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A Comparative Study on Performance of Conventional and Pre-Engineered Steel Frames Subjected to Crane Load

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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 present study, conventional (pratt type) steel roof truss and pre-engineered (portal type) steel roof frame with crane load is considered for an industrial warehouse construction located in Davangere city. 2D Modelling of both conventional and pre-engineered steel frame with crane load is done using STAAD Pro. software. Both the steel frames are subjected to different combinations of Dead load (DL), Live load(LL), Crane Load(CL) and Wind load(WL) as per IS 800 (2007) codal provisions. For the factored bending moments and shear force, referring IS 800 (2007) codal provisions, crane gantry girder is designed as a laterally unsupported member having a combination of I and channel sections. The members of both conventional and pre-engineered steel frames with crane load are designed for the worst load combination as per IS 800(2007) codal provisions. It is concluded that about 25% reduction in quantity of steel can be achieved by choosing pre-engineered steel frame than the conventional steel frame.
Keywords: CSB, PEB, CL, STAAD Pro.

I. INTRODUCTION

Steel is one of the most commonly used building materials, as it plays the most prominent role especially in industrial sector and where there is a need of faster rate of construction over a huge area. Industries require larger area as there is a usage of heavy equipment and machines. Even steel structures are used to transport the goods from one place to another within the warehouse by using cranes. As steel is strong, hard, and ductile and fire resistive material, it is very suitable for rapid construction especially in industrial sector. One more advantage of steel structures is it can be easily dismantled and shifted to anywhere around the site. Design of steel structures contains design of secondary members like bracings, tie rods, column base, purlins etc. Roof truss used in factories, cinema halls, transmission towers, chimney, warehouses, railways, crane girder, bridges etc. Are some of the steel structures. In the present study, both csb and peb frames are considered subjected to crane load. Dead load(dl), live load(ll), wind load(wl) and different load combinations are applied and designed both the frame for the worst load combinations. Crane load is also calculated by manual calculations and added to the supporting columns. Last part of the paper depicts the quantity of steel required for both the frames and the comparison between the cost. The paper aims at explaining the advantages of using peb over csb.

II. PROBLEM STATEMENT

In the present paper, conventional (i.e. Pratt truss) and Pre–Engineered (i.e. portal type) industrial steel frames subjected to crane load are considered for an industrial building located at Davangere City. Dead Load (DL), Live Load (LL), Crane Load(CL) 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(except the mass of connections, purlins and crane) 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 subjected to crane load. 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	60 × 25 m	–
2	Height of supporting columns	10 m	–
3	Rise of frame	3 m	–
4	Spacing of frames	6 m	Spacing of frame in the range of 1/4th to 1/5th of span length
5	Slope of roof	13.5º	$\tan^{-1}\left(\frac{\text{rise}}{\text{half of span length}}\right)$
6	Number of bays	11	$\frac{\text{Length}}{\text{Spacing}} + 1$
7	Type of roofing	–	Galvanized iron sheeting
8	Spacing of purlins	3.21 m	$\frac{\text{Slant roof length}}{\text{No. of Nodes}}$
9	Type of support condition for columns	–	Hinged
10	Type of Truss	–	Pratt
11	Type of Pre-Engineered Frame	–	Portal type

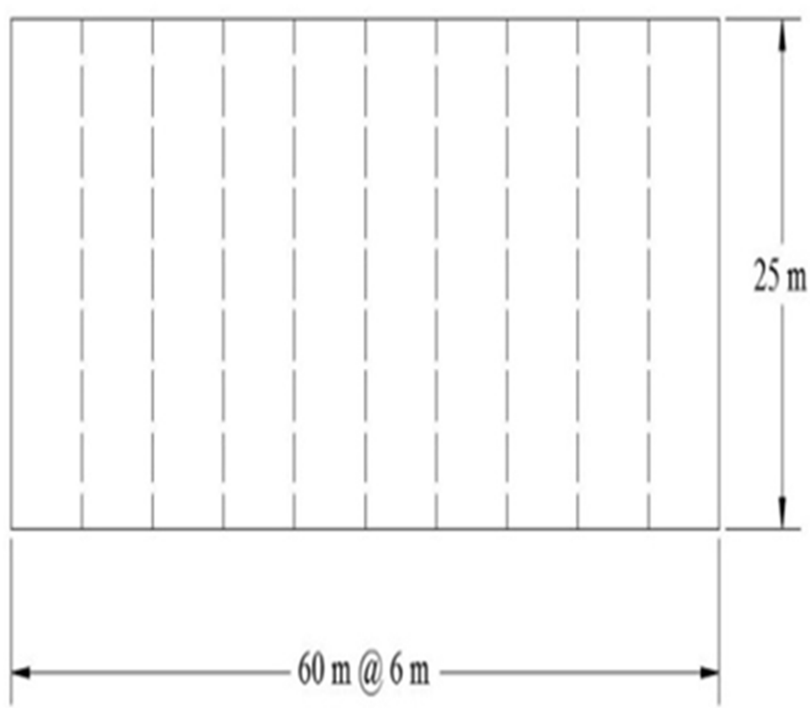

Fig. 1: Plan of conventional and pre-engineered steel frame

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

Table 2 shows the details of electric overhead traveling crane gantry girder considered in the present study.

