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Selection of Appropriate Roof Truss Configuration for an Industrial Shed

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Abstract

With the industrial development in recent years, the need of huge industrial sheds has increased where structural optimization & cost are the two major aspects of design. Trusses are triangular formations of steel sections in which the members are generally, subjected to axial forces due to external load. For industrial sheds, the truss configurations commonly used are Pratt, Howe, Warren and Fink truss. All of these truss configurations have their own structural advantages depending upon shapes and member arrangements. The aim of this study is to compare these trusses to select the optimal truss configuration for a particular span of 30m. The length of the bottom chord members of trusses are varied keeping the overall truss height, inclination angle, span, structure length, spacing and external load same, for all configurations. The analysis has been conducted using Tekla software. It is observed that Howe truss configuration with 12 divisions of bottom chord provide best selection based on weight of truss and connections. This paper helps the designer to select an appropriate truss of span 30m, considering the safety, self-weight, truss configuration and economical point of view.

Keywords: *Steel truss, Truss Configuration, Pratt, Howe, Fink, Warren, Tekla software*

1. Introduction

The use of shed in industrial buildings dates back to 19th century during industrial revolution [1]. Since then the construction of industrial buildings has increased paving the way for increased number of researches in the field of optimal design configuration. The industrial structures commonly used are warehouses, factories, godowns, workshops, storage plants, etc [2]. One of the main component of these structures are the shed which deals with gravity loads and lateral loads. There are mainly three types of frame structures used for the construction of industrial sheds, a) Truss frame structure b) Space frame structure c) Portal frame structure [1]. Among them truss frame structure is the most commonly used. It has several advantages over other structures. Due to its triangulation formation only two forces are developed, one is the tension force and other is compression force [2, 3]. Generally other forces such as shear force, bending moment are not developed in the truss members, due to triangular action, which makes the design economic [3, 4]. When it comes to the selection of material, steel is the most commonly used material since it can resist high tensile and compressive stress and is cost efficient due to its high strength to weight ratio [3]. Steel structures are also resistance to fire and pest infestation, unlike timber. The fabricated steel structures are 90% recyclable [2]. Depending upon the size, length, section and number of members, the cost of the truss varies. The members of a truss can be divided into five categories a) top chord b) bottom chord c) Struts d) slings e) sag tie [6]. Most commonly used truss configurations are the Pratt, Howe, Fan, Warren and Fink. Pratt is one of the oldest truss configuration which is been used in sheds of several railway station and warehouses. Howe truss configuration is very similar to Pratt, but the nature of forces in the members are opposite to it [8]. Warren truss, also known as equilateral truss, has the combined speciality of both Pratt & Howe truss as it can perform well under tensile and compressive forces [9]. Fink truss is also very popular due to its special member configuration which helps in providing high design strength in case of short span structures. This configuration, later has been modified & been known as Fan truss [10]. Cost of any industrial shed depend on the material being consumed to fabricate the truss, which is governed by arrangement of the members, type of sections used, length of the members and number of members for the chosen truss configuration.

Generally, a lot of open space and long spans are required in industrial sheds. Wastage of material are more in case of larger span of trusses, due to lengthier internal members & heavier sections. Therefore, structural optimization is required more in case of large span trusses rather than for small span truss. Recent trend shows that the industrial sector is approaching towards more economic and structurally optimized designs. Practical industrial sheds are

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usually around 30m span and it is reasonably long to be optimized. To meet that demand as a structural engineer, while selecting the truss for an industrial shed, look for the best available alternatives by studying the existing trusses. As per authors' knowledge, no proper comparison or study is available which gives an idea about how the cost is affected when the numbers of members in a particular truss is varied. In order to achieve the optimized truss configuration there is a requirement of comparative study, which will give the designer different alternatives while selecting an appropriate truss configuration for an industrial shed. Hence, the objective of this study is to select an appropriate truss considering (i) Truss Configuration, (ii) No. of divisions in bottom chord members, (iii) Self-weight of the truss (iv) Economical point of view for an industrial shed of span 30m.

