Design Optimisation of an Industrial Structure from Steel Frame to Pre-Engineered Building

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Abstract-Over the years, the technological improvements have contributed in enhancing the quality of our daily life to a large extent. Pre-engineered buildings are one such example in this revolution. Though it is known to have its origin in 1960's it has been in practice widely only during the recent years. The Pre-Engineered Building (PEB) is a new concept of single storey industrial building construction. It includes the technique of providing the best possible section according to the optimum requirement. This papergives a comparative study of Pre-Engineered Building (PEB) concept and Conventional Steel Building (CSB) concept. The study is achieved by designing an industrial building using both the concepts and analyzing them using the structural analysis and design software Staad pro. To achieve this, PEB andCSB are designed for dynamic forces, which include wind forces. The results obtained from the study shows that Pre- engineered buildings are advantageous over conventional steel buildings.

Index terms- Pre-Engineered Building, Conventional Steel Building, Staad pro.

1. INTRODUCTION

Steel is a material having high strength per unit mass. Hence it is used in the construction of column-free space structures. Steel structures are built in a very short time as time is an important consideration, which are widely used in the construction of industrial buildings.An industrial building is usually a single storey steel structure with or without mezzanine floors. Brick masonry, concrete walls or GI sheet coverings may be the enclosures of these structures. Generally the walls are non-bearing but sufficiently strong enough to withstand the lateral forces caused by wind or earthquake. These buildings can be categorized as Pre-Engineered Buildings (PEB) and Conventional Steel Buildings (CSB) according to the design concepts. PEB's are nothing but steel buildings in which excess steel is avoided by tapering the sections as per the bendingmoment's requirement.If we go for regular steel structures, time required and cost will be morewhichtogethermakes it uneconomical. Thus these buildings are fabricated fully in the factory after designing and then brought to the site. All the components are erected at the site with nut and bolts system which in total reduces the time needed for the completion of the structure.

This paper starts with the introduction to PEB and CSB systems. Load and load combinations considered in the analysis of the structure can be seen in the further portions. Final portion explains the results obtained from the software analysis of the structure and the inferences made from the same along with the inferences from the literature studies. The paper aims at stating the advantages of PEB over CSB.

2. METHODOLOGY

The present paper includes the design of an Industrial buildingconsidered to be located at Bangalore. The structure is proposed as a Pre-Engineered Building with 66 meter span and 34.2 meter width with an eave height of 7.5 meter. The design is carried out by considering wind load as the critical load for the structure. CSB frame is also designed for the same span. Both the designs are then compared to find out the economic output. The designs are carried out in accordance with the Indian Standards and by the help of the structural analysis and design software Staad.pro.

2.1. Pre-Engineered Buildings

Pre-Engineered Buildingsare the steel buildings which are predesigned and prefabricated. The basis of the PEB concept lies in providing the section at a location according to the requirement at that spot. These sections can be varying throughout the length according to the bending moment diagram. To achieve this criteria, tapered I sections made with built-up thin plates are adopted. The use of optimum least section leads to effective savings in steel and cost reduction.

2.2. Conventional Steel Buildings

Standard hot rolled I or C sections are used which may be in many segments much heavier than what is actually required as per design in CSB. These sections have standard dimensions which cannot be altered as per the requirement. The dimensions and loading details are same as in PEB. The CSB is then analyzed and designed using the software in the same manner as in PEB.

2.3.Design software Staad pro

Staad pro is a powerful tool for computerized structural engineering for 3D model generation, analysis and multi-material design. It has been the choice of design professionals around the world for the static or dynamic analysis of the steel structure.It gives theBending Moment, Axial Forces, Shear Forces, Torsion and Beam Stresses of bothPEB and CSB so that the design canbe done using tapered and standard sections and checked for safety.

3. ANALYSIS AND DESIGN

The analysis and design of the proposed PEB and CSB are done using Staad pro 2007 and IS codes.
Structural components of the study considered for the analysis and design are:

(1) Main frame
(2) Gable end frame
(3) Secondary structural components: Roof purlins, Wall girts and Bracing system
(4) Connections

- Main frame connections
- End frame connections

3.1. Building details:

The plan of the building is shown in figure 1.