Table.2: Details of gantry girder

Sl. No.	Parameter	Value
1	Span of the crane girder	25 m
2	Span of gantry girder	6 m
3	Capacity of crane	200 kN
4	Self-weight of crane excluding crab	160 kN
5	Weight of crab	75 kN
6	Wheel base distance	3.5 m
7	Minimum hook approach	0.9 m
8	Self-weight of rail	0.4 kN/m
9	Height of rail	60 mm
10	Total height of supporting columns	10 m
11	Position of gantry girder from base of column	6 m

1) *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.

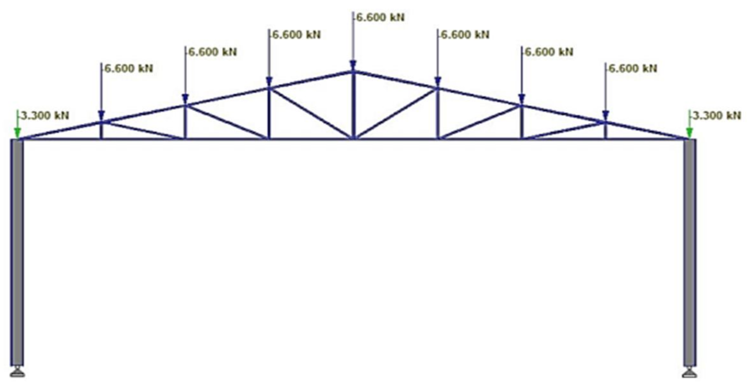

Fig.2: Dead loads acting at the purlin positions of conventional steel frame

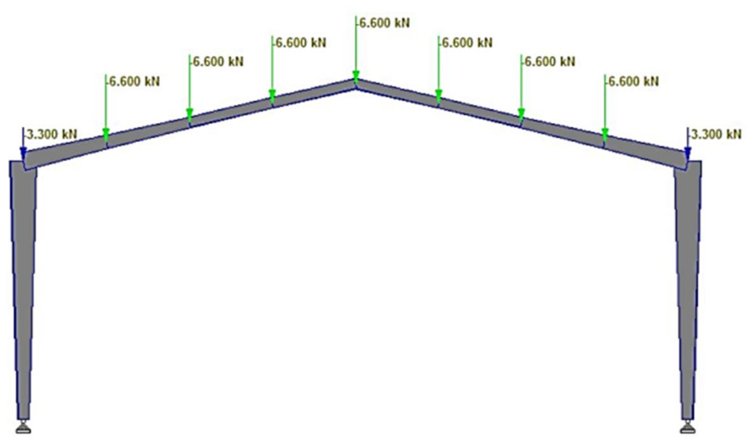

Fig.3: Dead loads acting at the purlin positions of pre-engineered steel frame

2) *Calculation of Live Load (LL):* Live loads acting on the frames is calculated as per IS 875–Part 2 (1987).
Figures 4 and 5 shows the application of live loads acting at the purlin positions of conventional and pre-engineered steel frames.

