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A COMPARATIVE STUDY ON PERFORMANCE OF CONVENTIONAL AND PRE–ENGINEERED STEEL FRAMES

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Abstract— Conventional steel frames are low rise steel frames with roofing systems of truss and roof coverings. Standard hot rolled sections are used for truss elements which are usually much heavier than what is actually required as per the design. Pre–Engineered steel frames are the steel frames in which excess steel is tapered as per the bending moment requirements. In the present study, conventional (i.e. Pratt truss) and Pre–Engineered (i.e. portal type) industrial steel frames are considered for an industrial building located at Davangere City. Dead Load (DL), Live Load (LL) and Wind Load (WL) are applied on both the frames as per IS 875–Part 1 (1987), IS 875–Part 2 (1987) and IS 875–Part 3 (2015) codal provisions respectively. The developed 2D models of Conventional and Pre–Engineered steel frames are analysed using STAAD Pro. software for various load combinations as specified by IS 800 (2007). The members of both the frames are designed for the worst load combination as per IS 800 (2007) codal provisions. Total mass of the steel required for both the conventional and Pre–Engineered steel frames is calculated and cost comparison is made to check the economy achieved in using Pre– Engineered steel frames over the conventional steel frames. About 90,000 Rs. saving in material cost is obtained by erecting the Pre–Engineered steel frames than the conventional steel frames. Thus Pre–Engineered steel frames are preferred over the conventional steel frames.

I. INTRODUCTION

Steel structures are the most suitable choice in industries as they require large column free open spaces for operation. Steel is strong, tough, hard, fire resistant, ductile and also has very high melting point. The design of industrial steel structures include designing of the structural elements such as principal rafter, columns and column base, bracings, tie rods, gantry girder, purlins, sag rods etc. The use of steel structures is not only economical but also eco–friendly as there is a threat of global warming due to huge construction of concrete structures. The demand of steel for construction is increasing day by day over RCC as steel offers better tension and compression resulting in lighter construction. Steel structures have much better strength–to–weight ratio than RCC structures and can be easily dismantled and shifted or further expanded as per the requirements in future.

Conventional steel frames are low rise steel frames with roofing systems of truss and roof coverings. Standard hot rolled sections are used for truss elements which are usually much heavier than what is actually required as per the design. Pre–Engineered steel frames are the steel frames in which excess steel is tapered as per the bending moment requirements**.**Tapered I sections, hot rolled sections and cold form sections are used to achieve this arrangement. Pre–Engineered steel frames are fully fabricated in factories and are carried to the location as per the requirement. These structures are erected on the site by bolting the various components together as per the specifications.

II. PROBLEM STATEMENT

In the present paper, conventional (i.e. Pratt truss) and Pre–Engineered (i.e. portal type) industrial steel frames are considered for an industrial building located at Davangere City. Dead Load (DL), Live Load (LL) and Wind Load (WL) are applied on both the frames as per IS 875–Part 1 (1987), IS 875–Part 2 (1987) and IS 875–Part 3 (2015) codal provisions respectively. The developed 2D models are analysed using STAAD Pro. software for various load combinations as specified by IS 800 (2007) codal provisions. The members of both the frames are designed for the worst load combination as per IS 800 (2007). The total mass of steel required for both the conventional and Pre–Engineered steel frames is calculated and cost comparison is made to check the economy achieved in using Pre– Engineered steel frames over the conventional steel frames.

III. PARAMETERS CONSIDERED FOR MODELLING

Conventional and Pre–Engineered steel frames suitable for Davangere city is considered for modelling in STAAD Pro. software. Table 1 shows the details of conventional and Pre–Engineered steel frames. Figure 1 shows the plan details of Conventional and Pre–Engineered steel frames.

Table 1 : Details of conventional and Pre–Engineered steel frames

Sl. No.	Parameter	Dimension	Remarks
1	Plan dimension	20 x 50 m	–
2	Height of supporting columns	8 m	–
3	Rise of frame	3 m	–
4	Spacing of frames	5 m	Truss spacing in the range 1/4th to 1/5th of span length (i.e. 20m)
5	Slope of roof	16.69^0	$\tan^{-1}\left(\frac{rise}{half\ of\ span\ length}\right)$
6	Number of bays	10	$\frac{Length}{Spacing}$
7	Type of roofing	–	Galvanized Iron Sheeting
8	Spacing of purlins	2.61 m	$\frac{Slant\ roof\ length}{No.of\ nodes}$
9	Type of support condition for columns	–	Hinged
10	Type of Truss	–	Pratt
11	Type of Pre– Engineering Frame	–	Portal type

