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Comparative Analysis of Long Span Howe and Pratt Parallel Chord Truss in ETABS Software

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ABSTRACT: The large-open spaces below the roofs are required for some purposeful functions of a building. For that the trusses can be an efficient structural element as it functions without any intermediate supports. A truss is essentially a triangulated system of straight interconnected structural elements. The most common use of trusses is in buildings, where support to roofs, the floors and internal loading such as services and suspended ceilings, are readily provided. The need of this study emerges where in cases it is difficult or requires much investment to choose a successful and optimum truss configuration during the design period. This research shows the comparison of simply supported parallel chord Howe and Pratt trusses with 30m span with different truss height and web spacing. These truss models are comprised of different steel sections like I section, Angle section and Pipe section. The roof truss is analysed and designed by ETABS software. Limit State Method is adopted in the design of truss members. Effect of stress reversal has been taken into account in the analysis of the truss. The weights acquired from the ETABS are in the unit of kg which is used to find the cost of the trusses. This study limits the height of truss as 2m. The configuration of web member has been attributed to know whether the web member is in compression or tension. And hence allows the truss to distribute the load in most effective way and thus decides a better effective truss.

KEYWORDS: ETABS, Parallel chord truss,Stress reversal, Truss height, Web spacing

I. INTRODUCTION

Trusses are structural support members made up of triangles. They are commonly used in the design and construction of roofs and bridges. The Webster's Encyclopaedic Dictionary defines a truss as: “Any of various structural frames based on the geometric rigidity of the triangle and composed of straight members subject only to longitudinal compression, tension, or both: functions as a beam or cantilever to support bridges, roofs, etc. Trusses may be defined as deep, long-span beams with open webs. Trusses offer a lighter, stiffer and more economical construction for relatively large spans when standard rolled beams or built-up girders may not be adequate.
The parallel chord or flat truss gets its name from having parallel top and bottom chords. The main difference between the designs is their web member configuration. By positioning the web members in different patterns at different locations, the primary force in the web member can be either compression or tension.

II. METHODOLOGY

The Study has been done for parallel chord roof truss design for in order to overcome choosing efficient web configuration for long span which is further optimized to give economical section selection, web spacing and height of the truss. For that two 30m span steel parallel roof truss (Howe and Pratt) were considered. The truss is designed for a 30m×60m rectangulararea. Truss is at 6m spacing and the eave height is 10m. In designing of the trussesvarious webspacing (0.5m,1m and 1.5m), with different truss height (1m,1.5m and2m)and Indian standard section (Pipe Section, I section and angle sections) are considered and economical study is also done through cost analysis. Truss is designed in the ETABS Software and various sections are studied by trial and error method and further optimization of the sections are also studied so that the correct sections are placed at right places and the final design is very economical. The cost considerations are also done for different sections used in the trusses and the steel price was considered as 90 rupees per kilogram.

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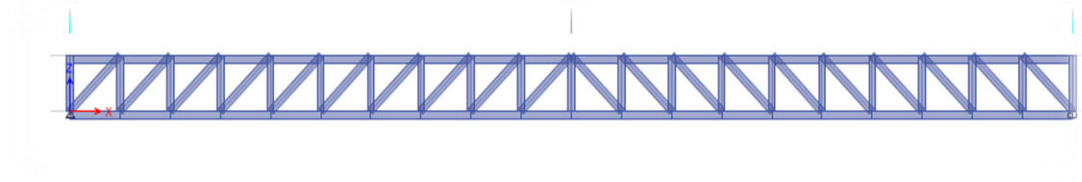
III. MODELLING

Howe and Pratt truss are taken for different spacing and heights. Three different spacing 0.5m, 1m, and 1.5m have taken in to consider with truss height of 1.0m, 1.5m and 2.0m.

A Howe truss is shown in Fig. 1(a) and the Pratt truss shown in figure 1(b). All of the web members areconfigured in this manner.