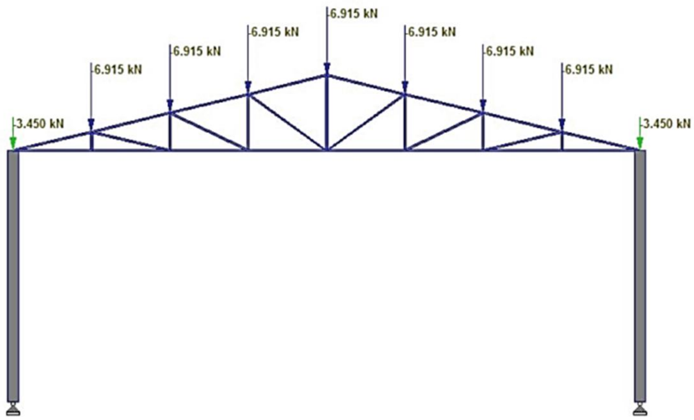

Fig. 4: Live loads acting at the purlin positions of conventional steel frame

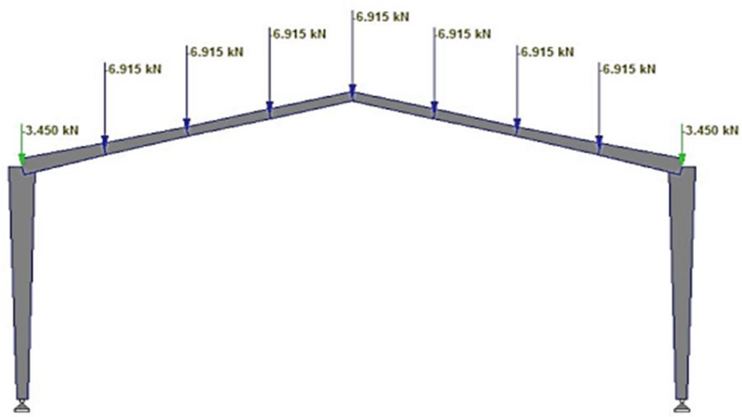

Fig. 5: Live loads acting at the purlin positions of pre-engineered steel frame

3) *Calculation of Wind Load (WL):* Wind loads acting on both conventional and pre-engineered steel frames subjected to crane load are calculated as per IS 875–Part 3(2015). Table 3 shows the wind loads acting on both frames. Figures 6 and 7 respectively show the application of wind loads (considering wind angle 0º) at the purlin positions of both conventional and pre-engineered steel frames.

Table 3: Wind loads acting on conventional and pre-engineered steel frame for wind angle 0° and 90°

Wind angle	Pressure coefficients			$C_{pe} \pm C_{pi}$		Area X P_d (kN)	WW (kN)	LW (kN)
	WW	LW	Cpi	WW	LW			
0°	-0.92	-0.4	-0.5	1.42	– 0.9	14.45	– 20.5	– 13
			+0.5	-0.42	0.1	14.45	– 6.07	1.44
90°	-0.76	-0.6	-0.5	1.23	– 1.1	14.45	– 18.2	– 15.9
			+0.5	– 0.23	– 0.1	9.13	– 3.75	1.4

Note: WW: Windward, LW: Leeward.

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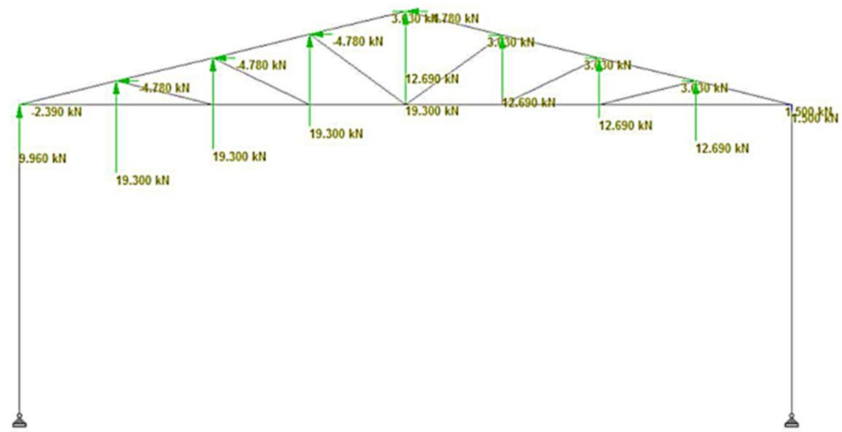

Fig. 6: Wind loads acting at the purlin positions of conventional steel frame for wind angle 0º

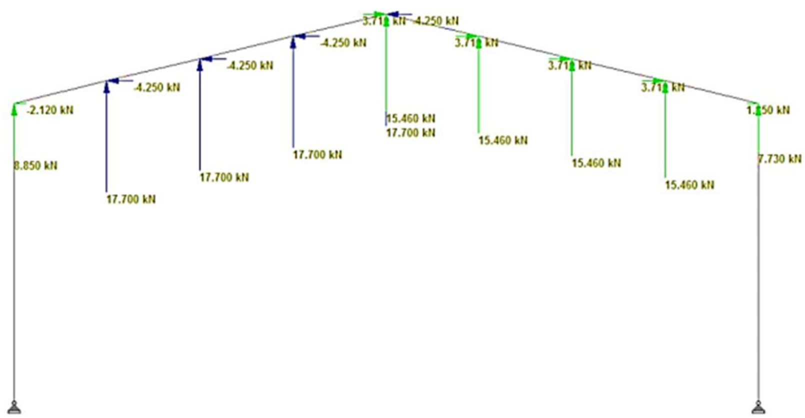

Fig. 7: Wind loads acting at the purlin positions of pre-engineered steel frame for wind angle 0º

Figures 8 and 9 respectively show the application of wind loads (considering wind angle 90º) at the purlin positions of both conventional and pre-engineered steel frames.

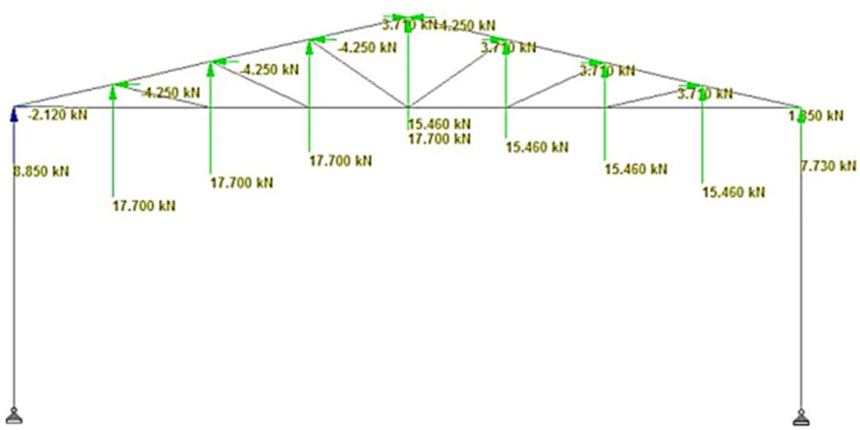

Fig. 8: Wind loads acting at the purlin positions of conventional steel frame for wind angle 90º

