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Optimization of Industrial Shed Using Fully Stressed Design Method for Butterfly Roof

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Abstract: In this direction, in the present study an effort has been carried out to optimize the section based on the bending moment diagram and made tapered to obtain a suitable utility for a most critical load combination as per IS 800:2007 [table 4]. The conventional structure is costly due to uniform steel sections throughout the member length. In contrast, the tapered section reduces steel consumption by a certain amount. In this study, an optimization of industrial sheds of different spans and geometries is carried out. The load calculations are carried out as per IS 875 parts 1, 2 and 3. The design checks are performed as p er Indian Standard Code IS 800:2007 (LSM). The analysis and design have been carried out using the staad-pro software. The main goal of the study is to achieve the cost-effective frame based on changes in geometry, width, and angle of roof in terms of weight, as well as to investigate the variation in results.

Keywords: Industrial shed, tapered section, hot-rolled section, monoslope roof, pitched roof, butterfly roof.

I. INTRODUCTION

In industrial shed a tapered section design has been invented in market which is more economical compared to the conventional hot rolled design. It includes factory designed built up members with tapered profile that leads to an economical design of whole shed and economical design of foundation. It is also a time saving technology that decreases the time of construction as its members are designed and welded in factories after which they are transported to site of work and assembled using bolts. This kind of structures are nowadays used everywhere. Places such as metro stations, parking spaces, aircraft carrier, industrial buildings, petrol pumps, etc.

The process of constructing a PEB typically involves the following steps: design, fabrication, transportation, and assembly. During the design phase, the building's specifications and requirements are determined, and the steel structures are designed and fabricated to meet those needs. The structures are then transported to the construction site, where they are assembled according to the design specifications.

In the early years, the design of PEBs was relatively simple, consisting of a basic frame structure with corrugated metal sheeting. However, as the demand for PEBs increased, the design and engineering of these structures became more complex and sophisticated. The development of computer-aided design (CAD) technology in the 1980s revolutionized the design and manufacturing of PEBs. This technology enabled the creation of detailed 3D models, making it easier to design and fabricate more complex structures. Additionally, the use of CAD technology made it possible to optimize the use of materials and reduce waste, resulting in cost savings for builders and clients. Usage of pre-engineered buildings has since spread throughout Asia and Africa, where the concept of PEB architecture has now been widely accepted and lauded. The principle of pre-engineered steel buildings is known as the most flexible and economical building. In the construction industry, the economy and the speed of delivery and installation of these buildings are unparalleled. No other building system matches the pre-engineered building system in terms of speed and cost from excavation to occupancy. Use of tapered sections for any construction was banned until 1990 but now it has been praised all over the world. In India it is still a growing industry lots of investment is still required to develop this industry in India.

II. CONCEPT OF OPTIMIZATION

Optimization is the process of finding the best solution to a problem within a given set of constraints. It involves selecting the most favorable outcome from a range of possible choices or options, while considering the limitations or constraints that exist. Utilization Ratio

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It is used to determine how optimum is our section going to be for the given weight. The section is ought to be optimum if the utilization ratio lies between 0.8 to 1. Where 0.8 means that 80% of our member is been utilized to carry the given load.

Optimization in this paper is done for hot rolled section as well as tapered sections the optimization details are as follows;

A. Optimization For Hot Rolled Section

The optimization for hot rolled section is been done using staad pro commands in this process the staad pro itself optimizes and selects the optimum section from pre listed hot rolled sections.

a) Determine the structural requirements: Before optimizing steel sections, it is important to determine the structural requirements of the building, including the loads, design codes and standards, and other design considerations.
b) Create the model: In STAAD Pro, create a 3D model of the building, including all beams, columns, braces, and other steel members. Ensure that the model accurately reflects the structural requirements of the building.
c) Assign steel sections: Assign appropriate steel sections to each member in the model. This can be done manually or using STAAD Pro's automatic section selection tools.
d) Analyze the model: Analyze the model in STAAD Pro to determine if any members fail to meet the structural requirements of the building. This will help identify members that require optimization.
e) Optimize steel sections: Using STAAD Pro's optimization tools, analyze the model to find the most cost-effective steel sections that meet the structural requirements of the building. This may involve adjusting member sizes, changing the orientation of members, or using different steel sections altogether.
f) Verify the design: Verify the optimized design by re-analyzing the model in STAAD Pro to ensure that all members meet the structural requirements of the building. Make any necessary adjustments to the design to ensure that it meets all requirements.
g) Generate reports: Generate design reports and other documentation using STAAD Pro to provide a detailed record of the optimized design and its structural performance.

