections (HSS) in various facets of consideration to enhance the serviceability of the structure It also includes the manufacturing and connection details of hollow sections. It is an effort to stress the ecological and environmental impact as the use of HSS leads to conservation of steel as a resource material. Another aspect which is especially favourable for circular hollow sections is the lower drag coefficients if exposed to wind or water forces. The internal void can be used in various ways, e.g. to increase the bearing resistance by filling with concrete or to provide fire protection. In addition, the heating or ventilation system sometimes makes use of the hollow section columns.

II. OBJECTIVES OF THE STUDY

The objective of the study involves the following purposes:

1. To study and compare design of roof truss of certain span by using both Open sections and Hollow Sections.
2. To determine most economic sections among the sections used namely Open Sections, Rectangular Hollow Sections, Square hollow sections and Circular Hollow Sections.
3. To study the geometric and physical advantages of hollow sections over Open sections.
4. To calculate percentage saving in steel for given structure.
5. To study various aspects of design and maintenance in Hollow Structural Sections.

III. APPLICATION AND REASON FOR USE OF HOLLOW STRUCTURAL SECTIONS

A. *Application: -*

i. Architectural: -
Shopping Malls, Canopies or Atrium, Glass Curtain Wall Frames, Partition Frames, Space Frame, Guard Rails and Staircase, etc.

ii. Infrastructural: -
Airport Terminal Buildings, Bridges, Bus Stands, Sign Supporting Structure, Pedestrian Walkovers (Footbridge), Sports Galleries, Railways Platforms / Foot Over Bridges.

iii. Industrial: -
Industrial Sheds, Trusses, Purlins and Columns, Material Storage Racks, Mine Roof Support Systems (cog, props), Pallets, Pipe Racks, Conveyor Gantries, Trestles, Drilling Rigs.

iv. General Engineering :
Automobile Chassis, Green House Structures, Truck and Bus Body Members, Hoarding Structures, Amusement Park and Playground Equipment, Exhibition Stalls, Scaffolding, Furniture.

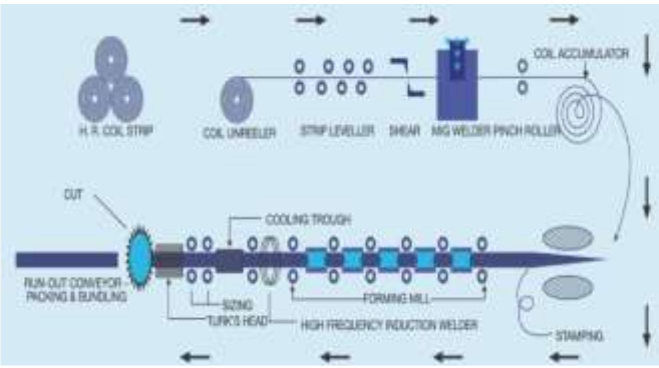
B. *The reasons to use hollow structural sections are as following:*

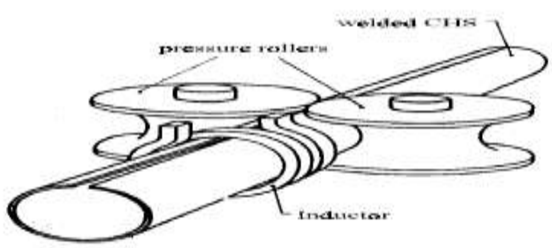
1. Structural hollow sections have excellent static properties, not only with regard to buckling and torsion, but also in Overall design of members they can offer economic advantages compared to open section.
2. The closed shape and the smooth change over from one section to another at joints reduce the costs of corrosion protection. It was possible to change the strength by varying the wall thickness or by filling the section with concrete without changing the outside dimensions.
3. The inner space gives possibilities for the combination of the strength function with others, e.g. Fire protection, heating, ventilation, etc. The rational application of hollow sections will, in general, lead to clean, spacious, functional structures which appeal to architects. Circular hollow section often offer a decisive advantage with regard to structure exposed to air or water flow. In other situations, square and rectangular hollow sections were favored because they use simple connections with straight end cuts of the connecting members. To reduce the number of joints and to obtain a better joint strength, a Warren-type truss was preferred to a Pratt type truss.