(a) Parallel Chord Howe Truss



(b) Parallel Chord Pratt Truss

Fig.1.Parallel Chord Truss with 30m span

IV. LOADING

A.Dead Load (DL)

IS: 875 (Part I) – 1987 has been considered to calculate dead load

Weight of sheet = 0.15 kN/m^2

Weightofbracing=0.015 kN/m^2

Self-weight of roof truss $=\left(\frac{SPAN}{3}+5\right)$ x10 N/m^2

$=(20/3+5)$ x 10 N/m^2 = 0.116 kN/m^2

Weight of purlins = 0.15 kN/m^2

Total dead load (DL) = 0.465 kN/m^2

Dead load of parallel roof truss is shown in Table 1

Table 1 Dead load of parallel roof truss

Dead Load(kN/m²)	Bay Length (m)	Web Spacing (m)	Dead load (kN)	
			Intermediate Node	End Node
0.465	6	0.5	1.395	0.6975
	6	1	2.79	1.395
	6	1.5	4.185	2.0925

B.Live Load (LL)

IS: 875-1987 (Reaffirmed 1992)has been considered to calculate live load

For roof of slope of Howe and Pratt configuration, $\alpha = 0°$

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Live load = 0.75kN/m^2 (access not provided except maintenance).
Live load of parallel roof truss is shown in Table 2

Table 2 Live load of parallel roof truss

Live Load(kN/m^2)	Bay Length (m)	Web Spacing (m)	Live Load (kN)	
			Intermediate Node	End Node
0.75	6	0.5	2.25	1.125
	6	1	4.5	2.25
	6	1.5	6.75	3.375

C. Wind Load (WL)

IS: 875 (Part III) – 2015 has been considered for the calculation of wind loads. Assuming the life of the industrial building to be 50 years and the land to be flat and surrounded by small buildings.

k_1 = Probability factor or risk factor= 1 [for general buildings and structures]

k_2 = Terrain, height and structure size factor = 0.998 [for terrain of category]

k_3 = Topography factor = 1 [For flat topography]

k_4 =Important factor for cyclonic region =1.15

Design wind speed, $V_z = V_b \times k_1 \times k_2 \times k_3 \times k_4$

V_b = Basic wind speed at Kozhikode, V_b= 39 metre/second

Design wind speed, V_z = 1 x 0.91x 1 x1.15× 39 = 40.365metre/second

Design wind pressure, $p_z = 0.6\ V_z^2 = 0.6(46.906)^2 = 1320\ N/m^2 = 1.320\ kN/m^2$

$P_d = k_a \times k_b \times k_c \times p_z = 1 \times .9 \times .8 \times .9775 = .704\ kN/m^2$

Eave height, h = 10 m.

Width of building, w = 30m.

h/ w = 10/ 30 = 0.6 [h/ w ≤ 1/2]

$F = (C_{pe} - C_{pi}) \times P_d \times A$

Where C_{pe} = external wind pressure coefficient and C_{pi} = internal wind pressure coefficient. A = surface area of structural element

For building having medium permeability, the internal pressure coefficient, C_{pi} is ±0.5.

External wind pressure coefficient are shown in Table 3

Table 3External wind pressure coefficient

External wind pressure coefficient				
Wind angle	0 degree		90 degree	
Wind direction	windward	leeward	windward	leeward
	-0.8	-0.8	-1.0	-0.6

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Table 4 Wind load calculation

		Wind load, F = (Cpe-Cpi) x A x P_d					
Spacing of Web		0.5m		1m		1.5m	
Nodes		Intermediate	End	Intermediate	End	Intermediate	End
Wind angle α, 0°	Windward	-2.75	-1.37	-5.49	-2.75	-8.24	-4.12
		-0.63	-0.32	-1.27	-0.64	-1.90	-0.95
	Leeward	-2.75	-1.37	-5.49	-2.75	-8.24	-4.12
		-0.63	-0.32	-1.27	-0.64	-1.90	-0.95
Wind angle α, 90°	Windward	-3.17	-1.58	-6.34	-3.17	-9.50	-4.75
		-1.06	-0.53	-2.11	-1.06	-3.17	-1.58
	Leeward	-2.32	-1.16	-4.65	-2.33	-6.97	-3.49
		-0.21	-0.11	-0.42	-0.21	-0.63	-0.32

Positive internal pressure will act towards the roof while negative internal pressure will away from the roof. Hence +ve internal pressure will be added to –ve external pressure coefficient and vice-a-versa.