2. Different configuration of industrial truss

2.1 Howe Configuration

Howe truss was first designed by William Howe in the year of 1840[8]. Howe and Pratt truss looks similar. But there is a big difference in geometrical as well as structural aspect. Diagonals are inclined away from the centre of the span [4, 5].

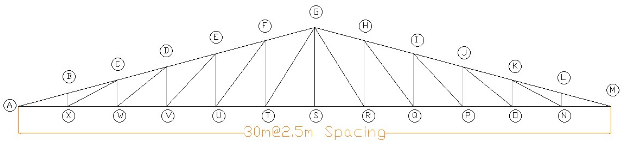

Fig.2 Howe Truss Arrangement

Construction of Howe truss is easy and they are stable [13]. Maximum number of member can be utilized to transmit the load in case of Howe than Pratt truss [5]. Howe truss length must be within 46m or less . First truss bridge that was constructed using Howe truss 23 m long bridge in Connecticut [13].

2.1 Pratt Configuration

Pratt truss is the one of the oldest truss configuration that was first developed by Thomas and Celeb Pratt in year 1844 [7]. Its configuration mainly consists of diagonal and vertical members. All the diagonal members are leaning downwards toward the centre of the span except end diagonal members [6].

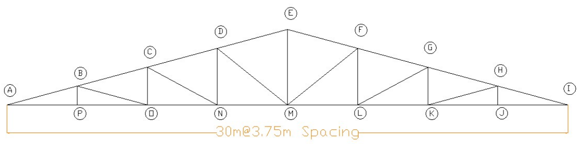

Fig.1 Pratt Truss Arrangement

Due to the simple design, fabrication is easy and cost efficient [5]. Its effective and efficient only when loads are static and vertically in nature [4, 5]. Pratt truss configuration was used in The Southern Pacific Railroad Bridge in Tempe, Arizona [12].

2.4 Warren Configuration

Warren Truss was designed James Warren and Willoughby Theobald Monzani in the year of 1848 [10]. This truss is triangular in shape but inverted. It consists of diagonal members, top chord and bottom chord. Alternate Diagonal members are subjected to compression and tension respectively toward the central triangle [4]. Top chord is subjected to compression whereas the bottom chord is in tension [5].

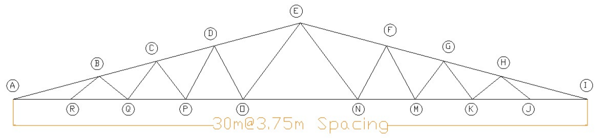

Fig.3 Warren Truss Arrangement

Loads gets distributed evenly between all the members [5]. As there is no vertical members present bulking and sagging might occur in bottom chord which destabilizes the structure [6]. Warren truss was used in Wills Creek Bollman Bridge by Wendel Bollman (1871) [14].

2.4 Fink Configuration

Fink truss was first developed by Albert fink in the year 1854 [11]. Truss configuration consist of top chord, bottom chord, struts, slings and sag tie. Both top chord and struts are subjected to compressive force whereas slings and bottom chords are subjected to tension force. Sag tie has no forces acting on them as they are provided to reduce the sagging in the bottom chord [6].

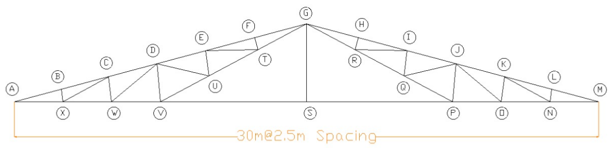

Fig.4 Fink Truss Arrangement

The loads get distributed evenly all over the truss without exerting any extra stress to the members, and is transferred to the supports easily [5, 15]. Fink truss was first used to build the Baltimore and Ohio Railroad in the year 1852 [16].

3. Numerical Study

In order to achieve the objective, an industrial shed of 30m span has been considered, which is located at Bhubaneswar, incorporating all the practical data like wind speed and seismic zone. Sixteen different truss configurations of Howe, Pratt, Warren & Fink trusses were modelled, analysed and designed to compare the design results in terms of materials being consumed by each of them. The pitch height for all the configurations is taken as 3 meter. To perform the optimization, the bottom chord members of each truss are divided into 6, 8, 10 & 12 equal parts as shown in Table 1.

