International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 06 Issue: 04 | April - 2022 Impact Factor: 7.185 ISSN: 2582-3930

ANALYSIS AND DESIGN COMPARISON OF CONVENTIONAL STEEL BUILDING WITH PRE-ENGINEERED BUILDING WITH PROVISION OF MEZZANINE FLOOR

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ABSTRACT

The Analysis and Design Comparison of Conventional steel building (CSB) and Pre-engineered building (PEB) with provision of mezzanine floor for a building was done in the work presented. Pre engineered building concept has helped in optimizing design, cost and time. The Pre-engineered building is the best option for basic requirements of construction nowadays like quick developments, economical and high quality for construction. Conventional steel building and Pre-engineered building are design for dead load, live load, wind load and earthquake load. All analysis of forces has been calculated as per is 875 (part 1, part2, and part3) and 1893 for earthquake forces. The design and modelling of 30m in length and 18m in wide building with roofing system has been carried out by using both the concept and the structural design has done in software STAAD Pro Vi8 to analyse the built frame.

Keywords: Conventional steel building, Pre-Engineered building, Mezzanine floor, Staad Pro, Tapered section.

I. INTRODUCTION

India is developing country and fastest growing economy which is rapidly flourishing in different sectors of development. Out of which Infrastructure is important one. In its development, the construction industry has discovered, invented and developed a numerous technologies, systems and products. Due to rapid growth of industrialization and population there arise a need of storage of space. Since 25%-30% of Indian population lives in towns and cities; hence construction is more in the urban places. But since the population is growing exponentially and the land is limited, there is a need of vertical growth of buildings in coming future. For the solution, we need structural concept which is economical, speedy, eco-friendly and will give effective span utilization. PEB is one of such concepts which fulfil this all requirements which is totally versatile.

A. Conventional Steel Building

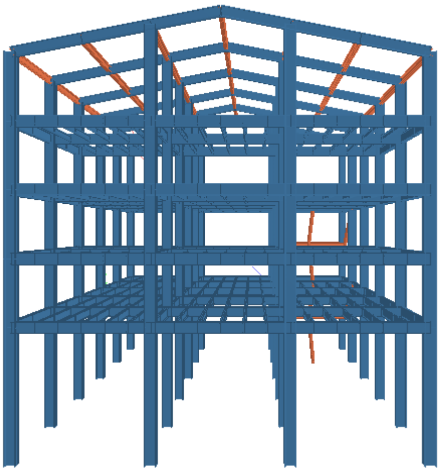

Fig no. 1 3D view of CSB model

Conventional steel buildings are constructed by using factory produced hot rolled steel sections. Fabrication involves cutting and welding or bolting of steel members to build the final structure.

In the design CSB, size of each member is selected on the basis of the maximum internal stress induce in the structural member. Since a hot rolled section has a constant dimension, many parts of the member in areas of low internal stresses are in excess of design requirements and also requires massive manpower. Therefore, time will be required more and also cost will be more, makes it uneconomical. It is suitable for design of complex structures.

A. Pre-engineered Building

Pre-Engineered Building concept contains the design of steel building systems which are predesigned in software and prefabricated in factory. As the name indicates, this system involves pre fabrication of structural elements using a predetermined registry of building materials and manufacturing techniques that can be skilfully complied with a wide range of structural and appealing design requirements of the sections which saves the time and cost. The roots of the PEB concept lies in providing the section at a location only as per requirement of that spot which makes it economical than the conventional concept. The sections can be varying throughout the length according to the bending moment which reduces steel quantity. This type of Structural system is generally cast off to build Industrial Buildings, Metro Stations, and Warehouses, etc.

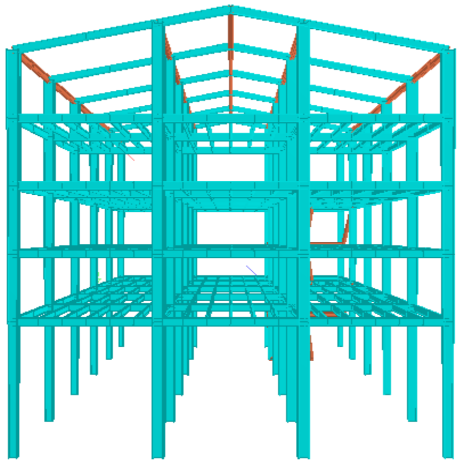

Fig no. 2 3D view of PEB model

B. Mezzanine Floor

Mezzanine floors are like temporary or provisional floors are used to increase a space of existing areas. These are easily removable and reusable. This type of mezzanine floors is used for industrial purpose, educational institute and storage yards. Based on the international code's mezzanine uses as much as one-third of the floor space compare to other floors. Mezzanine floors are used in modern days of architecture.

