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Analytical Study on Angle and Hollow Members for Steel Roof Truss

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Abstract:

This paper covers design and analysis of steel roof truss and their importance for the structural systems used in steel structures, mainly for roofing and other long-span applications. The paper specifically looks at performance aspects of angle sections as purlins, as well as comparing these with hollow sections. The modelling and analysis of steel roof truss done by STAADpro. Calculation of truss behaviour subjected to dead loads, live loads, wind load, seismic load considering factors such as buckling, stress distribution, and deflection. The code IS875 -1987 PART-1 used for finding design loads. The main aim is to find load-carrying capacity, weight efficiency, cost-effectiveness of the two types of members under regular loading conditions. A careful comparison between these two types of members is given by considering several design criteria such as ease of fabrication, availability of the material, and long-term durability. This analysis eventually optimizes steel truss designs and provides useful insight for the structural engineer to choose the appropriate purlin for a particular application.

Keywords — **Structural Analysis, Conventional Steel Truss, Angle Section, Tube Section, Comparison, STAADPro V8i, Steel Roof Truss.**

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I. INTRODUCTION

A steel roof truss is a framework made of steel that is used to support the roof of buildings like warehouses and factories. It is also used in halls and residential spaces. Steel roof trusses are widely used in warehouses, auditoriums, bridges, factory roofs, aircraft hangars and airport terminals where unobstructed space is required.

A steel roof truss is made up of connected parts that form a triangle shape. The parts of the truss are designed to work to make the structure strong. Steel roof trusses are often used in buildings to give the roof its strength and support. The steel members in a steel roof truss are designed to work to support the weight of the roof. They are connected in a way that helps to distribute the weight. This makes the steel roof truss very strong and stable. Steel roof trusses are a choice, for many types of buildings because they are strong and can last for a long time.

Steel roof trusses are really popular these days because they are strong and flexible. Steel roof trusses can span areas without any extra support. The weight of a steel roof truss varies depending on the length of the span and the slope of the roof. There are also a lot of design options for steel roof trusses. For example, in the case of a warehouse a steel roof truss is the best option for covering the roof. It is very cheap compared to other roof structure. Steel roof truss structures are also lightweight compared to structures made of concrete. The material used in a steel roof truss section is economical if a proper design is prepared.

Nowadays steel roof trusses are the common solution for problems in large scale roofing for example factories, workshops and railway stations. The economy of the structure for buildings depends on the configuration of the structure, type of roof structure.

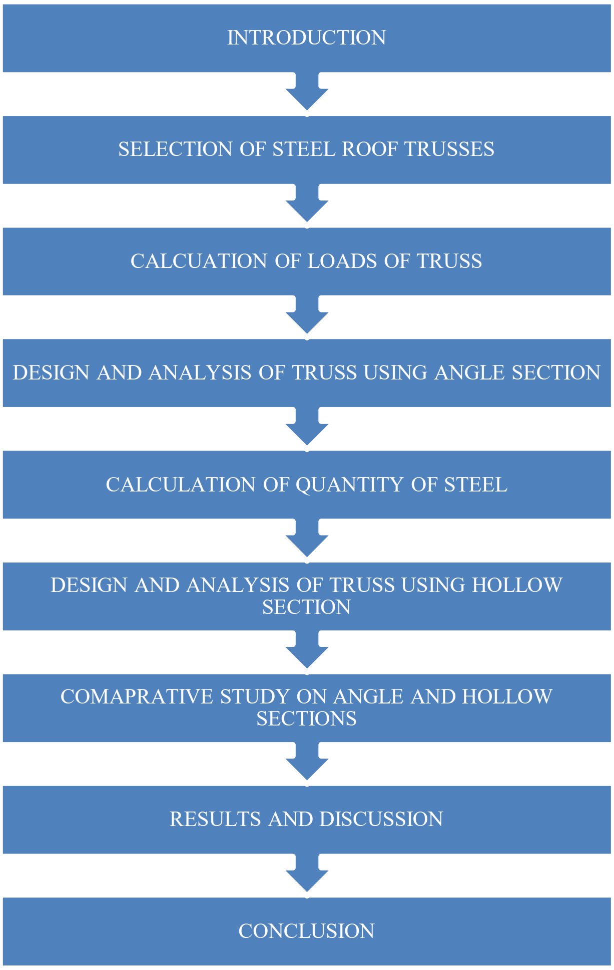
The selection of the truss is mainly based on the steel sections needed as per the force applied. To give the required space for working purposes we must avoid columns. If we use RCC slab in this case it requires areas so it does not satisfy the deflection condition and it becomes costly and uneconomical. The purpose of using steel roof trusses is that they have spans are light in weight reduce deflection percentages and give us the opportunity to support various loading conditions.