4. Although the unit material cost of hollow sections was higher than for open sections, a proper use will lead to economical designs. Good design in hollow section does not mean "change the member of an open section design to hollow section", but means making use of their specific properties right from other beginning.

IV. Manufacturing of Hollow Structural Section

Hollow sections can be produced seamless or welded. Seamless hollow sections are made in two phases, i.e. the first phase consists of piercing an ingot and the second one consists of the elongation of this hollow bloom into a finished circular hollow section. After this process, the tube can go through a sizing mill to give it the required diameter. Nowadays, welded hollow sections with a longitudinal weld are mainly made with electrical resistance welding processes or with an induction welding process. A strip or plate is shaped by rollers into a cylindrical shape and welded longitudinally. The edges are heated e.g. by electrical resistance. The rollers push the edges together, resulting in a pressure weld. The outer part of the weld is trimmed immediately after welding. Rectangular hollow sections are made by deforming circular hollow sections through forming rollers. This can be done hot or cold and seamless or longitudinally welded circular hollow sections can be used. It is common practice to use longitudinally welded hollow sections. For the very thick sections, seamless sections may be used. Square or rectangular hollow sections are sometimes made by using channel sections, which are welded together or by shaping a single strip to the required shape and closing it by a single weld, preferably in the middle of a face. Large circular hollow sections are also made by rolling plates through a so-called U-O press process. After forming the plates to the required shape, the longitudinal weld is made by a submerged arc welding process. Another process for large tubular is to use a continuous wide strip, which is fed into a forming machine at an angle to form a spirally formed circular. The edges of the strip are welded together by a submerged arc welding process resulting in a so-called spirally welded tube.





V. Fabrication and Connection Details.

A. *Cutting:*

i. The hollow sections can be cut by means of heavy duty circular/ hand saw or by manual / automatic flame cutting
ii. The path of the cut can be marked directly on the surface of the section or on a template after shop layout
iii. For section thickness of 5 mm and above, edges may be chamfered for proper welding penetration.

B. *Bending:*

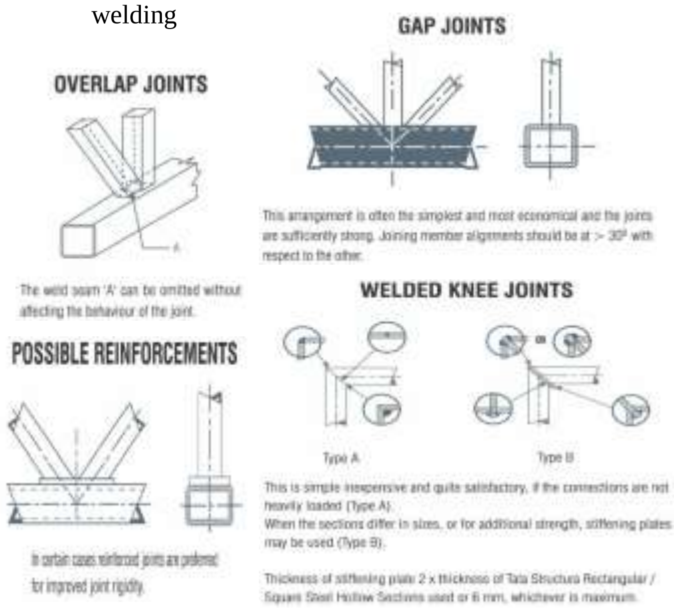
i. Axial cold bending is possible by using an internal mandrel and the roller must be adapted to the shape and size of the section.
ii. Bending is also possible by slow multiple pass using three roll bending machine.
iii. Thicker and larger sections are pre-heated in a normalising furnace before bending.