STAAD Pro performs steel structural optimization based on several ideas, including

a) Cross-Sectional Optimization: This technique entails determining the most effective cross-section for each steel structural component in order to save weight and material consumption while still guaranteeing that the member is sturdy enough to withstand the applied loads.
b) Optimizing the lengths of the steel members to minimize their weight and lower the structure's overall cost is known as member length optimization.
c) Connection Optimization: This entails designing connections between steel members optimally to reduce the quantity of material utilized while guaranteeing that the connection is sturdy enough to withstand the applied loads.
d) Load optimization: This entails distributing loads on the steel structure as efficiently as possible to lessen the stress on individual members and cut down on the structure's overall weight.
e) Overall, these optimization ideas are beneficial. Engineers create steel buildings that adhere to the necessary design norms and standards while still being efficient and affordable

B. Optimization For Tapered Section

The optimization of tapered section has been carried out by Fully Stressed Design method and it includes number of trials in order to obtain proper optimum tapered section. The (**Figure 1)** shows optimizing industrial shed from bending moment diagram. Initially, a point of contraflexure has been found at the length of the member then after at the selected point process of decreasing the section modulus must be carried out in order to reach up to the member's allowable stress. This could be achieved by changing dimensions of members such as web depth, web thickness, flange width (top & bottom) and flange thickness (top and bottom).

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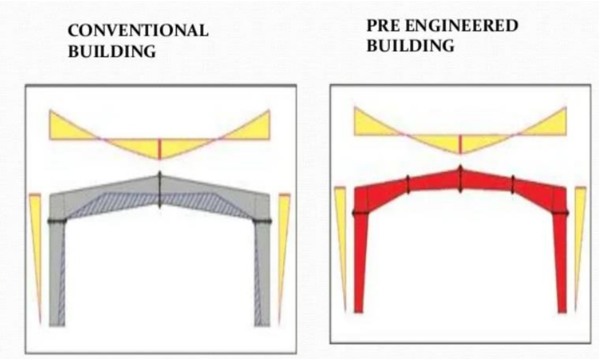

Figure 1 Optimization of Tapered Section

III. Structural Data of Modelling

There are total of 28 models for the study of an optimum solution for industrial shed. There are models with different widths i.e., 10m, 12m, 15m, 18m, 20m, 25m and 30m. The frames with 5.17^0 and 10^0. Having Butterfly roof. Profile. This range is used to get proper idea and conclusion for fulfillment of our objectives. As shown in (**Figure 2 and 3)** for butterfly roof model for hot rolled and tapered section. All the other details of modelling are in (**Table1).**

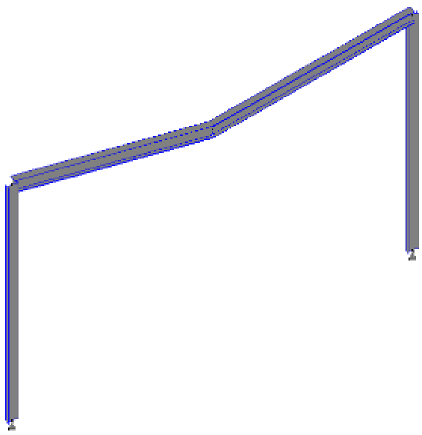

Figure 2 Hot Rolled Butterfly Roof

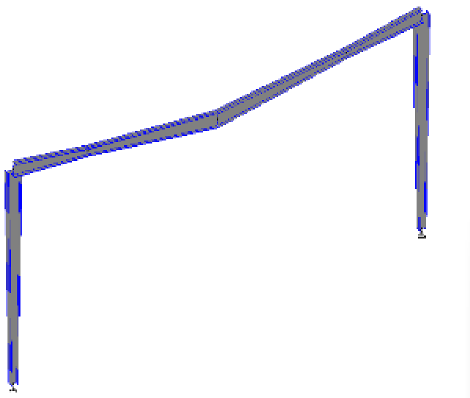

Figure 3 Tapered Butterfly Roof

Table 1 Building Parameters

Sr no	Description	
1.	TYPES OF STRUCTURE	HOT ROLLED & TAPERED
2.	TYPES OF PROFILE	BUTTERFLY ROOF
3.	LOCATION	Ahmedabad
4.	WIDTH	10m, 12m, 15m, 18m, 20m, 25m, 30m
5.	HEIGHT	6m
6.	ANGLE OF ROOF	5.17, 10
7.	SUPPORT CONDITION	HINDGE
8.	WIND SPEED	39 m/s
9.	NUMBER OF MODELS	28