Fig. 1 Pratt Truss

Buckling happens when a structural member is under much load. This can cause a failure without any warning. Buckling occurs when a structure becomes unstable under loading conditions. A steel roof truss is a structure made of members connected at their ends by welded bolted or riveted joints. Joint connections are made by bolting or welding the end members to a plate called a gusset plate. Every structure must meet structural criteria and economic requirements. To achieve this truss design needs to be perfect. The goal is to minimize weight and cost. Their design and construction are critical, to ensuring safety and durability. The use of steel roof trusses continues to grow in construction.

II. SELECTION AND METHODOLOGY

The steel roof truss design used in this study is a Pratt Truss, that is made up of a rafter, purlins, struct, Top and Bottom Chords, posts to support a roof. The steel roof truss has types of loads like dead load, live load, wind load, seismic load. The code IS875-1987 PART-1 is used to calculate the design loads on the steel roof truss. The analysis of the steel roof truss is done by a computer program called STAADpro, that is used for structure analysis and design. The loads are distributed in STAADpro with load combinations, including dead loads, live loads and wind loads and the design codes, for the steel roof truss are also considered in STAADpro.



III. DESIGN OF STEEL ROOF TRUSS

A. Design of Steel roof Truss per Code Specification

Designing and Analyse of Pratt Steel roof truss for industrial warehouse building of size 25m X

12m.The trusses are spaced 5m c/c. The building location is considered in Chennai, Tamil Nadu, India.

Dimensions = 10 m × 25 m
Span of Truss = 18 m
Spacing = 5 m
Rise of Truss = 3 m
Category – 3 Class – B for Chennai, Tamil Nadu, India.

B. Calculation of loads on Truss

As per IS 875 code specifications,
Depth (or) height of truss = span/6 or span/5
Height (H) = span/6
= 18/6
= 3 m
Pitch = height/span
= 3/18
= 0.1666
Slope = height/ (span/2)
= 2×pitch
= 2×0.1666
= 0.3333
Roof angle (θ) = $\tan^{-1}$(slope)
= $\tan^{-1}$(0.3333)
= 18.44°
Number of Purlins = 8
Length of rafter = 9.49 m
Length of each panel = 9.49/3
= 3.16 m
Length of panel in plan = 3.16 × cos 18.44°
= 2.898 m
Truss spacing = 5 m
Sloping Area of Roof Truss = 2 × 9.49 × 5
= 94.87 sq.m
Plan area of Roof Truss = Span × Spacing
= 5 × 18
= 90 sq.m

i) Dead Load:
Self-Weight of G.I. sheets = 180 N/m^2 (Assume)
Self-Weight of Purlins = 100 N/m^2 (Assume)
Self-Weight of sheet on plan area = 180 × 94.87
= 17076.30 N
Self-Weight of sheet Purlins = 5 × 100 × 8
= 4000 N
Total Deal Load = 17076.30 + 4000
= 21076.30 N
Deal Load on each panel point = 21076.30/6
= 3512.72 N
Dead Load on End point = 3512.72/2
= 1756.36 N