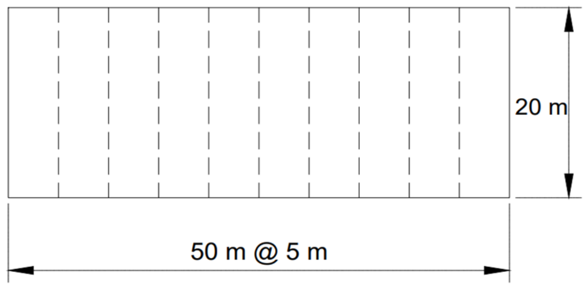

Fig. 1 : Plan of Conventional and Pre–Engineered steel frames

IV. CALCULATION OF LOADS ACTING ON CONVENTIONAL AND PRE–ENGINEERED STEEL FRAMES

Calculation of Dead Load (DL)

Dead loads acting on the frames are calculated as per IS 875–Part 1 (1987) which includes the loads of roofing materials, purlins and trusses. Figures 2 and 3 respectively show the application of dead loads acting at the purlin positions of conventional and Pre–Engineered steel frames.

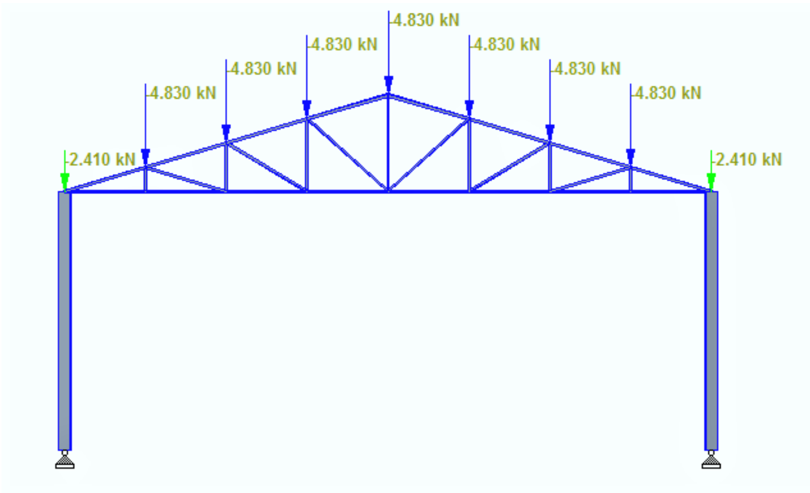

Fig. 2 : Dead loads acting at the purlin positions of conventional steel frame

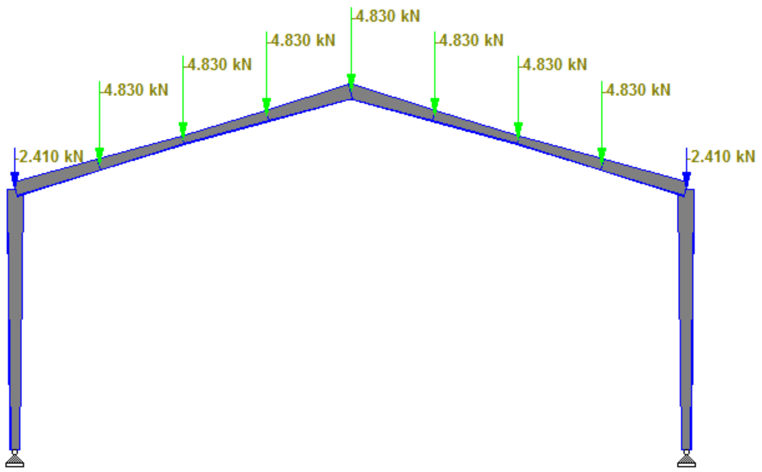

Fig. 3 : Dead loads acting at the purlin positions of Pre–Engineered steel frame

a. Calculation of Live Load (LL)

Live loads acting on the frames is calculated as per IS 875–Part 2 (1987). Figures 4 and 5 respectively show the application of live loads acting at the purlin positions of conventional and Pre–Engineered steel frame.