V. ANALYSIS OF PARALLEL TRUSSES

The steel trusses have been analysed as simply supported on columns. The support at one end is assumed to be hinged and the other end on rollers for the purpose of analysis. Here the roof truss is analysed and designed by ETABS software. Limit State Method is adopted in the design of truss members. The truss is analysed with all joints assumed to be pinned, then all of the member's neutral axes and axial forces meet at a single point, the truss joint.Parallel chord Howe and Pratt truss with different depth (1 m, 1.5 m, and 2 m) and different web spacing (0.5m, 1m and 1.5m) were analysed.

A. Axial Forces

The comparison of axial forces of parallel chord truss are shown in Table 5,Table 6,Table 7Table 8,Table 9 and Table 10

Table 5 Parallel chord Howe truss with 0.5m web spacing

	Types of Member	Maximum Axial Force (kN)					
		1m		1.5m		2m	
		Tension	Compression	Tension	Compression	Tension	Compression
Parallel chord Howe truss (0.5m)	Bottom Chord Member	1939.42	789.14	1137.11	534.51	986.02	400.88
	Top Chord Member	796.17	1944.28	540.04	1318.16	405.03	988.62
	Inclined member	305.61	138.19	288.13	130.29	281.76	127.41
	Vertical member	126.01	278.23	126.01	278.23	126.01	278.23

Table 6 Parallel chord Howe truss with 1m web spacing

	Types of Member	Maximum Axial Force (kN)					
		1m		1.5m		2m	
		Tension	Compression	Tension	Compression	Tension	Compression
Parallel chord Howe truss (1m)	Bottom Chord Member	1896.76	858.26	1264	572.17	948.37	429.13
	Top Chord Member	872.19	1902.51	569.63	1168.34	436.03	951.26
	Inclined member	365.81	181.54	310.88	154.28	289.19	143.52
	Vertical member	128.36	258.66	128.36	258.66	128.36	258.66

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Table 7 Parallel chord Howe truss with 1.5 web spacing

	Types of Member	Maximum Axial Force (kN)					
		1m		1.5m		2m	
		Tension	Compression	Tension	Compression	Tension	Compression
Parallel chord Howe truss (1.5m)	Bottom Chord Member	1896.29	858.28	1264.19	572.17	948.14	428.84
	Top Chord Member	874.78	1897.86	583.18	1265.24	437.39	948.64
	Inclined member	457.5	226.7	359.05	177.84	317.36	157.19
	Vertical member	133.37	268.07	133.37	268.07	133.37	268.07

Table 8 Parallel chord Pratt truss with 0.5m web spacing

	Types of Member	Maximum Axial Force (kN)					
		1m		1.5m		2m	
		Tension	Compression	Tension	Compression	Tension	Compression
Parallel chord Pratt truss (0.5m)	Bottom Chord Member	1939.42	789.14	1137.11	534.51	986.02	400.88
	Top Chord Member	796.17	1944.28	540.04	1318.16	405.03	988.62
	Inclined member	100.95	223.23	130.29	288.73	127.41	281.76
	Vertical member	138.26	70.33	233.27	118.77	263.56	118.76

Table 9 Parallel chord Pratt truss with 1m web spacing

	Types of Member	Maximum Axial Force (kN)					
		1m		1.5m		2m	
		Tension	Compression	Tension	Compression	Tension	Compression
Parallel chord Pratt truss (1m)	Bottom Chord Member	1896.76	858.26	1264	572.17	948.37	429.13
	Top Chord Member	872.19	1902.51	569.63	1168.34	436.03	951.26
	Inclined member	181.54	365.81	154.28	310.87	143.51	289.19
	Vertical member	239.78	118.20	239.78	118.20	239.78	118.20