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IV. MEMBER PROPERTIES DETAIL

A. butterfly roof property details

The (**Figure 4 and 5)** shows the property names marked in form of R series in order to confirm details given in (**Table 2, 3, 4 and 5)** for different angles considered in study. Here, **Table 2** represents Tapered sections used for 5.17^0 roof angle of monoslope roof profile. The (**Table 3)** shows hot-rolled section details of monoslope roof profile at 5.17^0 roof angle (**Table 4)** shows tapered section details of monoslope roof profile at 10^0 roof angle . (**Table 5)** shows hot-rolled section details of monoslope roof profile at 10^0 roof angle. Every section in table are optimized and given the suitable property as per loading conditions. The utilization ratio for each section is ranging from 0.8 to 1. The hot rolled sections are optimized using select optimized command. Whereas tapered sections are utilized using fully stressed design method.

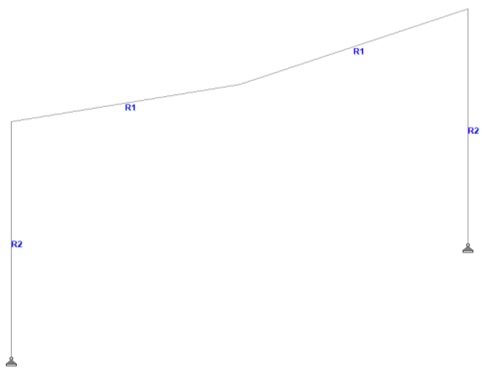

Figure 3 Hot-Rolled Property Detail for Butterfly Profile

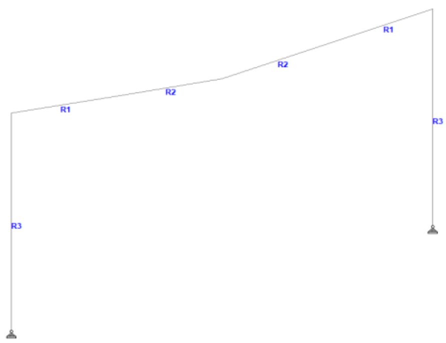

Figure 4 Tapered Property Detail for Butterfly Profile

Table 2 MODEL MEMBER DETAILS FOR TAPERED BUTTERFLY ROOF AT 5.17^0

	LOCATION	10 m	12m	15m	18m	20m	25m	30m
COLUMN WEB	R3	(350 - 180) x 6mm	(390 - 200) x 8mm	(500 - 230) x 8mm	(450 - 200) x 8mm	(400 - 250) x 8mm	(450 - 250) x 8mm	(600 - 300) x 9mm
COLUMN FLANGE	R3	200 x 8mm	200 x 8mm	200 x 8mm	240 x 8mm	250 x 12mm	250 x 10mm	300 x 10mm
RAFTER WEB	R1	(560 - 150) x 5mm	(350 - 200) x 6mm	(350 - 200) x 8mm	(340 - 250) x 8mm	(380 - 300) x 8mm	(300 - 250) x 8mm	(420 - 300) x 12mm
	R2	(160 - 150) x 5mm	(230 - 200) x 6mm	(400 - 200) x 8mm	(420 - 250) x 8mm	(400 - 300) x 8mm	(900 - 250) x 8mm	(800 - 300) x 12mm
RAFTER FLANGE	R1	150 x 5mm	180 x 6mm	200 x 7mm	250 x 8mm	250 x 12mm	350 x 12mm	350 x 12mm
	R2	150 x 5mm	180 x 6mm	200 x 7mm	200 x 9mm	250 x 12mm	350 x 12mm	350 x 12mm

Table 3 Model Member Details for Hot rolled Monoslope Roof At 5.17^0

	10m	12m	15m	18m	20m	25m	30m
COLUMN	NPB 250X175 X43.94	NPB 250X175 X43.94	ISHB 300	ISWB 400	ISLB 400	ISHB 450	ISWB 550
RAFTER	ISMB 100	ISWB 250	ISHB 300H	ISHB 400	ISHB 300	IM 600X400X16 32	IM 500X350X2040