II. LITERATURE REVIEW

1) **Ms. Shalaka Patil and Dr. M. B. Kumthekar (2021):** Authors have performed comparative study of PEB with Conventional steel structure method in terms of cost, for Industrial building by using STAAD-PRO for analysis and designing. Based on their calculation of estimation of steel in CSB building as well as steel in PEB building, conclude that PEB costs 21% lesser than cost for CSB.

2) **Md Shahid Waseem Chaudhry, Vishwajeet Kadlag and Dr. Nagesh Shelke (2020):** They have performed the comparative study of multi-storey Multi-Span G+4 building by PEB as well as CSB concept. In this paper, they carried out design by considering wind load as the critical load for the structure. And they also designed for the same span for CSB frame. The design they have carried out is based on STAAD-Pro software with the Indian standards. The research concludes that the weight of PEB model is lesser than that of the CSB model of same length, width

and height. Provide good resistance to seismic forces because the PEB structures are lighter than the CSB structures.

3) **T. D. Mythili (2017):** Researchers studied an overview of Pre-engineered Building Systems. They used STAAD-Pro software for design and analyse the PEB structure and also design CSB structure for the same manner. Authors compare both the structural design between them and conclude that PEB structures building offers low cost, strength, durability, design flexibility, adaptability and recyclability as compare CSB structures building.

4) **Akhila Mukunda, K. Anju Lakshmi and Sudheer D Kulkarni (2021):** In this paper authors have studied enhancing storage capacity by utilizing vertical space using mezzanine flooring system in an industry. In this work, analyse and design for the company which having total area 4800 square feet which was not sufficient enough to store the required quantity of materials, for this as per economical and convenient solution various vertical storage systems they were considered and evaluated. Through the evaluation of the models, they found that as per cost the use of a mezzanine as the storage system would be ideal solution. They declared that used of mezzanine floor is cost effective, has a high load capacity, does not required training of personal or forklifts or pallet inventory and can be easily accessed by the workers through the opening or by the use of portable stairs.

5) **B Cano, J Galarza, J Rodr Guez and F Garc (2020):** In this research study authors performed the cracking control in mezzanine floor slab using Rice Husk Ash and Polypropylene Fibbers. In this paper they find the reasons of cracking in mezzanine floor slab and they also find how to control that cracking by using Rice Husk Ash and Polypropylene Fibbers. Plastic shrinkage cracking decreases, indicating that the combined incorporation of RHA and FPP helps in reducing the crack fissures. Finally, they declared that Compressive strength and flexural strength decrease, with RHA particles favourable for fissure reduction and FPP reinforce concrete elements.

III. METHODLOGY

In the present project, all of the specified information like building layout also as span lengths and bay-spacing of pre-engineered steel buildings is set based upon the foremost common industrial building's construction practices. A study was planned to research the behaviour of CSB and PEB steel buildings. The steel main frame of both building was analysed and designed on computer software STAAD PRO. The steel frame was subjected to the various load combinations and therefore the frame sections were optimized by using the technique of the bending moment profile. The steel frames were subjected to the load combinations consisting of dead, live, wind and seismic load. The steel mainframes were analysed by considering the building under fully enclosed conditions. The research work mainly discusses the comparison between PEB frame and CSB mainframes steel weight, lateral displacement (sway), and vertical displacement (deflection). The entire study is comprised of two parts. A typical CSB and PEB frame modelled in STAAD Pro.

CONVERTING CSB TO PEB:

Tapered Beam with variable section that is wider at one end and gradually becomes narrower towards the other end. A tapered beam transitions smoothly from one end to the other end.

Where the BM is more size is more & where its show less BM size will be less accordingly. In our structure we provide tapered section to main beams of floors, verticals columns, rafters, etc. Tapering members reduces steel quantity of overall structure, therefore it is more preferable.