ii) Live Load:
Imposed load on truss = 581.11 N/m^2
Live load on the truss = 0.666 × 581.11 × 90
= 34831.97 N
Live load on each panel point = 34831.97 × 6
= 5805.33 N
Live load on end panel point = 5805.33 / 2
= 2902.66 N

iii) Wind Load:
From IS: 875 (Part-3) 1987,

a) Basic wind speed (V_b):
[Cl. 5.2 pg-8 Appendix A pg-53)
V_b = 50 m/s for Chennai, Tamil Nadu

b) Design wind speed (V_z): (Cl. 5.3 pg-8)

$$V_z = k_1 \text{ x } k_2 \text{ x } k_3 \text{ x } k_4 \text{ x } V_b$$

k_1 = 1.0
k_2 = 1.0 (Terrain Category=3, Class of building, B= 1.0)
k_3 = Assuming plane ground so that k_3 = 1.0
k_4 = 1.15
$V_z = k_1$ x k_2 x k_3 x k_4 x V_b
= 1 x 1 x 1 x 1.15 x 50
= 57.50 m/s

c) Design wind pressure:
P_z = 0.6 x (V_z) x 2
= 0.6 x (57.50)2
= 1369.03 N/m^2
iv) Wind Load on roof truss:
F = (C_{pe} – C_{pi}) x A_e x P_d

Calculation of Cpe,
where V_z = design wind velocity in m/s at ht. z
C_{pe} = external pressure coefficient
C_{pi} = internal pressure coefficient
A_e = Surface area the structural member or cladding unit
P_d = design wind speed
= 0.8 h/w = 11/25 = 0.44 θ = 18.44°

For θ = 0° (Wind Angle),

θ	EF	GH
20°	-0.4	-0.4
18.44°	x	x
30°	0	-0.4

By interpolation:
C_{pe} for Windward side = -0.76
C_{pi} for Leeward side = -0.50
For Windward Side Slope, 1 = -0.50p
2 = -0.70p
For Leeward Side Slope, 1 = -0.30p
2 = -0.96p

For θ = 90° (Wind Angle θ),

θ	EF	GH
20°	-0.7	-0.6
18.44°	x	x
30°	-0.7	-0.6

By interpolation:
C_{pe} for Windward side = -0.80
C_{pi} for Leeward side = -0.60
For Windward Side Slope, 1 = -0.60p
2 = -0.80p
For Leeward Side Slope, 1 = -0.40p
2 = -1.00p
Maximum value from all values = -1.00p
Total Wind Pressure = 129877.17 N
Wind load on end points = 129877.17/2
= 21646.19 N
Wind load on end panel points = 21646.19
= 10823.10 N
Load Combination:

- 1.5 (DL+LL)
- 1.2 (DL+LL+WL)
- 1.2 (DL+LL-WL)
- 1.5 (DL+WL)
- 1.5 (DL-WL)

C. Analysis and Design of Steel Roof Truss Using STAADPro

The selected Pratt Steel Roof truss model is modelled by using all components of roof truss by conventional angle section using STAADPro Software.

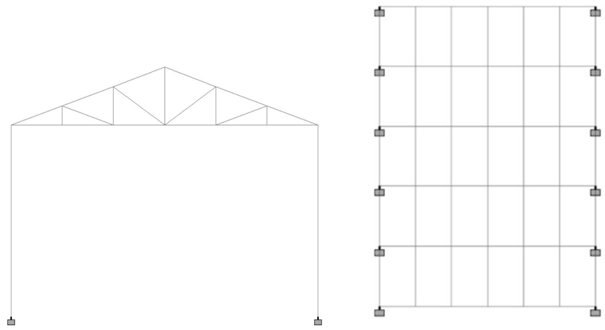


Fig. 2 Front and Top view of Pratt Truss

TABLE I
MAX. & MIN. NODE DISPLACEMENT VERTICAL Y(MM)