Table 4 Model Member Details For Tapered Butterfly Roof At 10^0

	LOCATION	10 m	12m	15m	18m	20m	25m	30m
COLUMN WEB	R3	(560 - 200) x 7mm	(400 - 200) x 8mm	(450 - 220) x 8mm	(400 - 250) x 8mm	(550 - 250) x 12mm	(730 - 300) x 14mm	(500 - 300) x 12mm
COLUMN FLANGE	R3	180 x 8mm	200 x 8mm	220 x 8mm	280 x 8mm	250 x 10mm	250 x 14mm	300 x 14mm
RAFTER WEB	R1	(160 - 150) x 5mm	(350 - 180) x 6mm	(400 - 200) x 7mm	(400 - 250) x 8mm	(400 - 230) x 8mm	(500 - 400) x 8mm	(420 - 350) x 14mm
	R2	(160 - 150) x 5mm	(250 - 180) x 6mm	(380 - 200) x 7mm	(600 - 250) x 8mm	(750 - 230) x 8mm	(850 - 400) x 8mm	(950 - 350) x 14mm
RAFTER FLANGE	R1	160 x 5mm	180 x 6mm	200 x 7mm	250 x 8mm	300 x 10mm	300 x 14mm	350 x 14mm
	R2	160 x 5mm	180 x 6mm	200 x 7mm	250 x 8mm	300 x 10mm	300 x 14mm	350 x 14mm

Table 5 Model Member Details for Hot rolled Butterfly Roof At 10^0

	10m	12m	15m	18m	20m	25m	30m
COLUMN	NPB 250X17X4 3.94	WPB 220X220X40 .40	ISWB 350	ISHB 400	ISLB 400	ISHB 450	WPB 80X300X179. 89
RAFTER	ISMB 100	NPB 250X175X43 .94	ISHB 300H	ISWB 550	ISHB 300	IM 600X400X1 632	WPB 600X300X28 5.47

V. LOADING CALCULATIONS AND DETAILS

The calculations are carried out using excel sheets where data must be changed for different types of roofs and with change in data as there has been a change in loading. The calculation for respected excel sheets are presented below.

A. Dead Load Calculation

Dead load on roof has been calculated using IS 875: Part 1 (1987). The calculation starts off from assuming load of purlins and taking standard sheet loadings in consideration. Then those loads of sheets and purlins are calculated further to be

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applied on rafter as UDL. Other than that, the self-weight of rafter and columns are calculated by giving -1 factor in staad pro connect.

- Weight of sheeting =7.5 kg/m^2 (Included other services and accessories)
- Load of purlins = 80 N/m (Assumed)
- Permissible span of sheet = 1.6 m
- Bay spacing = 7.5m

$$\text{Dead load on purlins} = \frac{7.5 \text{ x } 1.6}{1000} = 0.120 \text{ kN/m}$$

$$\text{Total dead load} = 0.12 + 0.08 = 0.2 \text{ kN/m}$$

$$\text{Sheeting and Purlin loads on rafter} = \frac{0.2 \text{ x } 7.5}{1.6}$$

$$= 1 \text{ kN/m}$$

B. Live Load Calculation

Live load on roof has been calculated as per IS 875 :1987 (Part 2). The live load on roof must be taken from table 2 of is 875 (part 2) pg. no. 14. In which the table suggests the values of load varying as per roof angle. For roof having slope greater than 10^0 the live load on purlin is considered 0.75 kN/m^2. For slope more than 10^0 the table suggests 0.75Kn/m^2 less 0.02kN/m^2 less for every degree increase in slope.

- Live load on purlin = 0.75 KN/m^2 (slope < 10^0)
- Live load on purlin = 0.65 kN/m^2 (slope =15^0)

$$\text{Live load on purlins (UDL)} = 0.75 \text{ x } 1.6 = 1.2 \text{ kN/m}$$

$$\text{Live Load on rafter} = \frac{1.2 \text{ x } 7.5}{1.6} = 5.625 \text{ kN/m}$$

C. Wind Load Calculation

Wind load for industrial shed has been calculated using IS 875:2015 (Part 3). The external coefficients for wall load on industrial shed are same for all angle and width force on wall remains same for each profile.