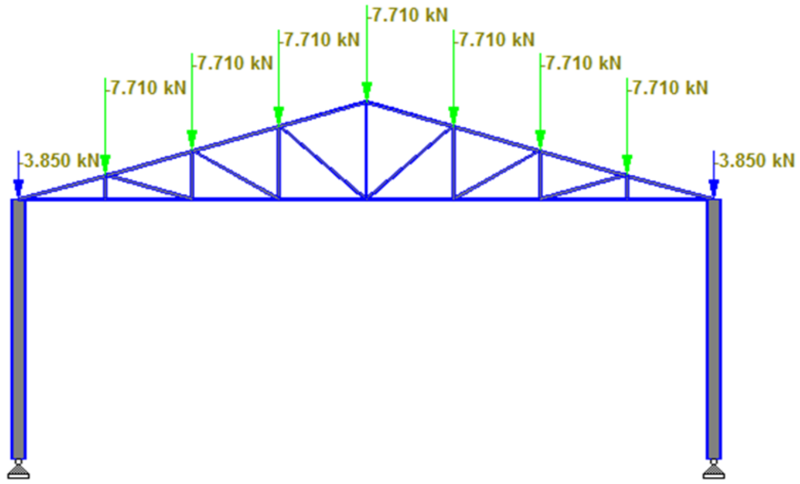

Fig. 4 : Live loads acting at the purlin positions of conventional steel frame

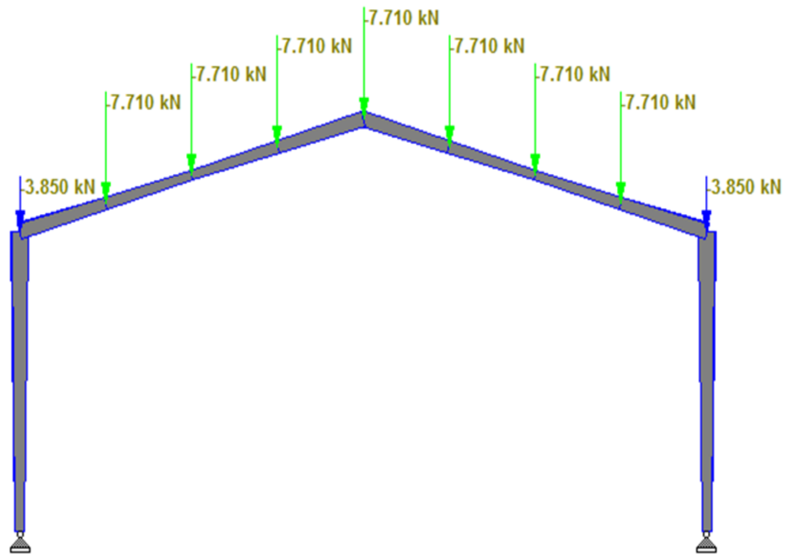

Fig. 5 : Live loads acting at the purlin positions of Pre–Engineered steel frame

b. Calculation of Wind Load (WL)

Wind loads are calculated as per IS 875–Part 3 (2015). The basic wind speed for Davangere is 33 m/s. The frame is considered to be open terrain with a total height of 11 m having a dimension of 50 m. Table 2 shows the wind loads acting on conventional and Pre–Engineered steel frames for wind angle 0^0 and 90^0.

Table 2 : Wind loads acting on conventional and Pre–Engineered steel frames for wind angle 0^0 and 90^0

Wind angle	Pressure Coefficients			$C_{pe} \pm C_{pi}$		Area $\times$ P_d	WW	LW
	WW	LW	C_{pi}	WW	LW	(kN)	(kN)	(kN)
0^0	–0.664	–0.4	–0.5	–1.16	–0.9	9.13	**–10.59**	**–8.21**
			+0.5	–0.16	0.1	9.13	–1.46	0.913
90^0	–0.73	–0.6	–0.5	–1.23	–1.1	9.13	**–11.22**	**–10.02**
			+0.5	–0.23	–0.1	9.13	–2.09	–0.91

Note : WW : WindWard, LW : LeeWard

Figures 6 and 7 show the application of wind loads (considering wind angle 0^0) at the purlin positions of conventional and Pre–Engineered steel frames.