C. *Welding:*

Technique in principle is similar for that of conventional section.

i. Electrodes: Low hydrogen electrodes are suggested for use.
ii. Butt welds: The throat thickness of the seam is equal to: a) Wall thickness of the section when joining members are of equal thickness. b) Wall thickness of thinner section, if thickness is different. Backing strip may be provided to ensure total root penetration in case of thicker section design size.
iii. Fillet welds: Various types may be provided. Size of the fillet is guided by the throat thickness as explained above

Note: All free ends should be properly sealed by welding, to prevent internal corrosion. Moisture from the electrodes should be removed by baking before welding



Connection Distortions:

Post weld distortions, despite precautions, can be corrected by cold bending, hammering of the welds or by applying controlled local compensating heating on

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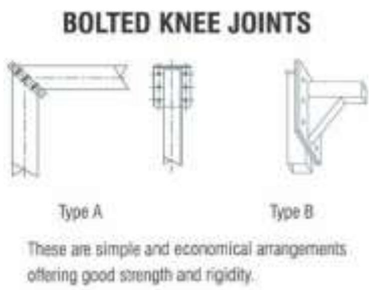
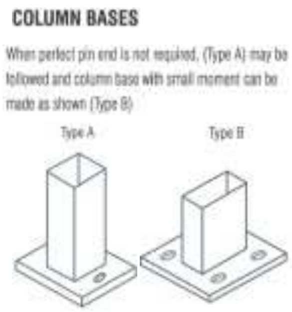
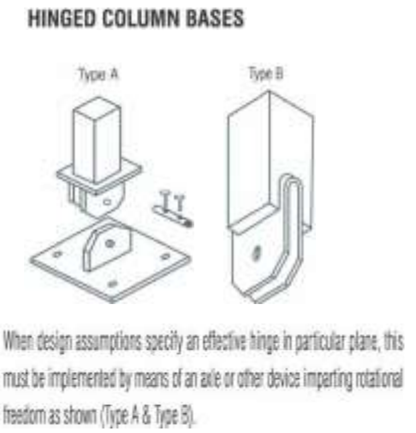
opposite sides. It is imperative to avoid excessive thermo-mechanical operation.

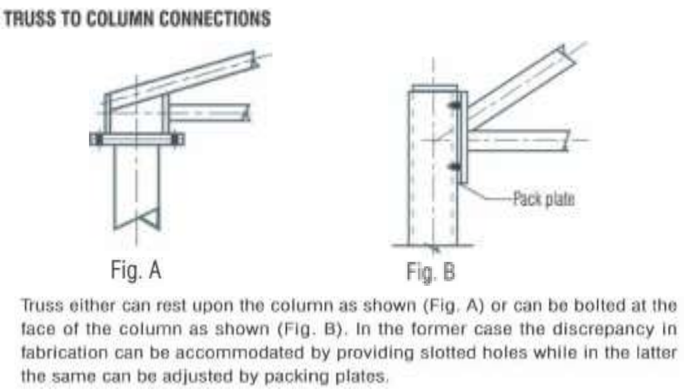
D. Bolted / Riveted Connections:

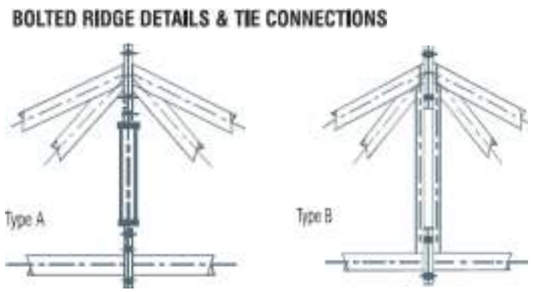




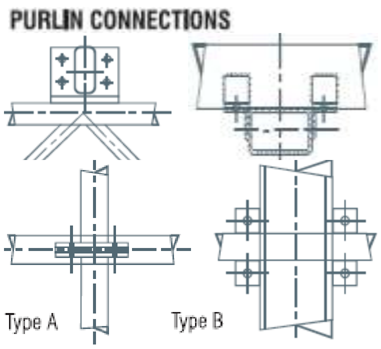


For large axial load, column base should be stiffened as shown (type C) to minimize the thickness of base plate.