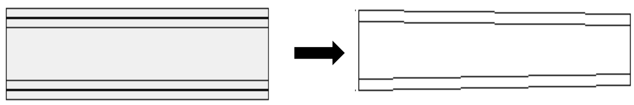

Fig no. 3 Section variation form CSB to PEB

A. Loads and loads combinations

Following loads and loads combination are used for analysis and design of building.

i. Dead load

These loads are permanent loads which are carried to the structure throughout their lifespan. Dead loads are also called as stationary loads. It includes the self-weight of rigid frames and imposed dead load due to secondary elements like roof sheeting, purlins, insulation, etc. To achieve accurate results, the self-weight of structural members is computed by STAAD Pro. The calculation of dead loads of each structure are calculated by the volume of each section and multiplied with the unit weight. The calculation of dead loads to be done as per IS 875 (part1) – 1987.

Self-weight = -1.1KN/m (10% more for connection like bolt, plate weight)

Floor load = Thickness x Density = 0.15×25 = -3.75KN/m^2

Floor finish = -0.5KN/m^2

Staircase = -1.5KN/m (assuming 1000kg/m^2)

ii. Live loads

Live loads are also called as imposed or sudden loads. Live loads changes with respect to time. These loads are assumed to be produced by the intended use or occupancy of the building including weights of movable partition or furniture etc. The live load cannot be calculated from the specific formula. Generally, it is assumed for a design. The minimum values of live loads to be assumed are given in IS 875 (part2)-1987.

Floor load = 400kg (assumed) = 4KN/m^2

Staircase = -6KN/m

iii. Wind load

Wind load is primarily horizontal load caused by the movement of air relative to earth. Wind load is required to be considered in structural design especially when the height of the building exceeds two times the dimensions transverse to the exposed wind surface. For low rise building say up to four to five stories, the wind load is not critical because the moment of resistance provided by the continuity of floor system to column connection and walls provided between columns are sufficient to accommodate the effect of these forces. Complete details of calculating wind load on structures are given (by the IS-875 (Part 3) -1987).

Wind pressure:

Pressure load at intermediate panel = 1.05×-0.7×6 = 4.41KN/m

Pressure load at end panel = 4.41/2 = 2.205KN/m

Wind in suction:

Suction load at intermediate panel = 1.05×0.4×6 = -2.25KN/m

Suction load at end point = -2.25/2 = -1.26KN/m

Wind load in x-direction:

(Column) = 1.05×0.4×0.9=0.198KN/m

(Beam) =1.05×0.5×2.05 = 1.07KN/m

(Mezzanine exterior beam) = 1.05×0.4×2.05 = 0.861KN/m

(Purlin) =1.05×0.15×2 = 0.315KN/m

Wind load in z-direction:

(Beam) = 1.05×0.5×2.05 = 1.07KN/m

(Column) = 1.05×0.6×2.05 = 1.29KN/m

iv. Load combinations:

For wind calculation:

a) Limit state of serviceability:

1. Load combination 1: 1.5(DL + LL)
2. Load combination 2: 0.9DL + 1.5WLP
3. Load combination 3: 0.9DL + 1.5WLS
4. Load combination 4: 1.5DL + 1.5WLP
5. Load combination 5: 1.5DL + WLS
6. Load combination 6: 1.2(DL + LL + WLP)
7. Load combination 7: 1.2(DL + LL + WLS)

b) Limit state of serviceability:

1. Load combination 1: DL + LL
2. Load combination 2: DL + WLP
3. Load combination 3: DL + WLS
4. Load combination 4: DL + 0.8LL + 0.8WLP
5. Load combination 5: DL + 0.8LL + 0.8WLS

For seismic forces calculation:

1. Load combination 1: DL+LL
2. Load combination 1: DL+/-EL
3. Load combination 1: DL+0.8LL+0.8EL
4. Load combination 1: 1.5DL+LL
5. Load combination 1: 0.9DL+/-1.5EL
6. Load combination 1: 1.2DL+1.2LL+/-1.2EL

IV. PROBLEM STATEMENT

For CSB and PEB

Sr. No.	Description	
1	Type of structure	Double story mezzanine floor
2	Location	Mumbai
3	Length	30M
4	Width	18M
5	Height	18M
6	Height of column	6M
7	Bay spacing	6M
10	Roof slope	2 in 10
11	Rise of truss	1.8
12	Roof material	G.I. sheet
13	Mezzanine floor height	3M
14	Mezzanine floor material	P.C.C
14	Wind speed	44m/s
15	Wind terrain category	2
16	Steel grade	Fe415

Table no.1 Problem Statement

V. RESULTS AND OPTIMIZATION

The models of buildings are analysing and design in Staad-Pro software. For both the models, clear spacing of column is considered as 6m and then optimization of structure has been carried out.