- Terrain category = 2
- Location = Ahmedabad
- Wind speed = 39m/s
- Bay spacing = 7.5
- Purlin spacing = 1.6m
- Slope = 5.17^0, 10^0, 15^0
- Upwind slope = < 3^0

1. Step:1 Calculate design wind speed (V_Z) [21]

Since the place of construction is Ahmedabad, basic wind speed is 39m/s.

$$\text{Design wind speed } (V_d) = V_Z \text{ x } K_1 \text{ x } K_2 \text{ x } K_3 \text{ x } K_4$$

Where,

Risk coefficient K_1=1 (From Table 1 general buildings)

Terrain category factor K_2=0.82 (From table 2 for 6 m height)

Topography factor K_3=1 (From cl. 6.3.3) Cyclonic factor K_4=1 (From cl. 6.3.4)

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Design wind speed (V_d) = 39 x 1 x 1.05 x 1 x 1 = 41m/s

2. *Step: 2 Design wind pressure (P_d)* [21]

Wind pressure (P_Z) = 0.6 x V_z^2

Wind pressure (P_z) = 0.6 x 41^2 = 1008.6 N/m^2 = 1.01 kN/m^2

Design wind pressure (P_d) = K_c x K_d x K_a x P_z

Where,

K_a= area averaging factor, For Tributary area

=1.6x7.5 = 12 m^2

Thus, from IS-875:2015 (part 3), we get

k_a= 0.8

K_c= 0.9 (From cl. 7.3.3.13)

K_d=0.9 (From cl. 7.2.1)

Design wind pressure (P_d) = 0.9 x 0.9 x 0.8 x 1.01

P_d = 0.66 kN/m^2

3. *Step: 3 Calculating wind force on Column*

Wind force (F) = (C_{pe}-C_{pi}) x A x P_d [21]

Where,

C_{pe}= External pressure coefficient

C_{pi}= Internal pressure coefficient

A=Tributary area

For C_{pe} Table :5 IS 875:2015 (Part 3)

$$\text{Building height ratio} = \frac{h}{w} = \frac{6\,m}{20m} = 0.3 < 0.5$$

$$\text{Building plan ratio} = \frac{l}{w} = \frac{50\,m}{20m} = 1.5 < 2.5 < 4$$

Thus, we get value for C_{pe} as shown in (**Table 7)**

Table 6 Cpe Values for Column Load Calculation

Wind angle	Wall A	Wall B	Wall C	Wall D
0^0	+0.7	-0.25	-0.6	-0.6
90^0	-0.6	-0.5	+0.7	-0.1

For C_{pi} cl. 7.3.2 IS: -875:2015 (Part 3) [21]

C_{pi}= ±0.2

Calculating force at wall A positive C_{pi} [21]: -

- For 0^0 wind angle

Wind force (F) = (0.7 – 0.2) x 7.5 x 0.66 = 2.65 kN/m

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- For 90^0 wind angle

Wind force (F) = (-0.6 – 0.2) x 7.5 x 0.66 = 3.96 kN/m

Calculating force at wall A negative C_{pi}: -

- For 0^0 wind angle

Wind force (F) = (0.7 + 0.2) x 7.5 x 0.66 = 4.46 kN/m

- For 90^0 wind angle.

Table 7 Load On Columns

Type of loads	Load on column			
Wind load 1	A= 2.65kN/m	B= -2.23kN/m	C= -3.96 kN/m	D= -3.96 kN/m
Wind load 2	A= 4.46 kN/m	B= -0.25kN/m	C=-1.98 kN/m	D=-1.98 kN/m
Wind load 3	A= -3.96kN/m	B= -3.47kN/m	C= 2.48 kN/m	D= -1.49 kN/m
Wind load 4	A= -1.98kN/m	B= -1.49kN/m	C=4.46 kN/m	D=0.5 kN/m

Wind force (F) = (0.7 + 0.2) x 7.5 x 0.66 = -3.96 kN/m

Same way all the loads are calculated and load table is formed as shown in **(Table 19).** Here in this study analysing of a 2D frame has been carried out thus loading on Wall A and Wall B has only been considered and loading on Wall C and D has not been applied in staad proTable 8 LOAD ON WALL (SAME FOR ALL PROFILES) [21]

4. Step: 4 Calculating wind force on Rafter

The C_P values are calculated as per Table 9 of IS: -875:2015 (Part 3).