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Table 10 Parallel chord Pratt truss with 1.5m web spacing

	Types of Member	Maximum Axial Force (kN)					
		1m		1.5m		2m	
		Tension	Compression	Tension	Compression	Tension	Compression
Parallel chord Pratt truss (1.5m)	Bottom Chord Member	1896.29	858.28	1264.19	572.17	948.14	428.84
	Top Chord Member	874.78	1897.86	583.18	1265.24	437.39	948.64
	Inclined member	226.7	547.7	177.84	359.05	157.19	317.36
	Vertical member	225.56	110.51	225.56	110.51	225.56	110.51

The axial forces of top chord and bottom chord members of Pratt and Howe trusses are similar. Dominant wind direction can generally be determined whether the member is in tension or in compression. The top chord and inclined members of a Pratt and Howe trusses are compression member and bottom chord and vertical members of a Pratt and Howe trusses are tension member.Maximum axial forces are for bottom Chord Member with minimum truss height. The axial forces of member can be minimizing through increasing truss height. There is no variation in axial force of vertical member even if there is a change in truss height but a slight increase when web spacing of web increases.When increasing the web distance, increasing the axial force of inclined web members. Stability in terms of resisting axial force is more for Howe type trusses with more depth.In Howe truss, The vertical web members at each panel point extend from the top chord to bottom chord and are in compression. This is very economical due to the longestweb members are in tension and the shortest web members are in compression. Essentially it isthe opposite of Pratt truss.

B. **Effect of Section and cost analysis**

The least steel required truss is more economical and it is an optimised design for long span.for analysis. The section properties are assigned using ETABS software, and cost analysis are done based on market price of steel that is 90 rupees per kilogram. The truss models are comprised of different steel sections like I section, Angle section and Pipe section.Table 11,Table 12,Table 13,Table 14Table 15 and Table 16 shows the weight and cost analysis of parallel chord Howe trusses with different sections.

Table 11 Parallel Howe Truss with 0.5m web spacing

Truss Member	Parallel Howe Truss								
	1m height			1.5m height			2m height		
	I Section	Angle Section	Pipe Section	I Section	Angle Section	Pipe Section	I Section	Angle Section	Pipe Section
Bottom Chord Member	ISHB-250-2	ISA 200×200×25	ISNB350H	ISHB-200-1	ISA 150×150×18	ISNB225H	ISHB150-1	ISA 150×150×15	ISNB175H
Top Chord Member	ISHB-250-3	ISA 200×200×25	ISNB350H	ISHB200-1	ISA 150×150×15	ISNB225H	ISHB150-1	ISA 150×150×15	ISNB175H
Web Member	ISMB100	ISA 100×100×12	ISNB50L	ISMB125	ISA 90×90×10	ISNB80M	ISLB175	ISA 100×100×12	ISNB90L
Weight(kg)	4422.42	6246.72	4809.33	4387.28	4479.21	3461.73	5447.26	6169.61	3612.96
Cost (INR)	398018	562205	432840	394855	403129	311556	490253	555265	325166

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Table 12 Parallel Howe Truss with 1m web spacing

Truss Member	Parallel Howe Truss								
	1m height			1.5m height			2m height		
	I Section	Angle Section	Pipe Section	I Section	Angle Section	Pipe Section	I Section	Angle Section	Pipe Section
Bottom Chord Member	ISHB-250-1	ISA 200×200×25	ISNB350H	ISHB150-3	ISA 150×150×18	ISNB225H	ISHB150-1	ISA 150×115×15	ISNB175H
Top Chord Member	ISHB-250-1	ISA 200×200×25	ISNB350H	ISHB150-3	ISA 150×150×15	ISNB225H	ISHB150-1	ISA 130×130×15	ISNB175H
Web Member	ISMB100	ISA 80×80×8	ISNB80H	ISMB100	ISA 90×90×10	ISNB80M	ISMB200	ISA 100×100×12	ISNB80M
Weight (kg)	3747.72	4944.44	3557.99	3124.77	3440.16	2833.79	3589.16	3950.66	2730.76
Cost (INR)	337295	445000	320219	281229	309614	255041	323024	355559	245768