Following table shows design parameters of both CSB and PEB model:

Detailed Results for PEB and CSB:

Sr. no.	Description	PEB	CSB
1	Support Reaction (Fx) (Kn)	2138.447	2100.740
2	Max. SF (KN)	206.211	209.935
3	Max. BM (KN.M)	246.062	245.19
4	Steel takes off (KN)	2206.816	2480.598

Table no. 3 Detailed Results

From above table we can say that PEB required less quantity of steel as compared to CSB while carrying more loads

<u>% STRUCTURAL OPTIMIZATION AS PER WIND LOADING</u>

CSB		
PROFILE	LENGTH (M)	WEIGHT (KN)
ISHB450	446.40	689.274
ISMB500	660.00	562.780
ISMB400	840.00	506.548
ISMB250	360.00	131.638
ISMB450	110.14	78.093
ISMC300	226.27	160.954
TOTAL		2129.287

Table no. 4 Steel optimization of CSB

PEB		
PROFILE	LENGTH (M)	WEIGHT (KN)
Tapered	69.00	82.264
Tapered	230.40	288.851
Tapered	660.00	388.470
Tapered	33.00	45.935
Tapered	18.00	25.263
Tapered	36.00	57.301
Tapered	73.43	33.950
Tapered	36.71	16.341
Tapered	18.00	27.475
ISMC300	226.27	160.954
Tapered	1199.99	510.327
Tapered	3.00	3.208
Tapered	21.00	27.376
Tapered	18.00	27.060

TOTAL	1694.77

Table no. 5 Steel optimization of PEB

% OF STEEL OPTIMISATION

Weight of CSB - Weight of PEB
= 2129.287-1694.778

= 434.509

% OF STEEL OPTIMISATION
= x100 (434.509/2129.287)
= **20.40%**

% COST OPTIMIZATION AS PER WIND LOADING

STRUCTURE	CSB	PEB
WEIGHT (KN)	2129.287	1694.778
WT IN TON FORCE (METRIC)	212.9287	169.4778
COST OF STEEL	65000/TON	65000/TON
TOTAL COST	212.9287 X 65000 =13840366	169.4778 X 65000 =11016057

Table no. 6 Cost optimization of CSB and PEB

% COST OPTIMIZATION

COST OF CSB –COST OF PEB
= 13840366 – 11016057 = 2824309

% COST OPTIMIZATION

= x100 (2824309/13840366)

= **20.40**

% STRUCTURAL OPTIMIZATION AS PER SEISMIC LOADING

CSB		
PROFILE	LENGTH (M)	WEIGHT (KN)
ISHB450	446.40	997.904
ISMB500	660.00	562.780
ISMB400	840.00	506.548
ISMB250	360.00	131.638
ISMB450	110.14	78.093
ISMC300	286.27	203.635
TOTAL		2480.598

Table no. 7 Cost optimization of CSB and PEB

PEB		
PROFILE	LENGTH (M)	WEIGHT (KN)
Tapered	69.00	82.264
Tapered	230.40	800.889
Tapered	660.00	388.470
Tapered	33.00	45.935
Tapered	18.00	25.263
Tapered	36.00	57.301
Tapered	73.43	33.950
Tapered	36.71	16.341
Tapered	18.00	27.475
ISMC300	226.27	160.954
Tapered	1199.99	510.327
Tapered	3.00	3.208
Tapered	21.00	27.376
Tapered	18.00	27.060
TOTAL		2206.816

Table no. 8 Cost optimization of CSB and PEB

% OF STEEL OPTIMISATION

Weight of CSB - Weight of PEB
=2480.598-2206.816

=273.782

% OF STEEL OPTIMISATION

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 06 Issue: 04 | April - 2022 Impact Factor: 7.185 ISSN: 2582-3930

= (273.782/2480.598) X 100

= **11.036%**

% COST OPTIMIZATION AS PER SEISMIC LOADING

STRUCTURE	CSB	PEB
WEIGHT (KN)	2480.598	2206.816
WT IN TON FORCE (METRIC)	248.0598	220.6816
COST OF STEEL	65000/TON	65000/TON
TOTAL COST	248.0598X 65000 =16123887	220.6816X 65000 = 14344304