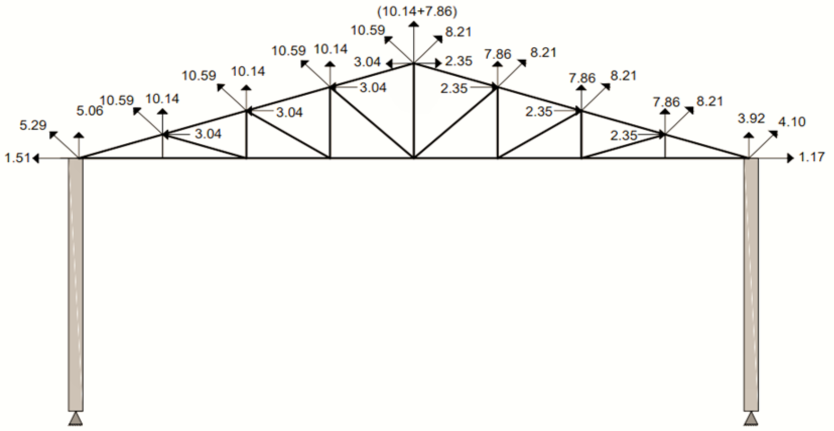

Fig. 6 : Wind loads acting at the Purlin positions of conventional steel frame for wind angle 0^0

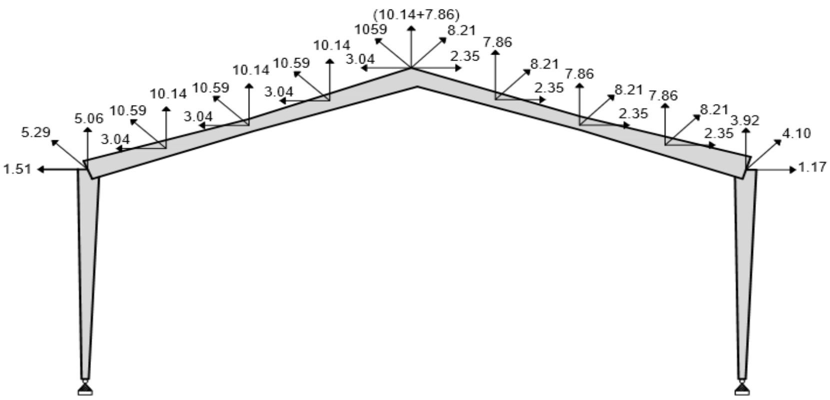

Fig. 7 : Wind loads acting at the Purlin positions of Pre–Engineered steel frame for wind angle 0^0

Figures 8 and 9 show the application of wind loads (considering wind angle 90^0) at purlin positions of conventional and Pre–Engineered steel frames.

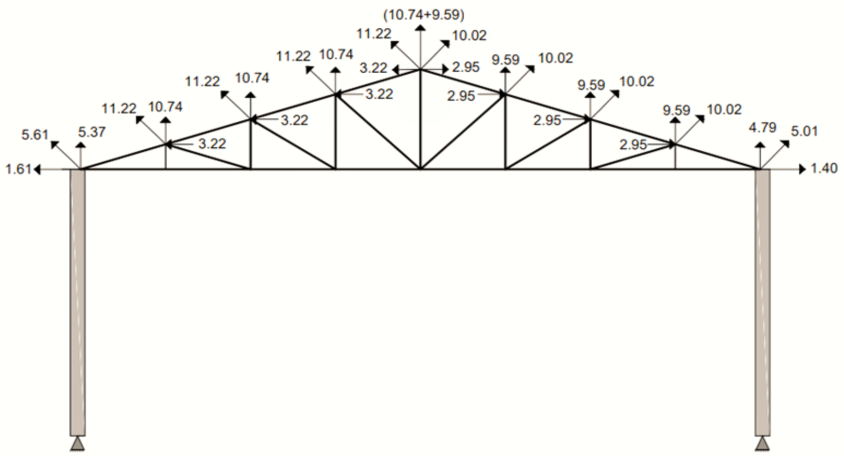

Fig. 8 : Wind loads acting at the Purlin positions of conventional steel frame for wind angle 90^0