	Node	Load Combination	Vertical Displacement Y mm
Max X	329	7 1.5(DL+WL)	10.789
Min X	324	7 1.5(DL+WL)	11.134
Max Y	332	7 1.5(DL+WL)	14.325
Min Y	315	4 1.5(DL+LL)	-2.374
Max Z	3	7 1.5(DL+WL)	6.6
Min Z	323	7 1.5(DL+WL)	11.347
Max r_X	1	4 1.5(DL+LL)	0
Min r_X	1	4 1.5(DL+LL)	0
Max r_Y	1	4 1.5(DL+LL)	0
Min r_Y	1	4 1.5(DL+LL)	0
Max r_Z	1	4 1.5(DL+LL)	0
Min r_Z	1	4 1.5(DL+LL)	0
Maximum Resultant	332	7 1.5(DL+WL)	14.325

TABLE III
MAX. & MIN. NODE REACTIONS F_X, M_X M_Z PARAMETER

	Node	Load combination	Fy KN	Mx KNm	Mz KNm
Max F_x	306	7 1.5(DL+WL)	-532.9	42.62	0.089
Min F_x	305	7 1.5(DL+WL)	-528.7	42.38	-0.092
Max F_y	305	7 1.5(DL+WL)	103.7	-3.605	0.018
Min F_y	306	4 1.5(DL+LL)	-532.9	42.62	0.089
Max F_z	322	7 1.5(DL+WL)	-397.7	-183.1	0.049
Min F_z	2	7 1.5(DL+WL)	-454.4	232.0	0.078
Max M_x	2	4 1.5(DL+LL)	-454.4	232.6	0.078
Min M_x	322	4 1.5(DL+LL)	-397.7	-183.1	0.049
Max M_y	2	4 1.5(DL+LL)	454.4	232.6	0.078
Min M_y	1	4 1.5(DL+LL)	-451.1	230.6	-0.082
Max M_z	18	4 1.5(DL+LL)	-525.6	124.4	0.114
Min M_z	17	7 1.5(DL+WL)	-521.3	123.5	-0.119

TABLE IIII
BEAM REACTIONS MAX. & MIN. AXIAL FORCE F_X PARAMETER

	Node	Beam	Load Combination	Fx KN
Max F_x	333	597	7 1.5(DL+WL)	398.702
Min F_x	326	604	7 1.5(DL+WL)	-206.883
Max F_y	177	621	7 1.5(DL+WL)	0
Min F_y	193	621	4 1.5(DL+LL)	0
Max F_z	1	1	7 1.5(DL+WL)	13.801
Min F_z	1	1	7 1.5(DL+WL)	13.801
Max M_x	1	1	4 1.5(DL+LL)	13.801
Min M_x	1	1	4 1.5(DL+LL)	13.801

Max M_y	1	1	4 1.5(DL+LL)	13.801
Min M_y	1	1	4 1.5(DL+LL)	13.801
Max M_z	1	1	4 1.5(DL+LL)	13.801
Min M_z	1	1	7 1.5(DL+WL)	13.801

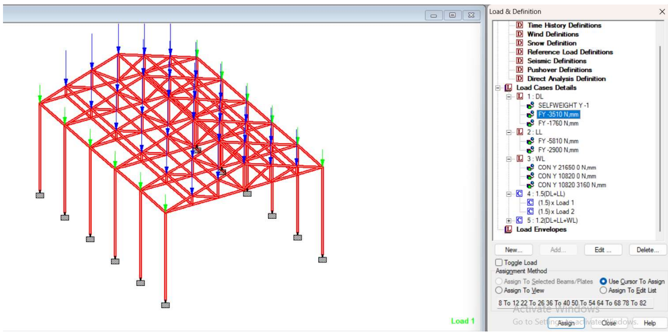


Fig. 3 Loads on Steel Roof Truss

Then Angle section given to satisfy the loads in Steel Roof Truss,

- Column – ISMC150D
- Rafter – ISA120X120x8 and ISA120X120x12
- Purlins – ISA125X75x10
- Bottom Chord – ISA100X65x8
- Diagonal Members/Strut – ISA110X110x8 and ISA90X90x10
- Vertical Members – ISA70X70x8