3.1 Load Consideration

The loads considered for the study are dead load, live load, wind load and seismic load. Dead load on the roof trusses of the industrial sheds consists of self-weight of claddings, purlins, bracings and the truss members such as top chord, bottom chord & internal truss members. Following unit weights are considered during this study[17]. The live load on roof trusses consist of the gravitational load during to erection and servicing period of the structure as well as dust load etc. and the maximum intensity among these is taken as 2 kN/m^2 on the roof of the truss as per IS:875 (Part II) - 1987[18].

Due to the suction effect of the wind blowing over the roof, the wind load on the roof trusses would be usually uplift force perpendicular to the roof, unless the roof slope is too high. Wind load is considered as per IS 875- part III. For calculation of wind load for the location of Bhubaneswar, the following parameters were considered[19].

Basic wind speed: 50 m/s
Probability factor or risk coefficient (K1): 1 (for 50 years)
Terrain category factor (K2): 0.946 (Category 3)
Topography factor (K3): 1 (for plain land)
Cyclonic Importance Factor (K4): 1.15 (Industrial Structure)

As per IS 1893:2016 the parameters considered for earthquake analysis are as following[20],

Seismic Zone : 3
Soil Type : Medium
Importance Factor : 1
Damping : 5%

Load combinations for design purposes should be those that produce maximum forces and effects consequently maximum stresses and deformations. The following combination of loads with appropriate partial safety factors were considered during analysis of the structure:

- 1.5 DL
- 1.5 (DL + IL)
- 1.5 (DL ± WL)
- 1.5 (DL ± EL)
- 1.2 (DL ± IL ± WL)
- 1.2 (DL ± IL ± EL)
- 0.9 DL + 1.5 WL (0º)
- 0.9 DL + 1.5 WL (90º)
- 0.9 DL + 1.5 WL (270º)
- 0.9 DL + 1.5 WL (360º)

(DL = Dead Load, IL = Imposed Load, WL = Wind Load, EL = Earthquake Load)

Table 1 : List of Truss Models prepared

Truss Type	Division of bottom chord members	Model number
Howe	6	model 1
	8	model 2
	10	model 3
	12	model 4
Pratt	6	model 5
	8	model 6
	10	model 7
	12	model 8
Warren	6	model 9
	8	model 10
	10	model 11
	12	model 12
Fink	6	model 13
	8	model 14
	10	model 15
	12	model 16

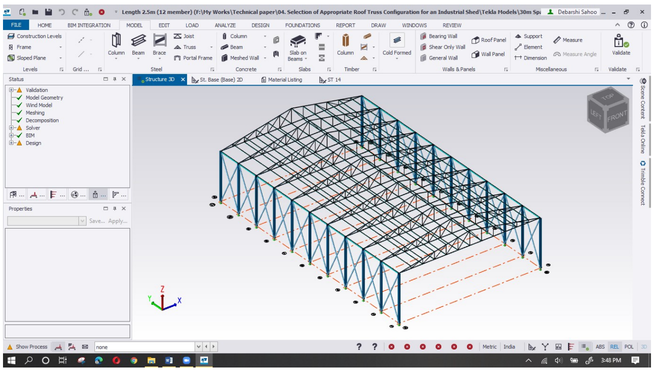

Fig.5 Modelling of Howe truss in Tekla Software
Table 1 : List of Truss Models prepared