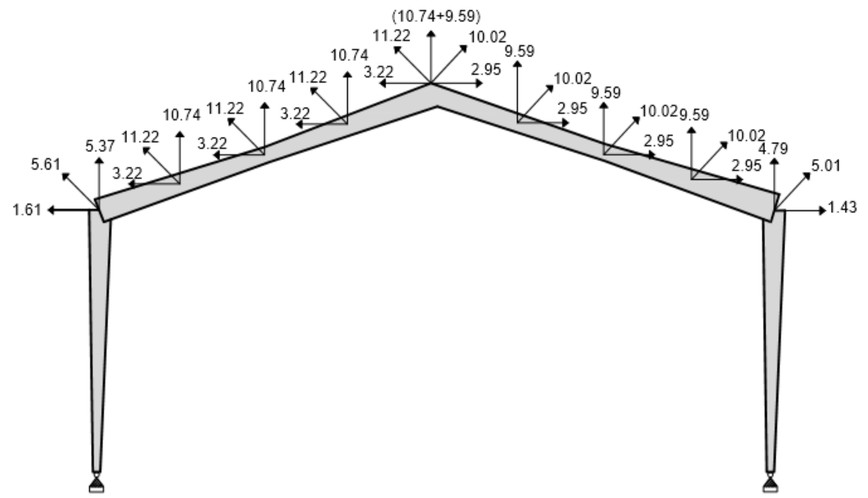

Fig. 9 : wind load acting at the Purlin positions of Pre–Engineered steel frame for wind angle 90^0

V. SECTIONAL PROPERTIES CONSIDERED FOR ANALYSIS

Figure 10 shows the member numbers of the conventional steel frame as specified by STAAD Pro. software

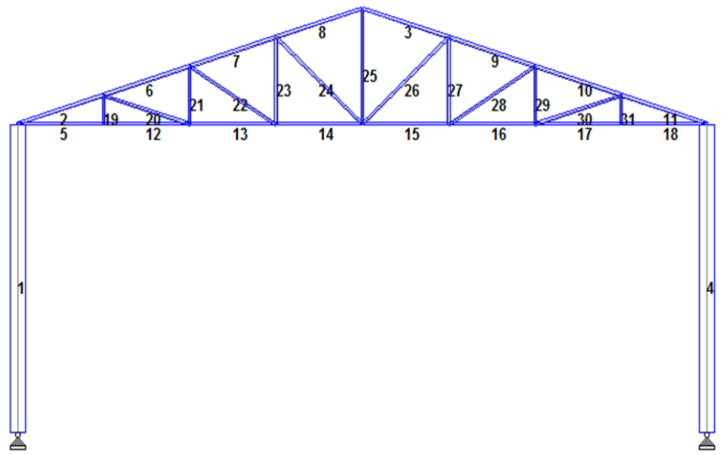

Fig. 10 : Member numbers of conventional steel frame

Table 3 shows the details of sectional properties of the members of conventional steel frame considered for modelling in STAAD Pro. software.

Table 3: Details of member sectional properties of the conventional steel frame

Sl. No.	Members	Member No.	Size
1	Top chord members	2, 6, 7, 8, 3, 9, 10 and 11	2 ISA 90x90x8 @ 21.6 kg/m
2	Bottom chord members	5, 12, 13, 14, 15, 16, 17 and 18	2 ISA 65x65x8 @ 15.4 kg/m
3	Inner members	19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30 and 31	ISA 100x100x8 @ 12.1 kg/m
4	Columns	1 and 4	ISHB 450 @ 87.2 kg/m

Figure 11 shows the member numbers of the Pre–Engineered steel frame as specified by STAAD Pro. software.

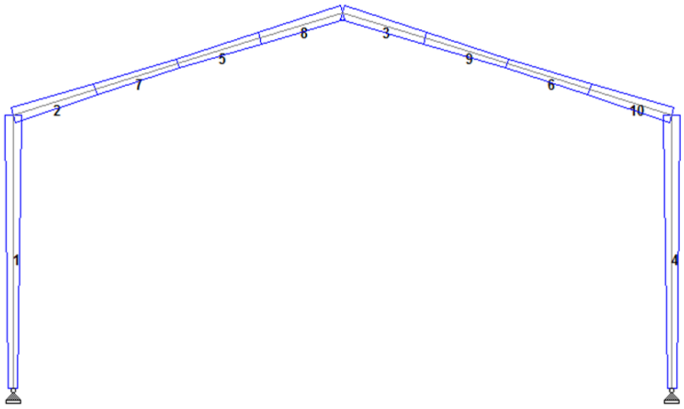

Fig. 11 : Member numbers of Pre–Engineered steel frame

Details of sectional properties of the members of Pre–Engineered steel frame considered for modelling in STAAD Pro. software is shown in Fig. 12, and Tables 4 and 5.