Wind force (F) = C_P x A x P_d

For C_f Table :9 IS 875:2015 (Part 3)

$$\text{Building height ratio} = \frac{h}{w} = \frac{6\,m}{20m} = 0.3 < 0.5$$

Here, in order to get C_p coefficients, are assume our solidity ratio $\emptyset = 1$

Thus, we get value for C_p [21] as shown in **(Table 8)**

Table 8 Cp Value for Butterfly Roof

Angles	Solidity ratio	- C_p (0^0 & 90^0)	+ C_p (0^0 & 90^0)
5.17^0	1	-0.8	+0.3
10^0	1	-0.8	+0.4
15^0	1	-0.8	+0.5

Calculating force for positive C_p: -

- For 0^0 wind angle $+C_p$

Wind force (F) = +0.3 x 7.5 x 0.66 = 1.485 kN/m

- For 90^0 wind angle $+C_p$

Wind force (F) = +0.3 x 7.5 x 0.66 = 1.485 kN/m

Calculating force for negative $C_{p:}$ -

- For 0^0 wind angle $-C_p$

Wind force (F) = -0.8 x 7.5 x 0.66 = -3.96 kN/m

- For 90^0 wind angle $-C_p$

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Wind force (F) = -0.8 x 7.5 x 0.66 = -3.96 kN/m

Same way all the loads are calculated and load table is formed as shown in **(Table 9 and 10)**

Table 9 : MODEL MEMBER DETAILS FOR HOTROLLED MONOSLOPE ROOF AT 5.17^0

Type of loads	Load on column	
Wind load 1	1.98 kN/m	-3.96 kN/m
Wind load 2	1.98 kN/m	-3.96 kN/m
Wind load 3	1.98 kN/m	-3.96 kN/m
Wind load 4	1.98 kN/m	-3.96 kN/m

Table 10 : MODEL MEMBER DETAILS FOR HOTROLLED MONOSLOPE ROOF AT 10^0

Type of loads	Load on column	
Wind load 1	1.485 kN/m	-3.96 kN/m
Wind load 2	1.485 kN/m	-3.96 kN/m
Wind load 3	1.485 kN/m	-3.96 kN/m
Wind load 4	1.485 kN/m	-3.96 kN/m

VI. Results and Discussions Comparison For Butterfly Roof Steel Take-Off

The comparison has been concluded for butterfly roof at different spans of range 10m to 30m for roof at different angles of 5.17^0 and 10^0 in **(Figure 6 and 7)** the graph has been prepared having x-axis for width and Y-axis for Steel take-off in kg.

The butterfly roof in **(Figure 6)** shows increase in steel take off comparision values in percentage as width increases this behaviour in **(Figure 7)** is observed upto 25m span then after there is an slight decrease in percentage of steel take-off. Thus there is economy upto 30m span for 5.17^0 roof angle.

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In **(Figure 7)** the angle inrease leads to increase in percentage economy for the butterfly roof and thus the 10^0 angle of roof proves to be most economic for butterfly profile. The **(Figure 7)** also shows increase in steel take off as increase in width. The steel take off increase in percentage for 10^0 graph takes place upto 30m.