Bolted connection as shown (Type A & Type B) are adopted by using single or double sag ties respectively.



Purlin becomes very efficient with rectangular and square steel hollow sections because of its lateral rigidity to avoid intermediate sag rods. The connection shown (Type A & Type B) can provide end – fixity.

i. Fasteners should conform to BIS specifications and arrangement should be adequate to withstand combination of design loads at joints and to facilitate ease of fixing.

ii. As internal surfaces of Hollow Sections are inaccessible, they are adaptable to: Special structural fittings for indirect bolting, Blind Bolts, Self threading bolts, etc.

Erection:

In principle similar techniques are adopted as those for conventional section assemblies. For hoisting and handling no additional stiffeners are required due to high torsional rigidity of hollow sections.

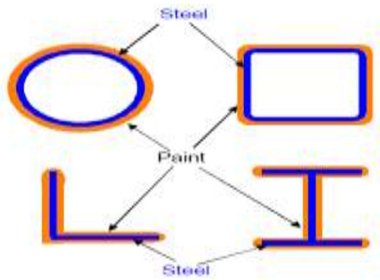
VI. CORROSION IN HOLLOW STRUCTURAL SECTION.

Corrosion is the wearing and tearing of metal surface due to the combined action of water and reactive gases like SO_2, CO_2 etc. present in the air. It decreases the overall dimensions of the member and causes appreciable reduction in strength. It has been proved that open sections are highly susceptible to corrosion.A Report by Omer W. Blodgett in the Lincoln Electric Co. Journal of August 1967 [2] studies the corrosion in hollow sections.

1) Sealed hollow sections require no internal protective coating and may be regarded as essentially immune from corrosive attack.
2) Condensation in a sealed section is impossible, and when found upon inspection is evidence of an opening having developed -possibly a small opening that is drawing surface water in through capillary action.
3) Adding a "pressure equilibrium hole" at any point in a hollow structure where water cannot enter by gravity will prevent aspiration in an imperfectly sealed system. (If the engineer has qualms about condensation, he might as well put the hole at a low point where it would serve for drainage also - merely to satisfy his peace of mind.')
4) An "open" system should generally be kept as tight as feasible with rubber gaskets used at manholes and such closures positioned so as to avoid water accumulation and the possibility of its entrance by capillarity action or aspiration. A strategically placed pressure equilibrium hole might be advisable. Such Systems should be protected with an interior coating.
5) A ventilated hollow structure should be internally protected and have adequate ventilation holes at each end and in the sides.
6) Bolt and rivet holes should be avoided where-ever possible; they create conditions conducive to water entrance by capillarity action.

Another study in Chelsea, U.K. also reflected the same results where two members were taken out from an existing structure. One member was cut lengthwise and other Circular Hollow Section incorporating a flange joints were checked. No corrosion was found in internal surfaces (British Steel Publication no. 347/10E/091)

Structures made of hollow sections offer advantages with regard to corrosion protection. Hollow sections have rounded corners which result in a better protection than open sections with sharp corners. This was especially true at joints in circular hollow sections where there was a smooth transition from one section to another. This better protection increases the protection period of coatings against corrosion.



Structures designed in hollow sections have a 20 to 50% smaller surface to be protected than comparable structures made using open sections. Many investigations have been carried out to assess the likelihood of internal corrosion. These investigations, carried out in various countries, show that internal corrosion does not occur in sealed hollow sections. Even in hollow sections which were not perfectly sealed, internal corrosion was limited. If there was concern about condensation in an imperfectly sealed hollow section, a drainage hole can be made at a point where water cannot enter by gravity.