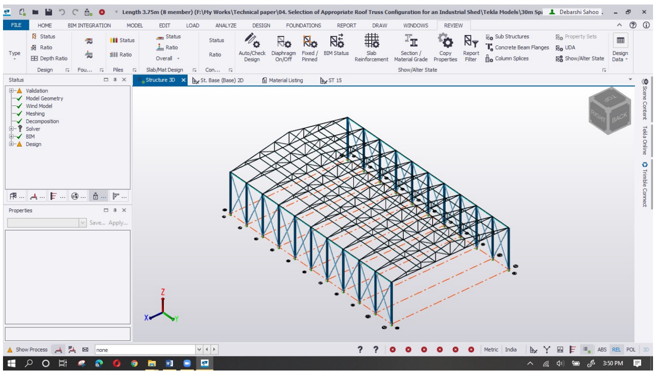

Fig.6 Modelling of Pratt truss in Tekla Software

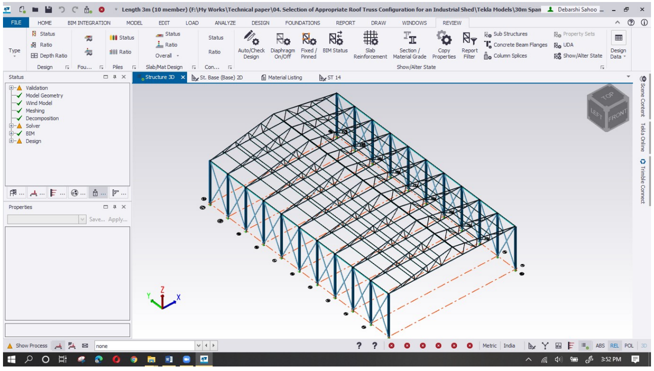

Fig.7 Modelling of Warren truss in Tekla Software

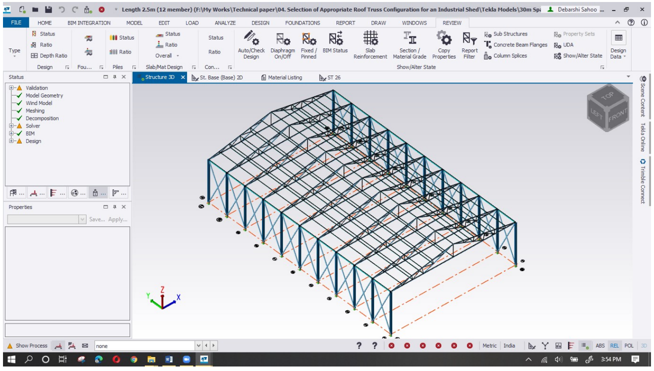

Fig.7 Modelling of Warren truss in Tekla Software

3.2 Analysis & Design

It is really common for any engineer to use different specialized software for analysis of concrete and steel frames, design of slabs and foundation and so on. Tekla is a revolutionary software and one of a kind in which modelling, analysis and design can be done under one platform. Some of the sophisticated features include BIM integrated model, automated load calculation, analysis based on codal provisions and automated section design. Due to these features, the tekla software has been considered for this study.
The 16 different truss models mentioned in Table 1 has been analysed in Tekla Structural Designer. Modelling of Howe, Pratt, Warren and Fink trusse, in Tekla are shown in Fig.5, Fig.6, Fig.7 and Fig.8 respectively, one from each type of truss.

To determine the optimal division of bottom chord members of each type of truss, figures 9, 10, 11 and 12 are plotted against the total weight of the truss for Pratt, Howe, Warren and Fink respectively. It is observed from the figures that 12 divisions for Howe, 8 divisions for Pratt, 10 divisions for Warren and 12 divisions for Fink truss are providing minimum truss weight for that type of truss. Hence, the trusses with these divisions of bottom chord are considered as optimized one for that type of truss. The details like member forces, members assigned etc. of these optimized configurations are shown in Table 2.