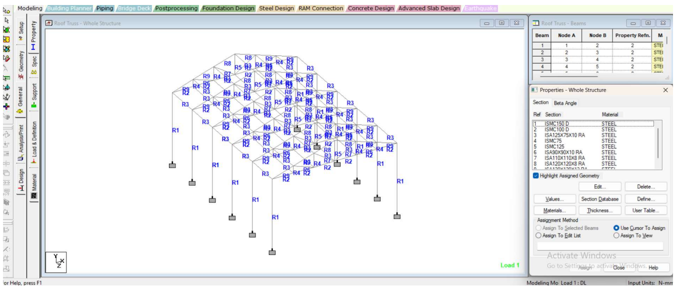


Fig. 4 Model of Steel Roof Truss using angle section

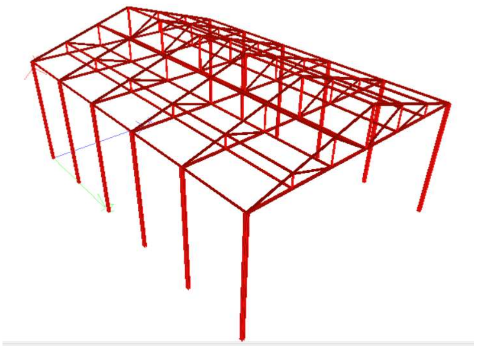


Fig. 5 Rendering view of Steel Roof Truss using angle section

Total Quantity of steel using angle section,

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STEEL TAKE-OFF
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   PROFILE                     LENGTH(MMS )      WEIGHT(NEWT)

LD   ISA100X65X8                108000.05          20907.200
RA   ISA120X120X12               75894.66          16091.328
RA   ISA120X120X8                37947.34           5480.379
LD   ISA70X70X8                  53999.98           8794.296
RA   ISA90X90X10                 37947.34           4984.814
RA   ISA110X110X8                43266.61           5683.562
D    ISMC150                    119999.99          39270.134
RA   ISA125X75X10               300000.16          43787.119
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                                  TOTAL =         144998.831
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Fig. 6 Steel Take-off – Angle section

The approximate quantity of steel take off to design the steel roof truss using angle sections is 145 kN.

The Steel Roof truss model is modelled by using all components of roof truss by tubular section using STAADPro Software.

TABLE IV
MAX. & MIN. NODE DISPLACEMENT VERTICAL Y(MM)

	Node	Load Combination	Vertical Displacement Y mm
Max X	328	7 1.5(DL+WL)	19.399
Min X	325	7 1.5(DL+WL)	19.898
Max Y	331	7 1.5(DL+WL)	21.124
Min Y	315	4 1.5(DL+LL)	-2.762
Max Z	3	7 1.5(DL+WL)	7.291
Min Z	323	7 1.5(DL+WL)	13.951
Max r_X	1	4 1.5(DL+LL)	0
Min r_X	1	4 1.5(DL+LL)	0
Max r_Y	1	4 1.5(DL+LL)	0
Min r_Y	1	4 1.5(DL+LL)	0
Max r_Z	1	4 1.5(DL+LL)	0
Min r_Z	1	4 1.5(DL+LL)	0
Maximum Resultant	331	7 1.5(DL+WL)	21.124