VII. OTHER ASPECTS OF APPLICATION OF HOLLOW STEEL STECTIONS.

a) Use of internal void:

The internal void in hollow sections can be used to advantage in various ways, e.g. to increase the bearing resistance by filling with concrete, or to provide fire protection. In addition, the heating or ventilation system was sometimes incorporated into hollow section columns. The possibilities of using the internal space were briefly described below.

b) Concrete filling:

If the commonly available wall thicknesses were not sufficient to meet the required load bearing resistance, the hollow section can be filled with concrete. For example, it may be preferable in buildings to have the same external dimensions for the columns on every floor. At the top floor, the smallest wall thickness can be chosen, and the wall thickness can be increased with increasing load for lower floors. If the hollow section with the largest available wall thickness was not sufficient for the ground floor, the hollow section can be filled with concrete to increase the load bearing resistance. A very important reason for using concrete-filled hollow sections was that the columns can be relatively slender.

c) Fire protection by water circulation and concrete-filling:

One of the modern methods for fire protection of buildings was to use water-filled hollow section columns. The columns were interconnected with a water storage tank. Under fire conditions, the water circulates by convection, keeping the steel temperature below the critical value of 450°C. This system has economical advantage when applied to buildings with more than 8 storeys. If the water flow was adequate, the resulting fire resistance time was virtually unlimited. In order to prevent freezing, potassium carbonate (K2CO3) was added to the water. Potassium nitrate was used as an inhibitor against corrosion. Concrete filling of hollow sections contributes not only to an increase in load bearing resistance, but it also improves fire resistance duration. The extensive test projects carried out by CIDECT and ECSC have shown that reinforced concrete-filled hollow section columns without any external fire protection like plaster, asbestos and Vermiculite panels or in tumescent paint, can attain a fire life of even 2 hours depending on the cross-section ratio of the steel and concrete, reinforcement percentage of the concrete and the applied load. Related calculation diagrams were available.

d) Heating and ventilation:

The inner voids of hollow sections were sometimes used for air and water circulation for heating and ventilation of buildings. Many examples in offices and schools show the excellent combination of the strength function of hollow section columns with the integration of the heating or ventilation system. This system offers maximization of floor area through elimination of heat exchangers, a uniform provision of warmth and a combined protection against fire.

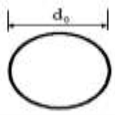
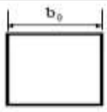
e) *Resistance to air pressure:*

.Hollow sections present a striking advantage for use in building structures exposed to fluid currents, i.e. Air or water. There drag coefficients were much lower than those of ordinary sections with sharp edges as shown in Fig. 3**.** The drag coefficients for wind loading on circular and rectangular hollow sections have been determined in the last twenty years by a series of tests. Based on these tests, the following conclusions can be derived: For all sharp edged profiles, open or closed (R/D<0,025), the drag coefficient Cw was independent of Reynold's number

$$Re = V.D/\upsilon$$

Where, V is the wind velocity; D is the width of the cross section; υ is the kinematic viscosity. The values were higher than those for hollow sections with rounded corners. Drag coefficient Cw for rectangular hollow sections with rounded corners, especially for circular hollow sections, was strongly dependent on Re .For Relower than a certain number (subcritical), Cw remains constant and was quite large. After exceeding this Re-value, Cw drops steeply. With increasing Re, Cw then rises slowly, but it never attains the initial values.

Table 2.10 Drag coefficients for I-profiles and hollow sections depending on Reynold's number

Section	Drag coefficient
	0.5 - 1.2
	0.6 - 2.0
	2.0

Comparison of wind flow profile between open and circular hollow section

VIII. TOLERANCE.

The tolerances for hot and cold formed rolled section can be referred from IS 4923 – 1997.

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IX. Design Methodology Used In Study .

A. Choice of Profile:

For this study Fink Type Truss was considered as sample truss for analysis

B. Choice of Section:

i. Open section :- Equal Angle Section (IS 808)

ii. Hollow section : - a. Circular section (IS 1161)

b. Square section (IS 4923)

C. Choice of Loading:

Three types of loads are considered while designing.

i. Dead Load (DL) : - FY -7.4 kNm

ii. Live Load (LL) : - FY -6.7kNm

iii. Wind Load (WL): - a. For Windward

FX 8.407 kNm, FY 16.815 kNm

b. For Leaveward

FX -7.826 kNm, FY 15.65 kNm

iv. Load Combinations: - a. 1.5(DL + LL)

b. 1.2(DL + LL + WL)

c. 1.5(DL + WL)

Same Loading conditions were considered while designing the truss with all the three type of sections mentioned above.