Table no. 9 Cost optimization of CSB and PEB

% COST OPTIMIZATION

COST OF CSB –COST OF PEB

= 16123887- 14344304

=1779583

% COST OPTIMIZATION

= (1779583/16123887) X 100

= **11.036%**

RESULTS FOR MAIN COLUMN

Sr. No.	Description	CSB	PEB
1	Section Size	ISHB4450 TB	Web 500*12mm Flange 400*20mm
2	Length m	6	6
3	Displacement maximum mm	4.382	8.813
4	Axial Force KN	1071.918	893.214
5	Shear Force KN	596.520	476.100
6	Bending Moment KN.m	922.068	864.99
7	Steel Quantity KN	40.239	28.65

Table no. 10 Results for main column of CSB and PEB

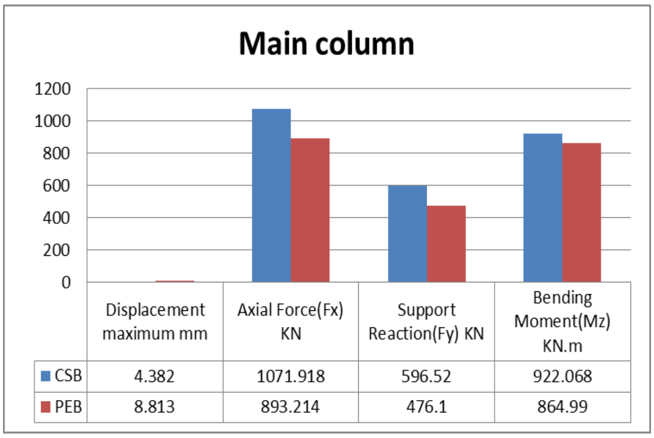

Fig no. 5 Results or main column of CSB and PEB

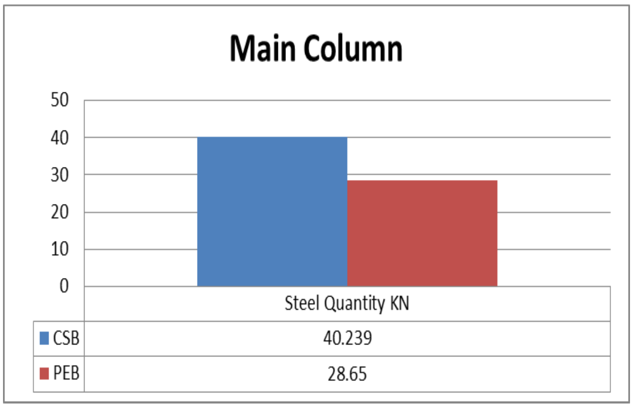

Fig no. 4 Steel quantity for main column of CSB and PEB

RESULTS FOR MAIN BEAM

Sr. No.	Description	CSB	PEB
1	Length m	6	6
2	Displacement maximum mm	62.922	140.988
3	Axial Force KN	32.832	71.958
4	Shear Force KN	187.296	188.801
5	Bending Moment KN.m	257.777	263.271
6	Steel Quantity KN	93.796	57.301

Table no. 11 Results for main beam of CSB and PEB

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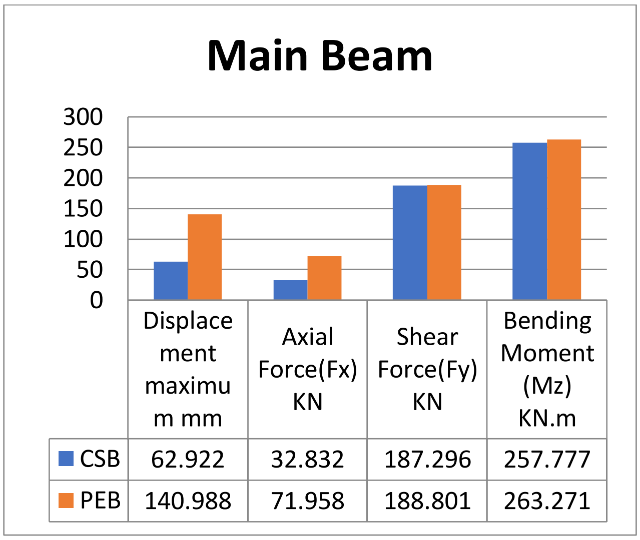