TABLE V
MAX. & MIN. NODE REACTIONS F_X, M_X M_Z PARAMETER

	Node	Load Combination	Fy KN	Mx KNm	Mz KNm
Max F_x	306	7 1.5(DL+WL)	565.0	50.78	0.136
Min F_x	305	7 1.5(DL+WL)	560.8	50.51	0.142
Max F_y	305	7 1.5(DL+WL)	79.56	-3.20	0.021
Min F_y	306	4 1.5(DL+LL)	565.0	50.78	0.136
Max F_z	322	7 1.5(DL+WL)	415.2	205.0	0.073
Min F_z	2	7 1.5(DL+WL)	479.4	254.6	0.123
Max M_x	2	4 1.5(DL+LL)	479.4	254.6	0.123
Min M_x	322	4 1.5(DL+LL)	415.2	205.0	0.073
Max M_y	2	4 1.5(DL+LL)	479.4	254.6	0.123
Min M_y	1	4 1.5(DL+LL)	476.1	252.5	-0.13
Max M_z	18	4 1.5(DL+LL)	553.4	137.5	0.181
Min M_z	17	7 1.5(DL+WL)	549.1	136.4	-0.19

TABLE VI
BEAM REACTIONS MAX. & MIN. AXIAL FORCE F_X PARAMETER

	Node	Beam	Load Combination	Fx KN
Max F_x	333	597	7 1.5(DL+WL)	411.449
Min F_x	326	604	7 1.5(DL+WL)	-213.395
Max F_y	189	861	7 1.5(DL+WL)	0
Min F_y	205	861	4 1.5(DL+LL)	0
Max F_z	1	1	7 1.5(DL+WL)	6.487
Min F_z	1	1	7 1.5(DL+WL)	6.487
Max M_x	1	1	4 1.5(DL+LL)	6.487
Min M_x	1	1	4 1.5(DL+LL)	6.487
Max M_y	1	1	4 1.5(DL+LL)	6.487
Min M_y	1	1	4 1.5(DL+LL)	6.487
Max M_z	1	1	4 1.5(DL+LL)	6.487
Min M_z	1	1	7 1.5(DL+WL)	6.487

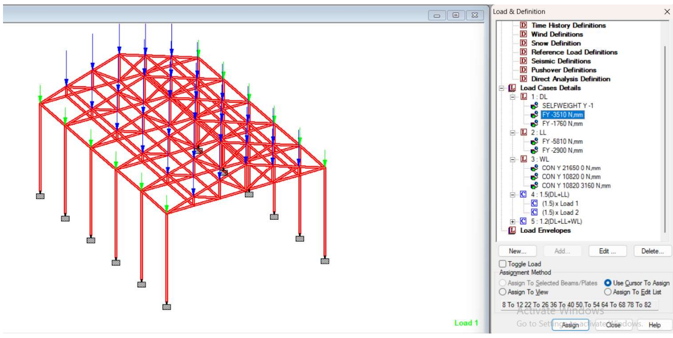

Fig. 7 Loads on Steel Roof Truss

Then Tube section given to satisfy the loads in Steel Roof Truss,

- Column – ISMC 150 D
- Rafter – TUB1001006
- Purlins – TUB80804
- Bottom Chord – TUB1001004
- Diagonal Members/Strut – TUB75754
- Vertical Members – TUB75754

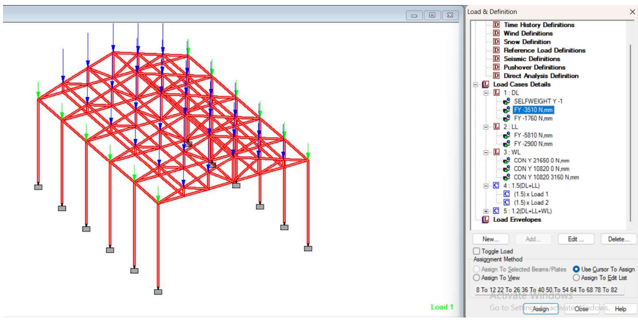

Fig. 8 Model of Steel Roof Truss using Tube section

Fig. 9 Rendering view of Steel Roof Truss using Tube section

Total Quantity of steel using Tube section,

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STEEL TAKE-OFF
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   PROFILE                    LENGTH(MMS )      WEIGHT(NEWT)