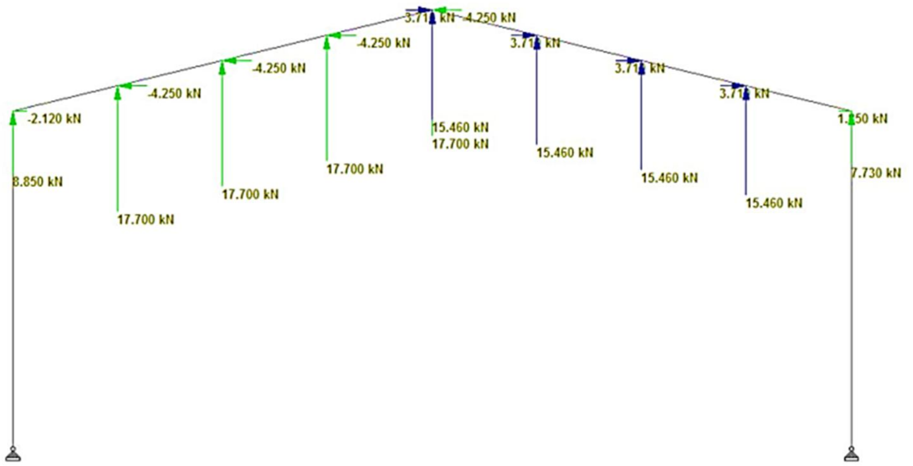

Fig. 9: Wind loads acting at the purlin positions of pre-engineered steel frame for wind angle 90º

4) *Calculation of loads on Crane Gantry Girder:* Gantry girder is assumed to be simply supported on bracket plates that are attached to the supporting column flanges. Figures 10 and 11 respectively show the factored load and couple moment acting on supporting columns of conventional and pre-engineered steel frames

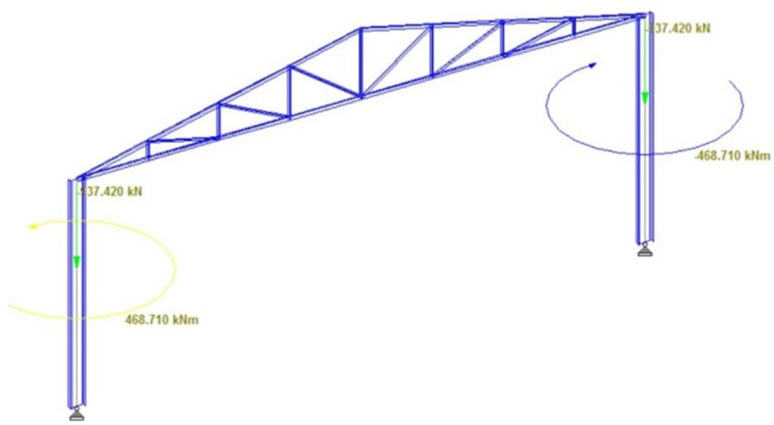

Fig. 10: Factored load and couple moment acting on supporting columns of conventional steel frame

Fig. 11: Factored load and couple moment acting on supporting columns of pre-engineered steel frame

V. SECTIONAL PROPERTIES CONSIDERED FOR ANALYSIS

Figure 12 shows the member numbers of the conventional steel frame subjected to crane load, as specified by STAAD Pro. software.

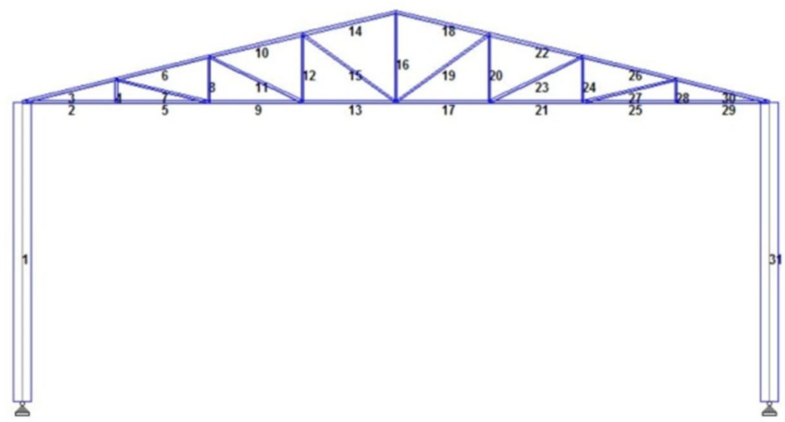

Fig. 12: Member numbers of conventional steel frame

Table 4 shows the details of sectional properties of the members of conventional steel frame considered for modelling in STAAD Pro. software