Table 13 Parallel Howe Truss with 1.5m web spacing

Truss Member	Parallel Howe Truss								
	1m height			1.5m height			2m height		
	I Section	Angle Section	Pipe Section	I Section	Angle Section	Pipe Section	I Section	Angle Section	Pipe Section
Bottom Chord Member	ISHB-250-2	ISA200×200×25	ISNB350H	ISHB200-1	ISA200×150×18	ISNB225H	ISHB150-1	ISA 150×150×15	ISNB200L
Top Chord Member	ISHB250-1	ISA200×200×25	ISNB350H	ISHB150-3	ISA200×100×15	ISNB225H	ISHB150-1	ISA130×130×15	ISNB175H
Web Member	ISLB175	ISA100×100×10	ISNB100M	ISLB175	ISA100×100×10	ISNB90M	ISMB200	ISA100×100×12	ISNB90L
Weight (kg)	3933.47	5122.42	4648.83	3262.73	3429.93	2724.78	3110.16	3181.14	2330.04
Cost (INR)	354012	461018	418395	293646	308694	245230	279914	286303	209704

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Table 14 Parallel Pratt Truss with 0.5m web spacing

Truss Member	Parallel Pratt Truss								
	1m height			1.5m height			2m height		
	I Section	Angle Section	Pipe Section	I Section	Angle Section	Pipe Section	I Section	Angle Section	Pipe Section
Bottom Chord Member	ISHB-350-1	ISA200×200×25	ISNB350H	ISHB200-1	ISA 150×150×18	ISNB225H	ISHB150-1	ISA 150×150×15	ISNB175H
Top Chord Member	ISHB-350-1	ISA200×200×25	ISNB350H	ISHB200-1	ISA 160×160×15	ISNB225H	ISHB150-1	ISA 150×150×15	ISNB175H
Web Member	ISLB125	ISA110×110×12	ISNB90L	ISLB150	ISA10×100×10	ISNB80M	ISMB175	ISA100×100×12	ISNB90M
Weight(kg)	4994.96	6446.84	3757.01	4547.8	4747.8	3461.73	6087.51	6161.61	3844.37
Cost (INR)	449546	580216	338131	409302	427302	311556	547876	554545	345993

Table 15 Parallel Pratt Truss with 1m web spacing

Truss Member	Parallel Pratt Truss								
	1m height			1.5m height			2m height		
	I Section	Angle Section	Pipe Section	I Section	Angle Section	Pipe Section	I Section	Angle Section	Pipe Section
Bottom Chord Member	ISHB-250-1	ISA 200×200×25	ISNB300H	ISHB150-3	ISA150×150×18	ISNB225H	ISHB150-1	ISA 130×130×15	ISNB175M
Top Chord Member	ISHB-250-1	ISA 200×200×25	ISNB300H	ISHB150-3	ISA 150×150×18	ISNB225H	ISMB200	ISA 130×130×15	ISNB175M
Web Member	ISLB175	ISA100×10012	ISNB90H	ISMB175	ISA100×100×12	ISNB90H	ISLB200	ISA110×110×12	ISNB90H
Weight(kg)	4019.14	5498.5	3557.99	3837.98	4055.76	3128.47	3971.09	4173.15	2909.69
Cost(INR	361722.6	494865	320219.1	345418.2	365018.4	281562.3	357398.1	375583.5	261872.1

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Table 16 Parallel Pratt Truss with 1.5m web spacing