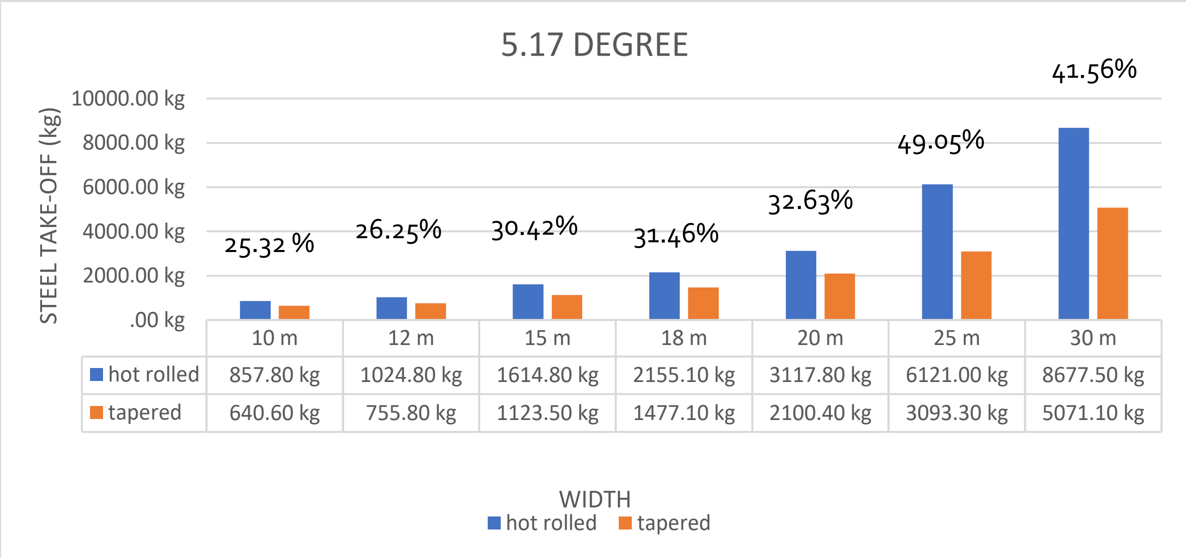

Figure 4 BUTTERFLY ROOF AT 5.17⁰ COMPARISON

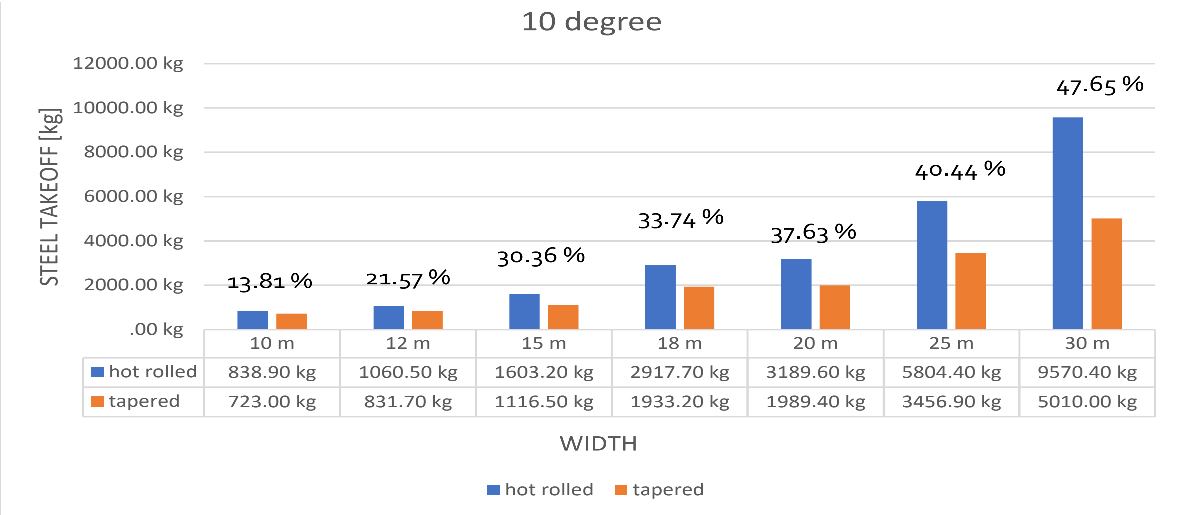

Figure 6 BUTTERFLY ROOF AT 10⁰ COMPARISON

VII. DISCUSSION

- It has been observed that for butterfly roof, tapered section has highest saving of material (economy) is up to 47% compared to hot rolled section. Moreover, the economy increases with increase in width.
- According to the observations, for a butterfly roof with a 5.17^0 angle, there is an increase in economy as the width increases up to 25 meters. However, at a width of 30 meters, there is a slight decrease in economy, indicating that the economy starts to decrease after a width of 25 meters.
- Similarly, for a butterfly roof at 5.17^0 angle, there is an increase in economy as the width increases up to 30 meters. Also, percentage economy for 10^0 compared to 10^0 is higher after width of 18m.

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- It is not possible to conduct study for butterfly roof with 15^0 angle as the floor height reduces tremendously from 6m to 2m at ridge line. Hence, it is practically difficult to give 15^0 slope for 6m height butterfly roof.

VIII. CONCLUSION

- Butterfly roof is economical for 5.17^0 roof angle when compared to 10^0 roof angle for all widths considered in present study.
- The economy percentage of butterfly roof increases as we increase the span.
- For 5.17^0 angle there is percentage decrease in steel saving of approximately. 7%. Thus, the width after 25m when increased shows decrease in economy for 5.17^0 roof angle.
- For 10^0 roof angle there in continuous increase in steel saving percentage as increase in width but for higher width the percentage increase in limited up to approximately 4% from 15 to 25m width
- This study also concludes that with increase in angle percentage steel saving decreases.

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