Table 4: Details of member sectional properties of conventional steel frame

Sl. No.	Members	Member No	Size
1	Top Chord Members	3, 6, 10, 14, 18, 22, 26 and 30	2 ISA 150×150×18 @ 39.3 kg/m
2	Bottom Chord Members	2, 5, 9, 13, 17, 21, 25 and 29	2ISA150×150×12 @ 27.2 kg/m
3	Inner Members	4, 7, 8, 11, 12, 15, 16, 19, 20, 23, 24, 27 and 28	2ISA110×110×12 @ 19.6 kg/m
4	Columns	1 and 31	ISWB 600 @ 133.7 kg/m

Figure 13 shows the member numbers of the pre-engineered steel frame subjected to crane load, as specified by STAAD Pro. software.

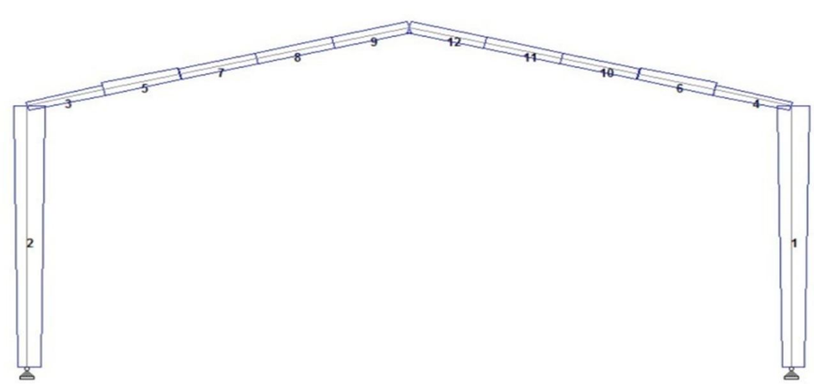

Fig. 13 : Member numbers of pre-engineered steel frame

Details of sectional properties of the members of pre-engineered steel frame subjected to crane load considered for the analysis in STAAD Pro. is shown in Fig. 14

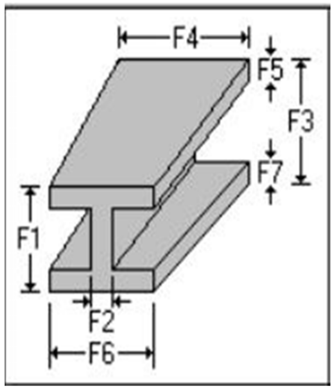

Fig. 14: Details of sectional properties of pre-engineered steel frame

Tables 5 and 6 respectively show the description and sectional properties of the pre-engineered steel frame.

Table 5: 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

Table 6: Details of sectional properties of the members of pre-engineered steel frame

Sl. No.	Notation	Member 1 (m)	Member 2 (m)	Member 3 (m)	Member 4 (m)	Member 5 (m)	Member 6 (m)	Member 7 (m)	Member 8 (m)	Member 9 (m)	Member 10 (m)
1	F1	1.016	1.016	0.716	0.516	0.416	0.416	0.716	0.516	0.416	0.416
2	F2	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
3	F3	0.416	0.416	0.516	0.416	0.416	0.416	0.516	0.416	0.416	0.416
4	F4	0.3	0.3	0.3	0.25	0.25	0.25	0.3	0.25	0.25	0.25
5	F5	0.008	0.008	0.008	0.008	0.006	0.006	0.008	0.008	0.008	0.008
6	F6	0.3	0.3	0.3	0.25	0.25	0.25	0.3	0.25	0.25	0.25
7	F7	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008

VI. ANALYSIS OF FRAMES

Both conventional and pre-engineered steel frames are modelled in STAAD Pro. software. DL, LL, WL, and factored crane gantry girder point load and couple moment are applied. Following load combinations as per Table 4 of IS 800 (2007) are considered during 2D analysis.

1) 1.5DL + 1.5LL
2) 1.5DL + 1.5 WL 0
3) 1.5DL + 1.5 WL 90
4) 1.5DL – 1.5 WL 0
5) 1.5DL – 1.5 WL 90

DL+LL+WL combinations are not critical as wind load acts in opposite direction to DL and LL (INSDAG Manual).

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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.

A. *Design Of Crane Gantry Girder*

Table 7 shows the sectional properties of gantry girder.