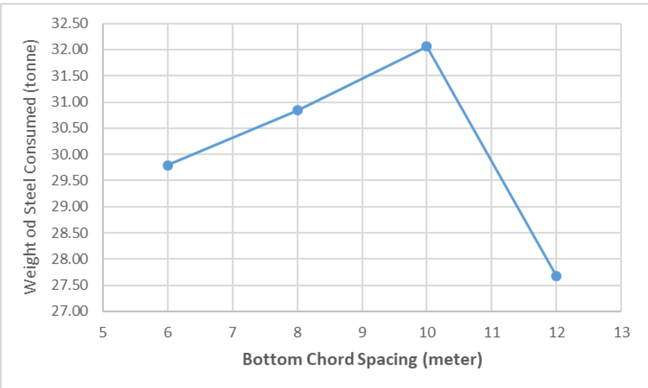

Fig.9 Comparison of different Howe Truss Arrangement

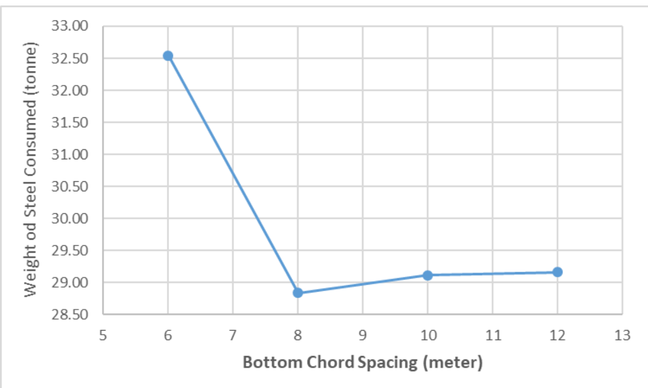

Fig.10 Comparison of different Pratt Truss Arrangement

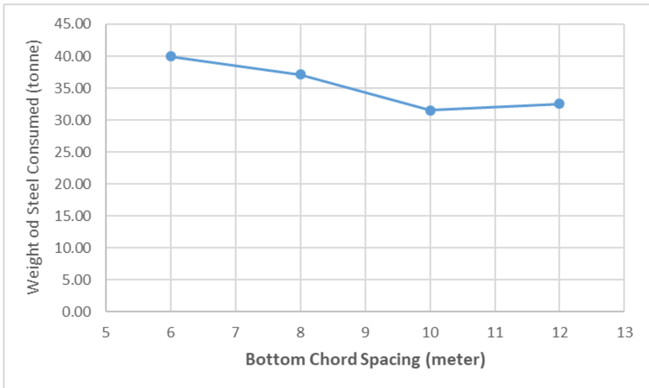

Fig.11 Comparison of different Warren Truss Arrangement

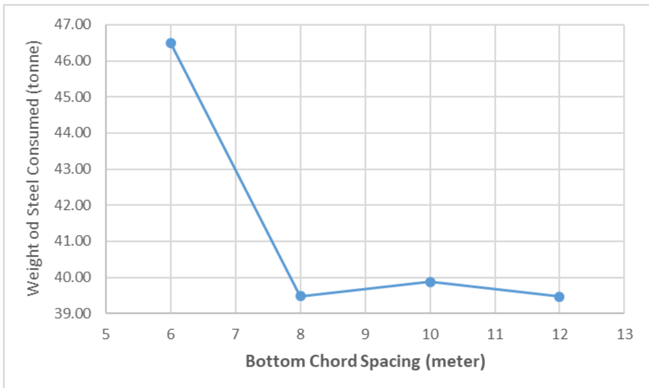

Fig.12 Comparison of different Fink Truss Arrangement

Table 2 : Design Table of the optimized trusses

Type of Truss	Member type	Member marked	Member Length (m)	Max. Compression (kN)	Max. Tension (kN)	Assigned Section
Howe Truss Model 4 (Fig.1)	Top Chord	AB, ML	2.587	36.04	1090.03	ISA 100X100X10
		BC, LK	2.587	42.31	1081.62	ISA 100X100X10
		CD, KJ	2.587	55.87	1066.79	ISA 100X100X10
		DE, JI	2.587	69.53	1034.08	ISA 100X100X10
		EF, IH	2.587	74.04	1012.52	ISA 100X100X10
		FG,HG	2.587	78.92	982.13	ISA 100X100X10
	Bottom Chord	AX, MN	2.5	1127.57	259.27	ISA 100X100X10
		XW, NO	2.5	1110.18	281.42	ISA 100X100X10
		WV, OP	2.5	1098.97	290.01	ISA 100X100X10
		VU, PQ	2.5	1078.68	302.06	ISA 100X100X10
		UT,QR	2.5	1065.44	327.76	ISA 100X100X10
		TS, SR	2.5	1054.55	351.78	ISA 100X100X10
	Internal members	BX, LN	.5	9.5	47.89	SHS 72x72x4
		CX,KN	2.69	103.58	20.8	SHS 72x72x4
		CW, KO	1	14.01	75.15	SHS 72x72x4
		DW,JO	2.92	162.02	25.66	7.57SHS 72x72x4
		DV, JP	1.5	9.95	107.29	SHS 72x72x4
		EV,IP	3.20	173.42	13.33	SHS 72x72x4
		EU, IQ	2	5.93	131.9	SHS 72x72x4
		FU,HQ	3.54	190.53	6.03	SHS 72x72x4
		FT,HR	2.5	12.68	166.06	SHS 72x72x4
		GT,GR	3.90	217.65	14.87	SHS 72x72x4
		GS	3	4.39	0	SHS 72x72x4
Pratt Model 6 (Fig.2)	Top Chord	AB, IH	3.824	21.68	1048.78	ISA 100X100X12
		BC,HG	3.824	28.67	1023.66	ISA 100X100X12
		CD,GF	3.824	32.44	1005.03	ISA 100X100X12
		DE,FE	3.824	37.75	993.83	ISA 100X100X12
	Bottom chord	AP, IJ	3.75	1391.55	185.44	ISA 100X100X12
		PO,JK	3.75	1379.74	175.04	ISA 100X100X12
		ON,KL	3.75	1353.09	159.01	ISA 100X100X12
		NM,LM	3.75	1329.88	143.22	ISA 100X100X12
	Internal member	BP, HJ	0.75	3.4	15.70	SHS 92x92x5.4