Fig no. 6 Results for main beam of CSB and PEB

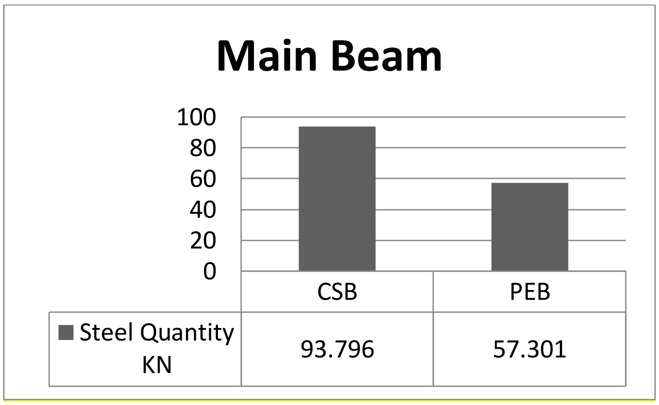

Fig no. 7 Steel quantity for main beam of CSB and PEB

RESULTS FOR MEZZANINE COLUMN

Sr. No.	Description	CSB	PEB
1	Length m	3	3
2	Displacement maximum mm	12.095	26.559
3	Axial Force KN	604.262	625.761
4	Shear Force KN	3.360	6.969
5	Bending Moment KN.m	4.550	14.057
6	Steel Quantity KN	6.706	4.510

Table no. 12 Results for mezzanine column of CSB and PEB

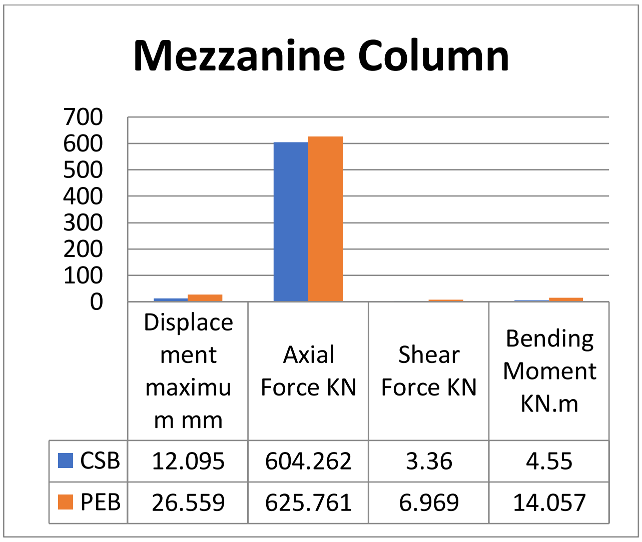

Fig no. 9 Results for mezzanine column of CSB and PEB

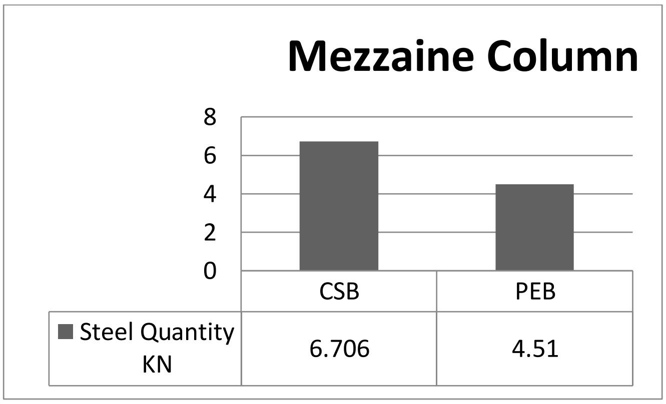

Fig no. 8 Steel quantity mezzanine column of CSB and PEB

RESULTS FOR MEZZANINE BEAM

Sr. No.	Description	CSB	PEB
1	Length m	6	6
2	Displacement maximum mm	18.55	39.25
3	Axial Force KN	11.910	63.011
4	Shear Force KN	29.653	39.230
5	Bending Moment KN.m	42.546	76.822
6	Steel Quantity KN	5.116	3.532