Table 7: Sectional properties of gantry girder

Sectional Property	ISMB 600 @1230 N/m	ISMC 300 @ 358 N/m
Area (mm^2)	15621	4564
Depth (mm)	600	300
Breadth (mm)	210	90
Thickness of flange (mm)	20.8	13.6
Thickness of web (mm)	12	7.6
Moment of Inertia, I_{zz} (mm^4)	91813 x 10^4	6362.6 x 10^4
Moment of Inertia, I_{yy}(mm^4)	2651 x 10^4	310.8 x 10^4
Section Modulus, Z_{zz}(mm^3)	3060 x 10^3	424.2 x10^3

B. *Design of Top Chord Members*

Table 8 shows the maximum axial forces (F_x, tension and compression) developed on the top chord members, obtained from STAAD Pro. software

Table 8: Maximum axial forces (F_x) acting on the top chord members of conventional steel frame

Top Chord Members	Node	F_x (kN)	Load Combination
3	Start	692.5	1.5DL – 1.5WL 0
	End	–324.96	1.5DL+1.5WL 0
6	Start	578.26	1.5DL – 1.5WL 0
	End	–258.95	1.5DL + 1.5 WL 0
10	Start	481.79	1.5DL – 1.5 WL 90
	End	–214.6	1.5DL + 1.5 WL 90
14	Start	397.6	1.5DL –1.5WL 90
	End	–179.2	1.5DL + 1.5WL 90
18	Start	398.2	1.5DL – 1.5WL 90
	End	–179.8	1.5DL + 1.5WL 90
22	Start	471.53	1.5DL – 1.5WL 90
	End	–207.3	1.5DL + 1.5WL 90
26	Start	541.06	1.5DL – 1.5WL 90
	End	–234.2	1.5DL + 1.5WL 90
30	Start	552.8	1.5DL –1.5WL 90
	End	–231.83	1.5DL + 1.5WL 90

2 ISA 150 ×150 × 18 @ 39.9 kg/m is taken for the analysis

C. *Design of Bottom Chord Members*

Table 9 shows the maximum axial forces (F_x, tension and compression) developed on the bottom chord members, obtained from STAAD Pro. software

Table 9: Maximum axial forces (F_x) acting on the bottom chord members of conventional steel frame

Bottom Chord Members	Node	F_x (kN)	Load Combination
2	Start	278.85	1.5DL + 1.5 WL 0
	End	–673.81	1.5DL – 1.5WL 0
5	Start	308.45	WL 0
	End	–664.5	1.5DL – 1.5 WL 0
9	Start	247.1	WL 0
	End	–538.06	1.5DL – 1.5 WL 0
13	Start	198.9	WL 0
	End	–452.26	1.5DL – 1.5WL 90
17	Start	190.27	WL 90
	End	–439.9	1.5DL – 1.5WL 90
21	Start	219.3	WL 90
	End	–511.6	1.5DL – 1.5WL 90
25	Start	229.3	WL 90
	End	–545.8	1.5DL – 1.5WL 90
29	Start	219.7	WL 90
	End	–527.1	1.5DL – 1.5 WL 90

2 ISA 150 ×150 × 18 @ 39.9 kg/m is taken for the analysis.

D. Design of Inclined Members

Table 10 shows the maximum axial forces (F_x, tension and compression) developed on the inclined members, obtained from STAAD Pro. software.

Table 10: Maximum axial forces (F_x) acting on the inclined members of conventional steel frame

Inclined Members	Node	F_x (kN)	Load combination
4	Start	9.7	1.5DL – 1.5WL 90
	End	–7.2	1.5DL + 1.5WL 90
7	Start	114.1	1.5DL – 1.5WL 0
	End	–76.4	1.5DL + 1.5 WL 90
8	Start	14.45	1.5DL + 1.5 WL 0
	End	–29.60	1.5DL – 1.5 WL 0
11	Start	112.03	1.5DL – 1.5WL 0
	End	–53.26	1.5DL + 1.5WL 0
12	Start	23.09	WL 0
	End	–51.4	1.5DL – 1.5WL 0
15	Start	120.83	1.5DL– 1.5WL 90
	End	–55.7	1.5DL + 1.5WL 0
16	Start	50.27	WL 90
	End	–122.5	1.5DL – 1.5WL 90
19	Start	94.6	1.5DL – 1.5WL 90
	End	–38.05	1.5DL + 1.5WL 90
20	Start	13.5	1.5DL + 1.5WL 90
	End	–28.05	1.5DL – 1.5WL 90
23	Start	80.1	1.5DL – 1.5WL 90
	End	–31.89	WL 90

Inclined Members	Node	F_x (kN)	Load combination
24	Start	3.6	1.5DL + 1.5WL 90
	End	–13.46	1.5DL– 1.5WL 90
27	Start	47.7	1.5DL – 1.5WL 90
	End	–9.816	1.5DL + 1.5WL 90
28	Start	21.48	1.5DL – 1.5WL 90
	End	–18.97	1.5DL + 1.5WL 90

2 ISA 110 ×110 × 12 @ 39.2 kg/m is taken for the analysis.

E. Design of Columns

Table 11 shows the maximum axial forces (F_x, tension and compression) developed on the column members, obtained from STAAD Pro. software.

Table 11: Maximum Axial Forces (F_x) developed on supporting columns of conventional steel frame

Column Members	Node	Axial Force(F_x) (kN)	Load Combination
1	Start	194.65	1.5DL – 1.5WL 0
	End	–75.71	WL 0
31	Start	189.603	1.5DL – 1.5WL 0
	End	–73.5	1.5DL +1.5WL 90

ISWB 600 @ 145.1 kg/m is considered for the analysis.