		BO, HK	3.824	14.83	85.7	SHS 92x92x5.4
		CO, GK	1.5	32.33	1.27	SHS 92x92x5.4
		CN, GL	4.039	9.9	245.06	SHS 92x92x5.4
		DN, FL	2.25	89.11	0	SHS 92x92x5.4
		DM, FM	4.373	7.28	255.64	SHS 92x92x5.4
		EM	3	275.94	0	SHS 92x92x5.4
Warren Model 11 (fig-3)	Top chord	AB, KJ	3	29.6	1487.25	ISA 110x110x12
		BC, JI	3	36.88	1472.09	ISA 110x110x12
		CD, IH	3	42.05	1459.2	ISA 110x110x12
		DE, HG	3	53.91	1447.44	ISA 110x110x12
		EF, GF	3	61.26	1428.05	ISA 110x110x12
	Bottom chord	AS, KL	3	1452.81	249.71	ISA 110x110x12
		SR, LM	3	1438.08	257.64	ISA 110x110x12
		RQ, MN	3	1425.77	269.04	ISA 110x110x12
		QP, NO	3	1410.4	277.5	ISA 110x110x12
		PO	6	1202.93	254.61	ISA 110x110x12

Warren Model 11 (fig-3)	Internal members	BS, JL	0.773	11.42	59.92	SHS 72x72x4
		CS, IL	3	135.73	23.53	SHS 72x72x4
		CR, IM	1.546	13.6	91.5	SHS 72x72x4
		DR, HM	3.285	179.01	21.8	SHS 72x72x4
		DQ, HN	2.319	3.19	125.43	SHS 72x72x4
		EQ, GN	3.712	184.69	2.14	SHS 72x72x4
		EP, GO	3.092	12.23	164.14	SHS 72x72x4
		FP, FO	5	216.15	12.61	SHS 72x72x4
Fink Model 16 (fig-4)	Top chord	AB, ML	2.5	187.25	1498.85	ISA 130x130x12
		BC, LK	2.5	194.92	1482.93	ISA 130x130x12
		CD, KJ	2.5	203.66	1452.06	ISA 130x130x12
		DE, JI	2.5	216.79	1441.69	ISA 130x130x12
		EF, IH	2.5	223.84	1421.02	ISA 130x130x12
		FG,HG	2.5	237.62	1417.94	ISA 130x130x12
	Bottom chord	AX, MN	2.5	1464.12	69.94	ISA 130x130x12
		XW, NO	2.5	1457.66	72.31	ISA 130x130x12
		WV, OP	2.5	1441.07	78.69	ISA 130x130x12
		VS, PS	2.5	1436.92	84.58	ISA 130x130x12
	Internal members	BX, LN	0.492	9.76	41.7	SHS 64x64x4.5
		CX,KN	2.595	68.53	22.24	SHS 64x64x4.5
		CW, KO	.985	13.5	69.34	SHS 64x64x4.5
		DW,JO	2.776	148.15	21	SHS 64x64x4.5
		DV, JP	1.478	4.26	162.2	SHS 64x64x4.5
		DU,JQ	2.687	141.37	19.4	SHS 64x64x4.5
		EU,IQ	0.985	11.39	72.12	SHS 64x64x4.5
		ET,IR	2.597	80.58	12.42	SHS 64x64x4.5
		FT,HR	0.49	6.9	41.76	SHS 64x64x4.5
		GS	3	9.87	0	SHS 64x64x4.5
	Side members	GT,GR	2.692	634.3	31.32	SHS 125x125x6
		TU,RQ	2.692	622.73	34.25	SHS 125x125x6
		UV,QP	2.692	614	36.83	SHS 125x125x6