ST  TUB1001004                 108000.05          12361.795
ST  TUB1001006                 113841.95          18889.819
ST  TUB75754                   135213.94          11321.904
D   ISMC150                    119999.99          39270.134
ST  TUB80404                   300000.16          19704.207
                                            ----------------
                                   TOTAL =       101547.858
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Fig. 10 Steel Take-off – Tube section

The approximate quantity of steel take off to design the steel roof truss using Tube sections is 101.55 kN.

D. Result and Discussion:

TABLE VII
COMPARSION BETWEEN ANGLE AND TUBE SECTION

	Angle Section	Tube Section
Cost per Kg	65-70/Kg	70/Kg
Built Type	Prefab	Tubular
Material	Steel	Customized Steel
Application	Commercial & Industrial	Commercial & Industrial
Finish	Colour coated	Colour Coated
Thickness	10mm to 20mm	12mm to 16mm

a) Using Angle section:
Steel Take off = 145 kN
Total Quantity of steel in kg = 145 x 102
= 14,790 kg of steel section required
Cost of the Angle section = 14,790 x 67
= Rs. 9,90,930/-
b) Using Angle section:
Steel Take off = 101.55 kN
Total Quantity of steel in kg = 101.55 x 102
= 10258.1 kg of steel section required
Cost of the Angle section = 14,790 x 70

= Rs. 7,25,067/-

Therefore, Total Cost Saving while using Tube Section instead of angle section,

= 9,90,930 – 7,25,067

= Rs. 2,65,863/-

Therefore **30.99%** of the total cost saving in tube section so that tube section is proved to be economical section for Steel roof truss for Industrial Warehouse.

Fig. 11 Steel Angle and Tube section

While comparing angle sections and tube sections for use in steel roof trusses, following factors involved:

i) Material Cost:

Angle Sections: Angle sections are generally cheaper per kilogram due to simpler manufacturing and lower material usage.

Tube Sections: Tube sections are slightly costlier per kilogram than angle section because of their closed shape and more intensive manufacturing process.

ii) Structural Efficiency:

Tube Sections: These are really strong and can hold a lot of weight without bending. So, we do not need to use more material to withhold the loads acting in truss. Even though the material itself is more expensive we use less of it overall which in turn makes the whole structure lighter. So, we can make simpler foundations and supports which saves money.

Angle Sections: These are not as strong as Tube section so we need to use more of them or place them together to get the same strength. This makes the whole thing heavier and more expensive.

iii) Corrosion Protection and Maintenance:

Tube Sections: Tube sections has a closed shape with exposed edges. This reduces the risk of corrosion. As a result, maintenance costs are lower in the run.

Angle Sections: Angle sections are open shape can trap dust and moisture. This leads to corrosion. The structure requires maintenance over its lifetime, which increases costs. Corrosion and maintenance issues are more, with Angle Sections compared to Tube sections.

iv) Aesthetic and Architectural Value:

Tube Sections: They are often liked for structures because they look neat and modern. This might even make a property more valuable.

Angle Sections: They are not as aesthetic as compared to tube sections and are usually used in factories or places that are not seen.

IV. CONCLUSION

- The Steel Roof truss design and analysis have been studied, including the load calculations, loads analysis and design of all Steel Roof truss components.
- Comparing the load-carrying capacity and the amount of material used and the cost of both the angle members and the hollow structural sections for Steel roof truss to see which one is better.
- Results of angle and hollow section have been taken from STAAD Pro.
- 30.99% of the total cost saving in tube section so that tube section is proved to be economical section for steel roof truss for Industrial Warehouse.
- Even though hollow sections are more expensive, they are often better because they are stronger and do not buckle easily. Thus, it reduces the total weight of the structure and that saves money on foundations and supports.

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