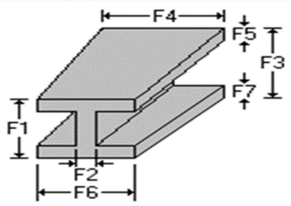

Fig. 12 : Details of typical sectional properties of the Pre–Engineered steel frame

Table 4 : Description of typical sectional properties of the Pre–Engineered steel frame

Sl. No.	Notation	Description
1	F1	Depth of section at start node
2	F2	Thickness of web
3	F3	Depth of section at end node
4	F4	Width of top flange
5	F5	Thickness of top flange
6	F6	Width of bottom flange
7	F7	Thickness of bottom flange

Table 5 : Details of sectional properties of the members of Pre–Engineered steel frame

Sl. No.	Notation	Member Dimensions in metres									
		1	2	3	4	5	6	7	8	9	10
1	F1	0.3	0.45	0.45	0.5	0.25	0.25	0.35	0.35	0.35	0.35
2	F2	0.01	0.008	0.005	0.01	0.005	0.005	0.005	0.005	0.005	0.008
3	F3	0.5	0.35	0.35	0.3	0.35	0.35	0.25	0.45	0.25	0.45
4	F4	0.3	0.26	0.16	0.3	0.16	0.19	0.19	0.16	0.16	0.26
5	F5	0.013	0.01	0.007	0.013	0.007	0.007	0.007	0.007	0.007	0.01
6	F6	0.3	0.26	0.16	0.3	0.16	0.19	0.19	0.16	0.16	0.26
7	F7	0.013	0.01	0.007	0.013	0.007	0.007	0.007	0.007	0.007	0.01

VI. ANALYSIS OF FRAMES

Both conventional and Pre–Engineered steel frames are modelled in STAAD Pro. software. DL, LL and WL acting at panel positions are also applied. During 2D analysis, following load combinations are considered.

i) 1.5 DL + 1.5 LL, ii) 5 DL + 1.5 WL 0, iii) 1.5 DL + 1.5 WL 90, iv) 1.5 DL – 1.5 WL 0, v) 1.5 DL – 1.5 WL 90

DL+LL+WL combinations are not critical as wind loads act in opposite direction to dead and live loads. (INSDAG Manual).

VII. DESIGN OF CONVENTIONAL STEEL FRAME

The design of all members of conventional steel frame is done for the worst load combination as predicted by STAAD pro. software

Design of Top Chord Members

Table 6 shows the maximum axial forces (F_x, tension and compression) developed on the top chord members.

Table 6 : Maximum axial forces (F_x) acting on the top chord members of conventional steel frame

Top Chord Members	Node	F_x (kN)	Load Combination
2	Start	304.407	1.5DL–1.5WL90
	End	– 144.15	WL90
6	Start	266.354	1.5DL–1.5WL90
	End	– 127.143	WL90
7	Start	228.237	1.5DL–1.5WL90
	End	– 110.136	WL90
8	Start	190.119	1.5DL–1.5WL90
	End	– 93.128	WL90
3	Start	190.542	1.5DL–1.5WL90
	End	– 93.410	WL90
9	Start	225.870	1.5DL– 1.5WL90
	End	– 108.557	WL90
10	Start	261.197	1.5DL– 1.5WL90
	End	– 123.705	WL90
11	Start	296.524	1.5DL– 1.5WL90
	End	– 138.852	WL90

The size 2 ISA 90 x 90 x 8 @ 21.6 kg/m is found to be safe as per Clauses 10.2.4.3, 10.3.4, 6.1, 6.3.3 and 7.1.2.1 of IS 800 (2007).

Design of Bottom Chord Members

Table 7 shows the maximum axial forces (F_x, tension and compression) developed on the bottom chord members.

Table 7 : Maximum axial forces (F_x) acting on the bottom chord members of conventional steel frame

Bottom Chord Members	Node	F_x (kN)	Load Combination
5	Start	136.461	1.5DL– 1.5WL90
	End	– 289.46	WL90
12	Start	136.461	1.5DL– 1.5WL90
	End	– 289.216	WL90
13	Start	116.951	1.5DL– 1.5WL90
	End	– 247.876	WL90
14	Start	97.441	1.5DL– 1.5WL90
	End	– 206.536	WL90
15	Start	95.389	1.5DL– 1.5WL90
	End	– 203.459	WL90
16	Start	112.848	1.5DL– 1.5WL90
	End	– 241.721	WL90
17	Start	130.306	1.5DL– 1.5WL90
	End	– 279.984	WL90
18	Start	131.566	1.5DL– 1.5WL90
	End	– 281.874	WL90

The size 2 ISA 65 x 65 x 65 @ 15.4 kg/m is found to be safe as per Clauses 10.2.4.3, 10.3.4, 6.1, 6.3.3 and 7.1.2.1 of IS 800 (2007).