F. Design Of Slab Base For Conventional Steel Frame

Assuming, = 250 N/mm2 and = 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).

G. Design Of RCC Footing For Conventional Steel Frame

Assuming SBC of soil = 180 kN/m2, Fe 500 grade reinforcing steel and M25 grade concrete, Depth of footing is given by 350 mm with # 16 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 12 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 12: Member utilization ratio for pre–engineered steel frame

Member	Utilization Ratio
1	0.986
2	0.986
3	0.561
4	0.589
5	0.554
6	0.543
7	0.468

Member	Utilization Ratio
8	0.421
9	0.422
10	0.381
11	0.382
12	0.35

From Table 12, utilization ratio less than 1 indicates that all the members of Pre–Engineered steel frame are safe and under stressed.

A. *Design of Slab Base for Pre–Engineered Steel Frame*

Table 13 shows the maximum axial force acting on supporting columns of Pre–Engineered steel frame.

Table 13: Maximum axial force (F_x) acting on supporting columns of pre-engineered steel frame

Column Members	Node	F_x (kN)	Load Combination
1	Start	101.25	1.5DL – 1.5 WL 90
	End	–80.93	1.5DL + 1.5WL 90
2	Start	101.25	1.5DL – 1.5WL 90
	End	–94.28	1.5DL + 1.5WL 90

Assuming = 250 N/mm2 and =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).

B. *Design of RCC Footing for Pre–Engineered Steel Frame*

Assuming SBC of soil = 180 kN/m2, Fe 500 grade reinforcing steel and M25 grade concrete, Depth of footing is given by 250 mm with # 16 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 2.57 m with inclination of 13.5 for both conventional and Pre–engineered steel frames. The size ISMC 250 @ 30.4 kg/m is found to be safe as per Cl. 9.3.1.1 of IS 800 (2007).

X. CONCLUSIONS

Figure 15 shows the graphical representation of the quantity of steel required for both the frames.

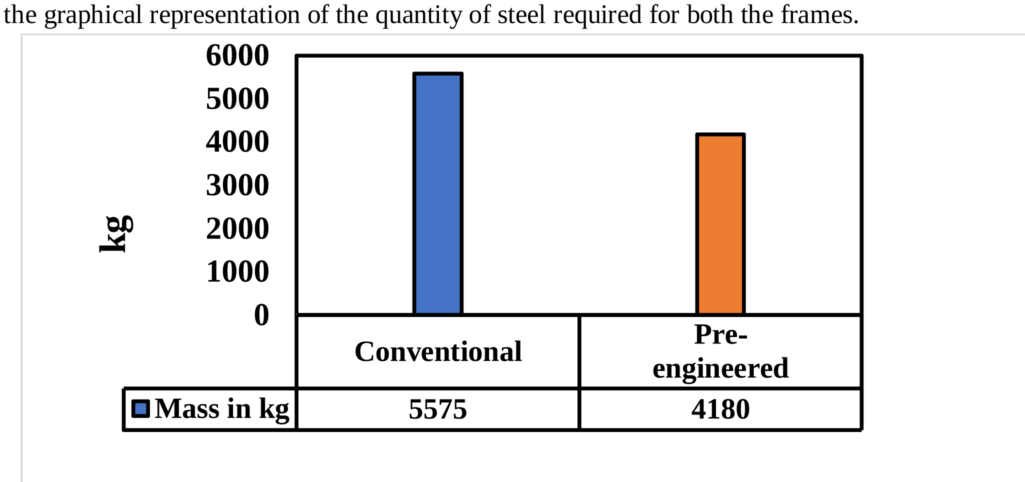

Fig. 15: Graphical representation of quantity of steel required for conventional and pre-engineered steel frames

It is observed that about 25% reduction in quantity of steel is achieved by choosing pre-engineered steel frame than the conventional steel frame.

As per the current market rate, the price of steel is assumed to be around Rs. 85 per kg. Hence the cost of steel (except the mass of connections, purlins and crane gantry girder) required to erect both conventional and pre-engineered steel frames subjected to crane load is graphically represented in Fig. 16