Truss Member	1m height			1.5m height			2m height		
	I Section	Angle Section	Pipe Section	I Section	Angle Section	Pipe Section	I Section	Angle Section	Pipe Section
Bottom Chord Member	ISHB-250-2	ISA 200×200 ×25	ISNB350 H	ISHB200 -1	ISA 200×150 ×18	ISNB225 H	ISHB150 -2	ISA 150×150 ×15	ISNB20 0L
Top Chord Member	ISHB250 -1	ISA 200×200 ×25	ISNB350 H	ISHB150 -3	ISA 200×150 ×18	ISNB225 H	ISHB150 -2	ISA 130×130 ×15	ISNB17 5H
Web Member	ISMB20 0	ISA 110×110 ×15	ISNB110 L	ISMB20 0	ISA 110×110 ×12	ISNB100 M	ISMB20 0	ISA 110×110 ×15	ISNB10 0L
Weight(kg)	4303.13	5635.24	4712.03	3884.09	4162.95	2901.65	3891.35	4025.07	2424.7
Cost (INR)	387281.7	507171.6	424082.7	349568.1	374665.5	261148.5	350221.5	362256.3	218223

It is observed that, Pipe section is comparatively economical and angle section is heavier and thereby costlier. Howe truss configuration is best and it is economical as the least steel take-off.The size of steel section can be minimising by increasing depth truss.

VI. RESULT AND DISCUSSION

The results of various analyses for different trusses with 30m span are compared for optimization of truss design. The least steel required truss is more economical and it is an optimised design for long span.Fig.2 shows a bar-chart graph of Howe and Pratt parallel chord truss.

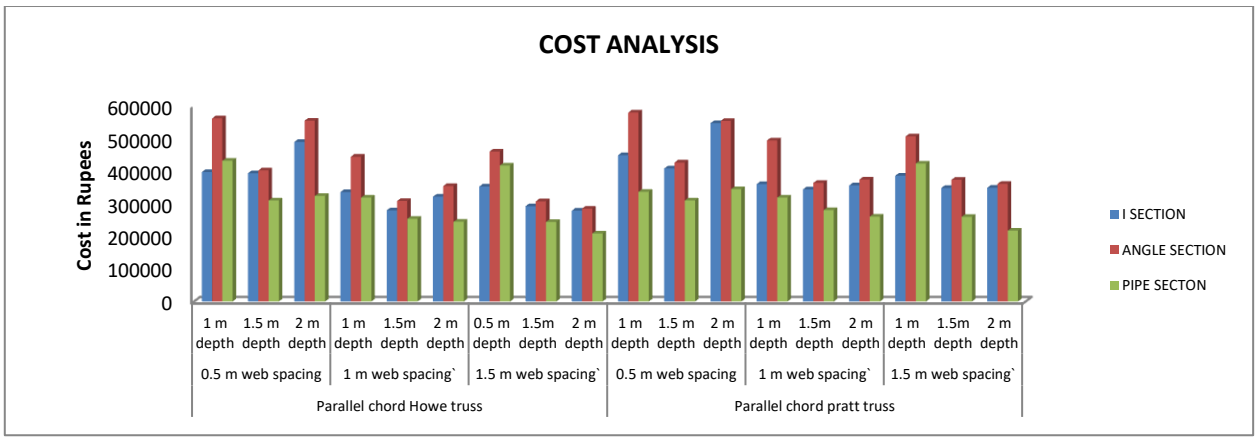

Fig. 2 cost analysis

From the analysis result,it is observed that Howe-type truss configuration with 1.5 m web spacing and 2m height gives economical design.

VII. CONCLUSION

The following conclusions were drawn out considering critical load combinations.

- The size of steel section can be minimising by increasing depth truss.

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- In parallel chord roof truss, stability in terms of resisting axial force is more in Howe type truss arrangement and Howe configuration is having lesser weight compared to Pratt truss geometry.
- When web spacing increases, the stress at inclined web member also increases.
- Dominant wind direction can generally be determined whether the member is in tension or in compression.
- A significant reduction in cost of truss is found by using pipe Section compared to angle section and I section.
- Howe truss with pipe section saves about 4%of material's weight than Pratt truss with pipe section.
- Howe truss with I section is approximately 29.5% economical than Pratt truss with I section.
- Pratt truss with angle section required about 26% more steel than Howe truss with angle section.

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