Design of Inner Members

Table 8 shows the maximum axial forces (F_x, tension and compression) developed on the inner members.

Table 8 : Maximum axial forces acting on the inner members of conventional steel frame

Inner Members	Node	F_x (kN)	Load Combination
19	Start	0	1.5DL– 1.5WL90
	End	0	WL90
20	Start	43.106	1.5DL– 1.5WL90
	End	– 20.369	WL90
21	Start	5.853	1.5DL– 1.5WL90
	End	– 12.402	WL90
22	Start	48.210	1.5DL– 1.5WL90
	End	– 22.752	WL90
23	Start	11.706	1.5DL– 1.5WL90
	End	– 24.804	WL90

Inner Members	Node	F_x (kN)	Load Combination
24	Start	55.617	1.5DL– 1.5WL90
	End	– 26.248	WL90
25	Start	33.272	1.5DL– 1.5WL90
	End	– 71.642	WL90
26	Start	51.477	1.5DL– 1.5WL90
	End	– 23.488	WL90
27	Start	10.475	1.5DL– 1.5WL90
	End	– 22.957	WL90
28	Start	44.621	1.5DL– 1.5WL90
	End	– 20.360	WL90
29	Start	5.238	1.5DL– 1.5WL90
	End	– 11.479	WL90
30	Start	39.947	1.5DL– 1.5WL90
	End	– 18.227	WL90
31	Start	0	1.5DL– 1.5WL90
	End	0	WL90

The design of bottom chord members is done for worst load combination, The size ISA 100 x 100 x 8 @ 12.1 kg/m is found to be safe as per Clauses 10.2.4.3, 10.3.4, 7.1.2.1 and 7.5.1.2 of IS 800 (2007).

Design of Columns

Table 9 shows the maximum load (F_x, compression) acting on the supporting columns.

Table 9 : Maximum compression force acting on the supporting columns of conventional steel frame

Column Members	Node	F_x (kN)	Load Combination
1	Start	99.159	1.5DL– 1.5WL90
	End	– 46.791	WL90
4	Start	96.006	1.5DL– 1.5WL90
	End	– 44.689	WL90

The size ISHB 450 @ 87.2 kg/m is found to be safe as per Cl. 7.1.2.1 of IS 800 (2007).

Design of Slab Base for Conventional steel Frame

Assuming, f_y=250 N/mm^2 and γ_m=1.10, Size of plate is given by 500x300x20 which is found to be safe as per Cl. 7.4.3.1 of IS 800 (2007).

Design of RCC Footing for Conventional Steel Frame

Assuming SBC of soil = 150 kN/m^2, Fe 500 grade reinforcing steel and M25 grade concrete, Depth of footing is given by 250 mm with # 10 bars @ 250 mm c/c (both ways) as per Cl. G–1.1 of IS 456 (2000).

VIII. DESIGN OF PRE–ENGINEERED STEEL FRAME

Design Utilization Ratio

Utilization ratio is a critical value which indicates the suitability of members. It is defined as the ratio of applied load to the member capacity. A value higher than 1 indicates the member to be over stressed and a value less than 1 indicates the member is under stressed and its reserve capacity is available. Utilization ratio is taken as a criterion to decide whether the member is safe or failed due to stresses. Table 10 shows the utilization ratio values of all the members of Pre–Engineered steel frame, as predicted by STAAD Pro. software considering IS 800 (2007).

Table 10 : Member utilization ratio for Pre–Engineered steel frame

Member	Utilization Ratio
1	0.938
2	0.912
3	0.837
4	0.996
5	0.994
6	0.957
7	0.714
8	0.966
9	0.862
10	0.977

From Tables 10, utilization ratio less than 1 indicates that all the members of Pre–Engineered steel frame are safe and under stressed.

Design of Slab Base for Pre–Engineered Steel Frame

Table 11 shows the maximum axial force acting on supporting columns of Pre–Engineered steel frame.

Table 11 : Maximum compression force acting on the supporting columns of Pre– Engineered steel frame

Column Members	Node	F_x (kN)	Load Combination
1	Start	99.159	1.5DL– 1.5WL90
	End	– 46.791	WL90
4	Start	96.006	1.5DL– 1.5WL90
	End	– 44.689	WL90

Assuming f_y=250 N/mm^2 and γ_m=1.10, Size of plate is given by 350x350x20 mm which is found to be safe as per Cl.7.4.3.1 of IS 800 (2007).