D. Design of truss using Equal Angle Sections

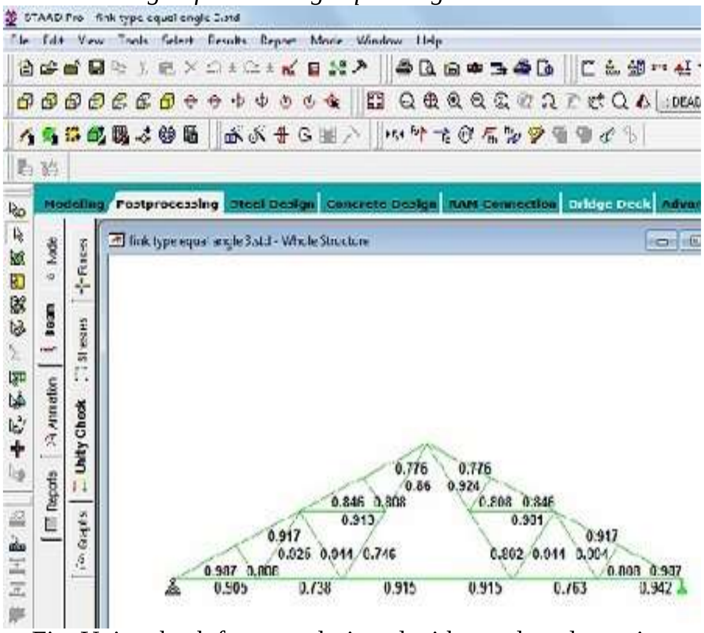
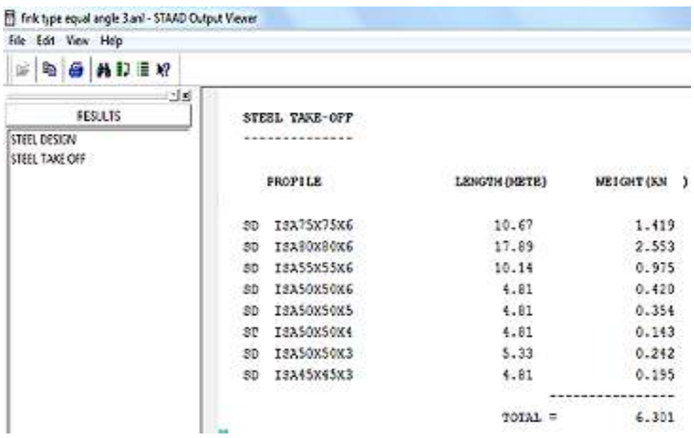


Fig. Unity check for truss designed with equal angle section



STEEL TAKE-OFF

PROFILE		LENGTH (METE)	WEIGHT (KN)
SD	ISA75X75X6	10.67	1.419
SD	ISA80X80X6	17.89	2.553
SD	ISA55X55X6	10.14	0.975
SD	ISA50X50X6	4.81	0.420
SD	ISA50X50X5	4.81	0.354
ST	ISA50X50X4	4.81	0.143
SD	ISA50X50X3	5.33	0.242
SD	ISA45X45X3	4.81	0.195
		TOTAL =	6.301