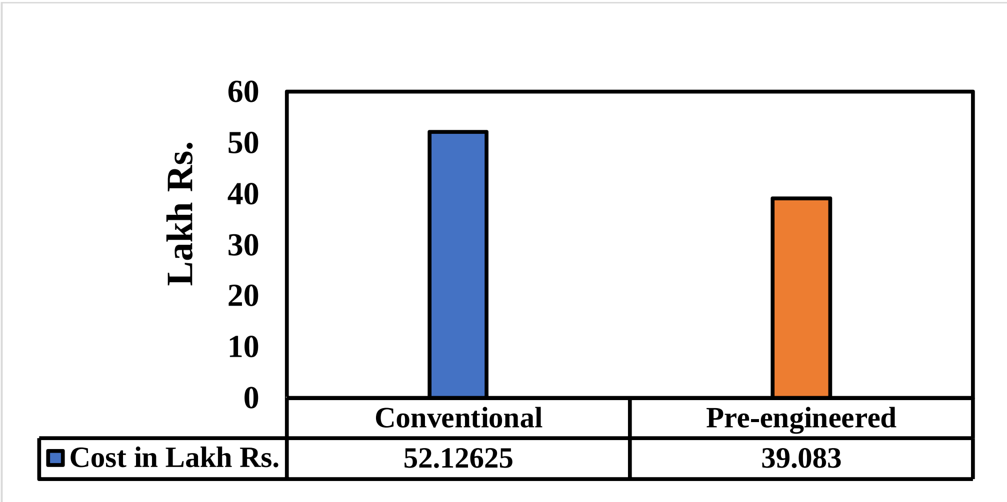

Fig. 16: Graphical representation of cost required to erect conventional and pre-engineered steel frames

From Fig. 16, it is observed that about 13 lakh rupees can be saved by erecting pre-engineered steel frame than the conventional steel frame.

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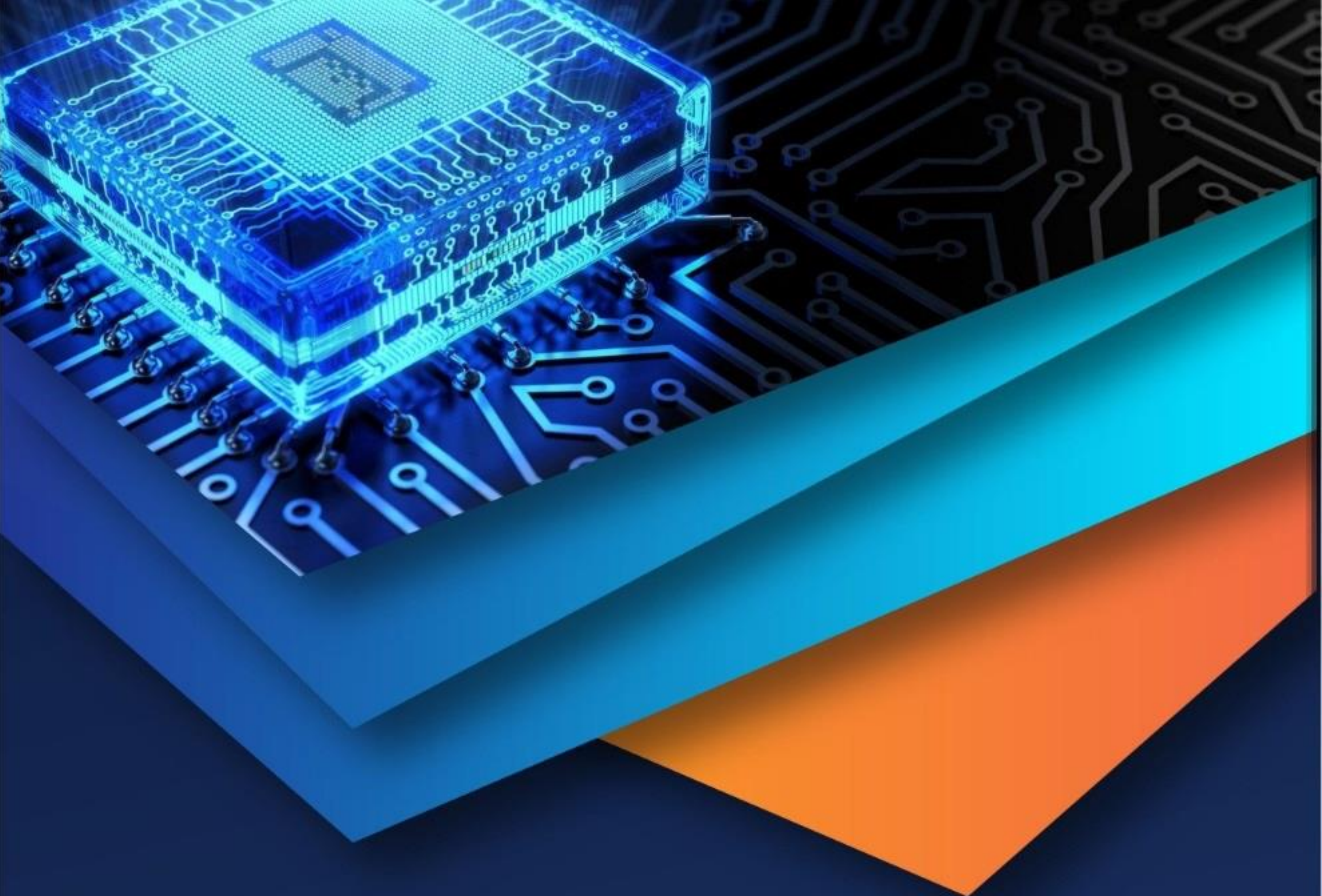

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