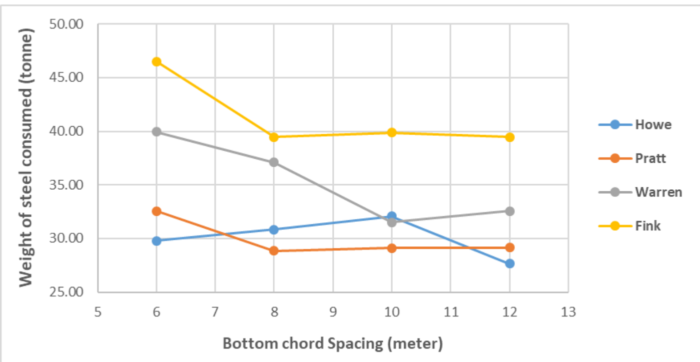

Fig.13 Performance of different types of truss based on number of divisions of bottom chord.

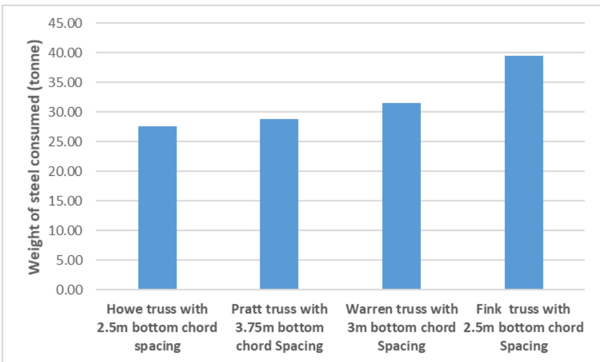

Fig.14 Comparison of total truss weight among the optimized truss configurations.

4. Discussion

From the numerical study it is observed that, bottom chord divisions of 12, 8, 10 and 12 are providing optimal weight of truss for Howe, Pratt, Warren and Fink configurations respectively. For direct comparison between these trusses Fig. 13 has been plotted. From Fig.14, it can be deduced that Howe truss with 12 bottom chord divisions providing the best configurations for 30m span considering the weight of truss, which includes both member and connection weight.

5. Conclusion

Different truss configurations were considered in this study to select the appropriate truss configurations for an industrial shed of 30m span. Sixteen different models of Howe, Pratt, Warren and Fink truss were analyzed and designed using commercial Tekla software. The following conclusions are drawn from this study,

1. The performance of Howe truss is optimal, when the bottom chord is divided into 12 equal parts. Total weight of the truss for this case is 27.67 tonne.
2. Eight divisions of bottom chord is found to be best for Pratt truss configuration, resulting into a total truss weight of 28.83 tonne.
3. Warren truss is proving to be best with 10 numbers of division in the bottom chord, resulting into a total steel consumption of 31.51 tonne.
4. Fink truss with 12 division is best among its other alternative arrangements with a truss weight of 39.46 tonne.

Considering the parameters considered in this study, like Truss Configuration, No. of divisions in the bottom chord, Self-weight of truss and Economic point of view, it can be concluded that Howe truss with 12 bottom chord divisions is the most appropriate truss, for an industrial shed of 30m span.

Disclosures

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