Design of RCC Footing for Pre–Engineered Steel Frame

Assuming SBC of soil = 150 kN/m^2, F_e 500 grade reinforcing steel and M25 grade concrete, Depth of footing is given by 250 mm with # 10 bars @ 250 mm c/c (both ways) is found to be safe as per Cl. G–1.1 of IS 456 (2000).

IX. DESIGN OF PURLINS FOR CONVENTIONAL AND PRE–ENGINEERED STEEL FRAME

The design of purlins is done for a spacing 2.61 m with inclination of 16.6^0 for both conventional and Pre–engineered steel frames. The size ISMB 175 @ 19.3 kg/m is found to be safe as per Cl. 9.3.1.1 of IS 800 (2007).

X. CONCLUSIONS

Figure 13 shows the graphical representation of the quantity of steel required for both the frames.

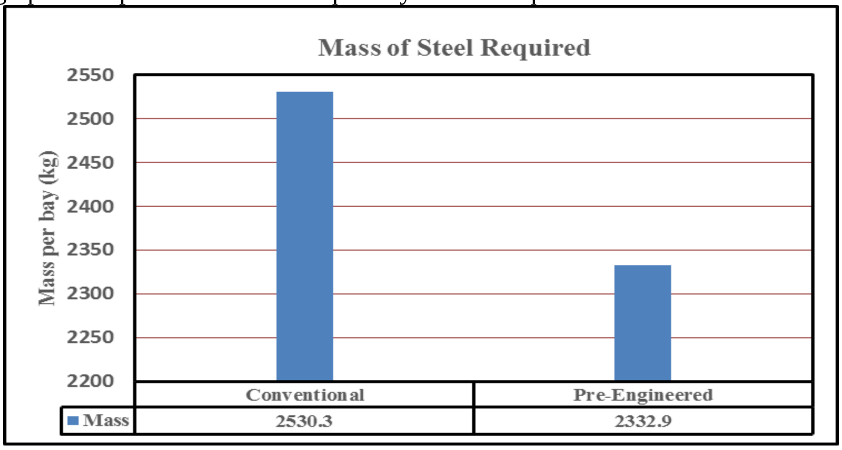

Fig. 13 : Graphical representation of quantity of steel required for Conventional and Pre–Engineered steel frames

From Fig. 13, about 8% reduction in quantity of steel is obtained in Pre–Engineered steel frame than the conventional steel frame. Assuming market price of steel as Rs. 44 per kg, the cost of steel (excluding the mass of connections and mass of purlins) required to erect conventional and Pre–engineered steel frames is graphically shown in Fig. 14.

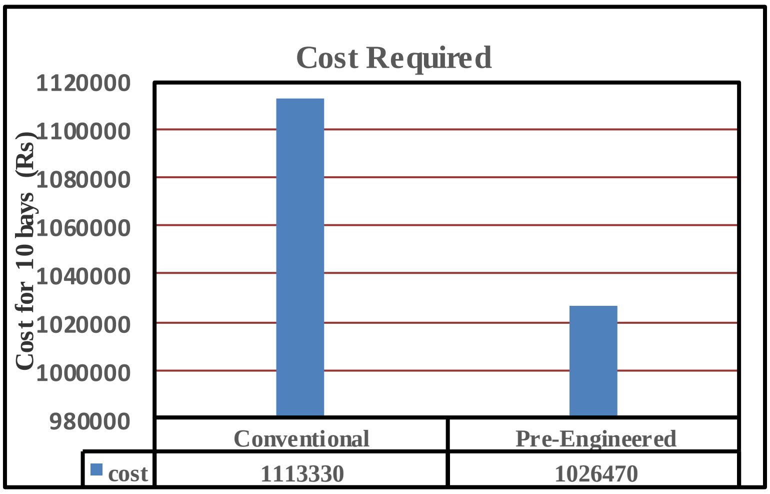

Fig. 14 : Graphical representation of cost required to erect Conventional and Pre–Engineered steel frames

From Fig.14, it can be inferred that about 90,000 Rs. saving in material cost can be obtained by erecting the Pre–Engineered steel frames than the conventional steel frames. Thus Pre–Engineered steel frames are preferred over the conventional steel frames.

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