Fig. Steel Takeoff for Equal Angle Section Truss

E. Design of truss using Pipe Sections

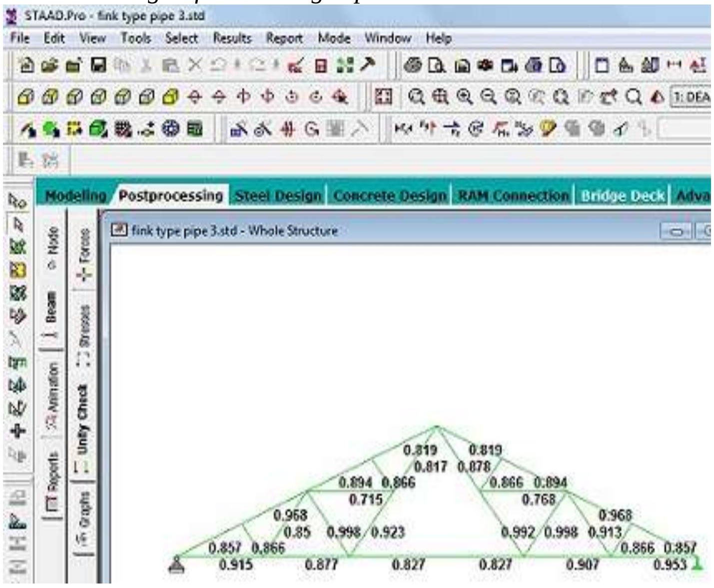
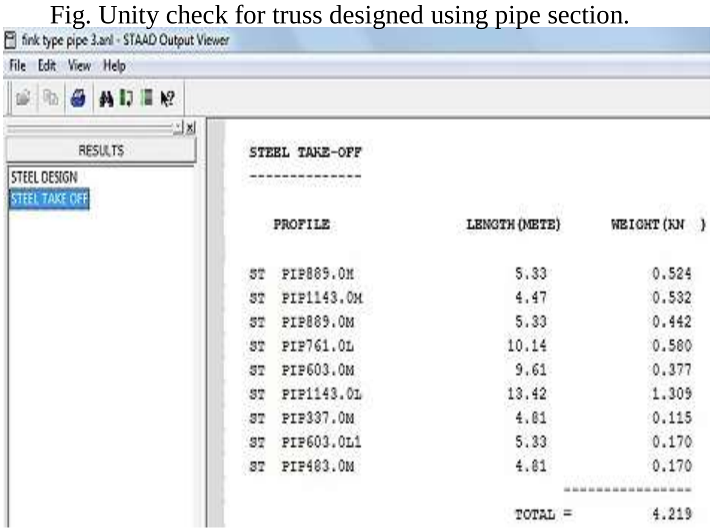


Fig. Unity check for truss designed using pipe section.



STEEL TAKE-OFF

PROFILE		LENGTH (METE)	WEIGHT (KN)
ST	PIP889.0M	5.33	0.524
ST	PIP1143.0M	4.47	0.532
ST	PIP889.0M	5.33	0.442
ST	PIP761.0L	10.14	0.580
ST	PIP603.0M	9.61	0.377
ST	PIP1143.0L	13.42	1.309
ST	PIP337.0M	4.81	0.115
ST	PIP603.0L1	5.33	0.170
ST	PIP483.0M	4.81	0.170
		TOTAL =	4.219