Table no. 13 Results for mezzanine beam of CSB and PEB

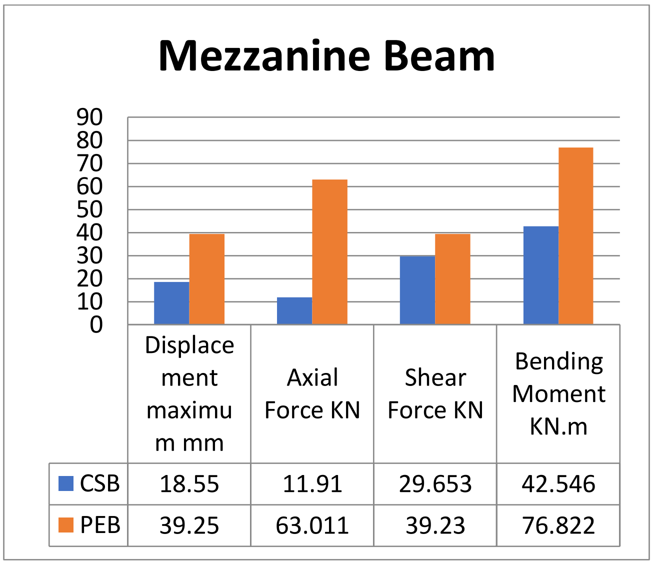

Fig no. 10 Results for mezzanine beam of CSB and PEB

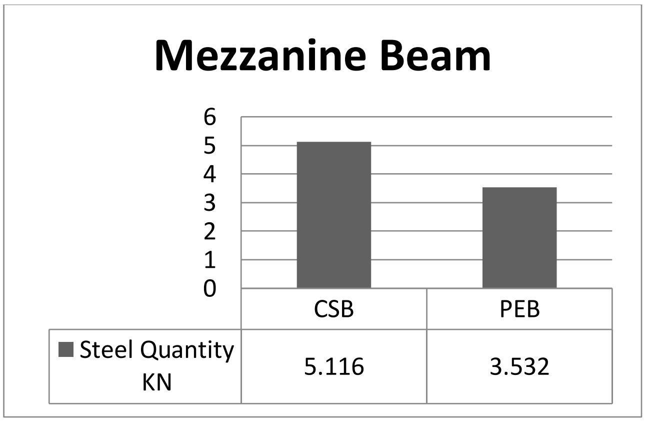

Fig no. 6.8 Steel quantity for mezzanine beam of CSB and PEB

RESULTS FOR PURLIN

Sr. No.	Description	CSB	PEB
1	Length m	6	6
2	Displacement maximum mm	8.821	19.153
3	Shear Force KN	3.521	3.521
4	Bending Moment KN.m	5.282	5.282
5	Steel Quantity KN	4.268	2.169

Table no. 14 Results for purlin of CSB and PEB

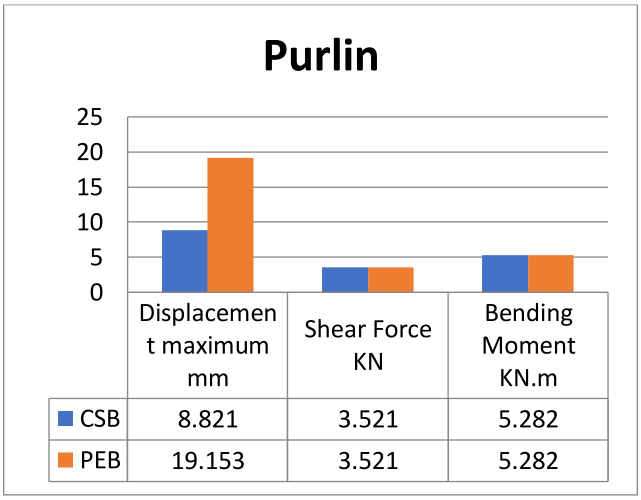

Fig no. 11 Results for purlin of CSB and PEB

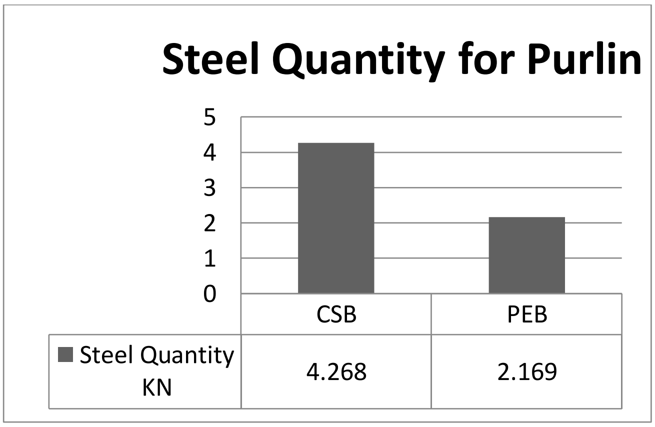

Fig no. 12 Steel quantity for purlin of CSB and PEB

RESULTS FOR RAFTER

Sr. No.	Description	CSB	PEB
1	Length m	18	18
2	Displacement maximum mm	55.96	121.32
3	Axial Force KN	172.435	86.056
4	Shear Force KN	82.348	53.590
5	Bending Moment KN.m	296.63	385.056
6	Steel Quantity KN	78.093	33.950