Fig. Steel Takeoff for Pipe Section Truss

F. Design of truss using Tube Sections

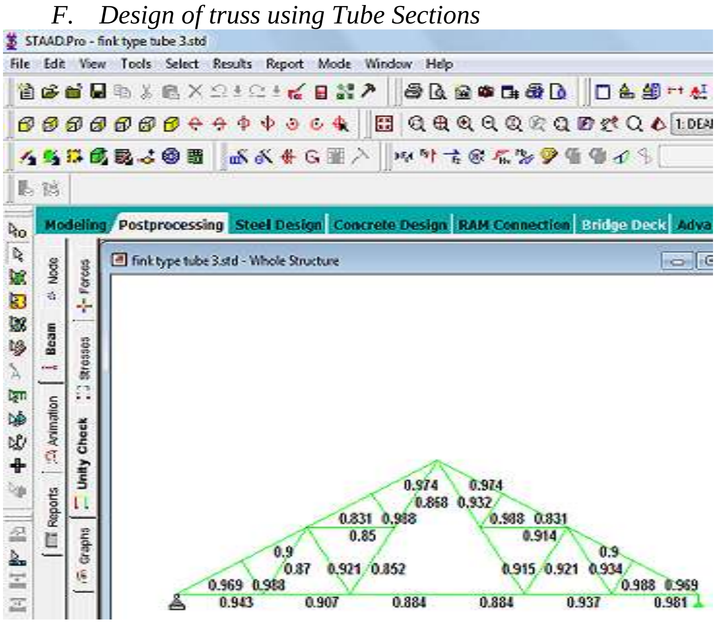


Fig. Unity check for truss designed with tube section

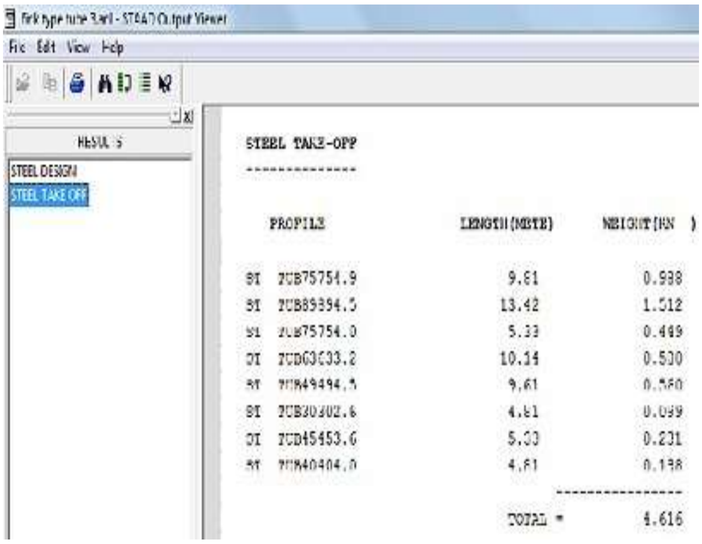


Fig. Steel Takeoff for Tube Section Truss

All the above mentioned design and analysis of truss is carried out using STAAD Pro. 2007. Design is carried out as per IS Codes 800 - 2007, 875, 4923 – 1997.

G. Result:

The above mentioned design and analysis indicate the economic benefits of hollow steel section as compared to open steel section. As shown in the above figures the steel take-off for same truss under same loading conditions designed with various sections are as follows:

Sections	Steel Take-off
Equal Angle Section	6.301 kN
Circular Pipe Section	4.219 kN
Square Tube Section	4.616 kN

Total percentage of steel saving:

i. When circular section is used = 33.042%

ii. When Square section is used = 26.742%

Quantity of steel required for Open Section Truss become less if Unequal Angle Section is used instead of Equal Angle Section but it hardly affect the percentage saving in steel.

X. Conclusion.

A. The Hollow Steel Sections are structurally more efficient then Open Steel Sections because of its properties like High Torsional Resistance, Smooth Surface Finish, High Strength to Weight Ratio, Free from Sharp Edges, etc.

B. When Open Sections are replaced by Hollow Sections saving in steel is to the tune of minimum 20 – 30%.

XI. Acknowledgment.

I am greatly thankful to Prof. Prabodh D. Pachpor, Asso. Prof. Shri Ramdeobaba College of Engineering and Management, Nagpur and Purushottam R. Atkare, Sr. Manager – Civil, Tata Consulting Engineers Limited, Mumbai for their continuous encouragement, support, constructive suggestions, and valuable advice. I also sincerely thank to Prof. Anand M. Gharad, Asst. Prof. Shri Ramdeobaba College of Engineering and Management, Nagpur, Ms. Jyoti Bhilawe, Research Scholar, VNIT, Nagpur and Mr. Kunal Dubey, B.Tech, SRCOEM, Nagpur for their technical support and sincere advice.

This paper is humbly dedicated to our parents and to the profession of structural engineering, with a hope that it will prove to be of immense benefit to all the readers, in the fact that it will give a second and considered opinion on most of the problems involved in the structural design of steel buildings.

XII. References.

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