Table no. 15 Results for rafter of CSB and PEB

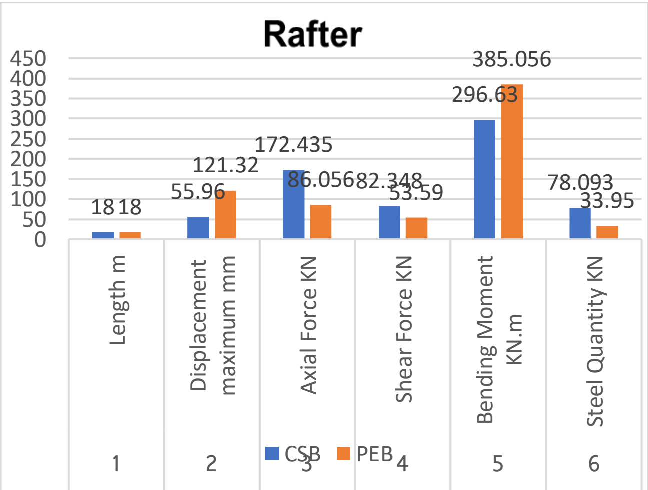

Fig no. 13 Results for rafter of CSB and PEB

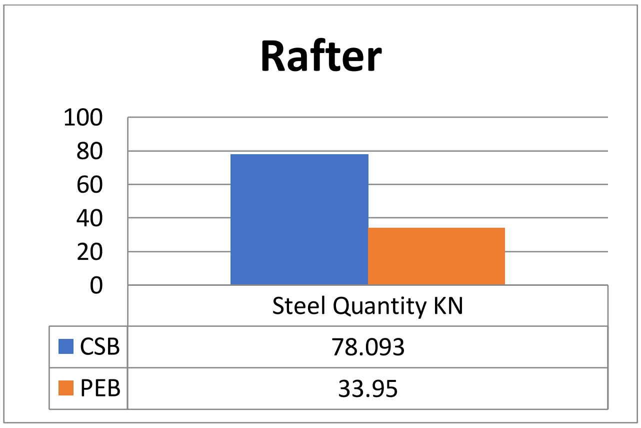

Fig no. 14 Steel quantity for rafter of CSB and PEB

VI. DISSCUSION

- On CSB the loading is nodal loading therefore the maximum load is taken care by member itself hence the support reaction is less for CSB.
- With reduction in self-weight, the loads and hence the forces on the PEB will be relatively lesser, which decreases the effective sizes of the structural members.
- By the wind modelling and design, it concludes that PEB building is approx. 20.40% lighter than CSB building.
- According to the wind modelling and design, CSB structure are expensive than PEB by approximately 20.40%.
- By the seismic modelling and design, it concludes that PEB building is approx. 11.036 % lighter than CSB building.
- According to the seismic modelling and design, CSB structure are expensive than PEB by approximately 11.036%.

VII. CONCLUSION

PEB offers low cost, strength, durability, design flexibility, adaptability and recyclability.

It negates from regional sources. Infinitely recyclable, steel is that the material that reflects the imperatives of sustainable development, supported the analytical and style results there on of conventional and pre-engineered steel buildings, in which optimum steel sections were assigned to the models for every member the following conclusions are drawn

1) The study of self-weight of the models showed that the self-weight for PEB is a smaller amount than that of CSB.
2) Steel quantity depends on primary members i.e., Columns, Rafters and Purlins.
3) Primary member steel consumption decreased as frame spacing increased, while secondary member steel consumption increased.
4) Wind loads are more resistant to PEB's low-weight, flexible frames.
5) Light weight foundation can be adopted for PEB which leads to simplicity in design and reduction in cost of construction of foundation.

6) Bending moment and shear force in column are maximum for PEB structure.

7) PEB structure with mezzanine floor in industrial shed is economic and safe.

8) It is also seen that the load of PEB depends on the Bay Spacing, with the increase in Bay Spacing up to certain spacing, the load reduces and further increase makes the weight heavier. To Conclude "Pre-Engineered Building Construction gives the very best users how more economical and better solution for long span structures where large column free areas are needed"

VIII. REFERENCES

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