Building type : Clear span PEB and CSB
Length of the building : 66 m
Width of the building : 34.2 m
No. of bays along length : 11 no.s of each 6 m
No. of bays along width : 4 Nos. of each length 5.53 m and 2 Nos. of each length 6.04 m
Slope of roof : 1 in 6
Eave height of the building: 7.5 m
Roof purlins : Span 6 m. Continuous and spaced at 1.4 m c/c
Wall girts : Span 6 m. Continuous and spaced at 1.4 m c/c

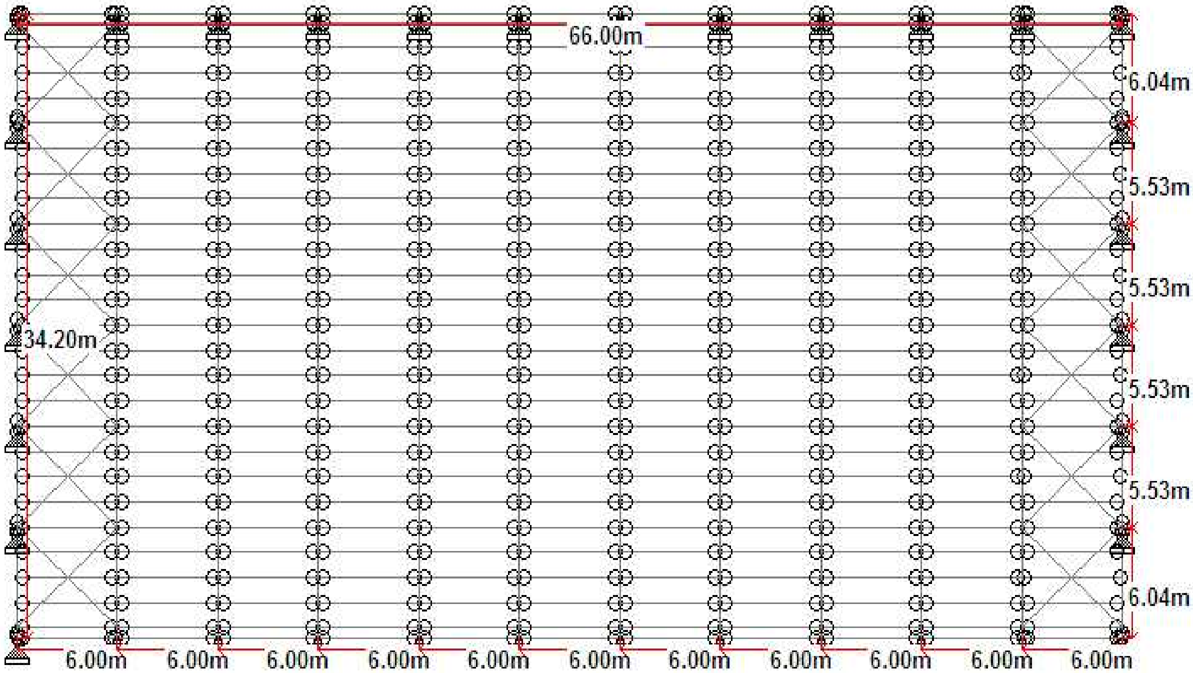

Fig.1. Building plan

3.2. Loads and Load combinations:

A building must be designed to support its own dead load, a specified live load and a specified wind load as a minimum requirement. Other loads such as seismic loads, crane loads, collateral loads, mezzanine loads or thermal loads are considered only when specified by the customer. For the PEB structure wind load is critical and hence the load calculation for the structure can be carried out in accordance with IS:875(Part 3)-1987. Therefore the load combinations of dead load, live load and wind load are incorporated in the design.

3.2.1. Dead load:

Sheet load = 0.11 kN/ m^2

Total Dead load per meter = 0.11*1.4
= 0.154 kN/m^2
Truss angle = 9.35 deg.
Horizontal load = 0.024kN/m^2
Vertical load = 0.152 kN/m^2

3.2.2. Live load:

On roof sheet = 0.75 kN/m^2
Total live load per meter = 0.75*1.4
= 1.050 kN/m^2
Truss angle = 9.35 deg.
Horizontal load = 0.167kN/m^2
Vertical load = 1.037kN/m^2

3.2.3. Wind load:

Wind load is calculated as per IS:875 (Part 3)-1987. The wind load over the roof can be provided as uniformly distributed load acting outward over the rafter. For side walls, the wind load is applied as uniformly distributed loads acting inward or outward to the walls according to the wind case.
Design wind speed as per Clause 5.3, IS:875 (Part 3) – 1987 is given by,

$V_z = V_b * k_1 * k_2 * k_3$For Bangalore, V_b = 33 m/s, from appendix A as per IS: 875 (Part 3) – 1987

k_1 = 1.00, from table 1 as per IS: 875 (Part 3) – 1987
k_2 = 0.98, from table 2 for terrain category 2- Class B buildings
k_3 = 1, for upwind slope (θ) less than 3^0
Therefore Design wind speed ($V_{z)}$ = $V_b * k_1 * k_2 * k_3$
= 33 * 1.0 * 0.98 * 1.0
= 32.34 m/s

Design wind pressure is given by, $p_z = 0.6\ V_z^2$
= 0.6 * 32.34^2
= 627.52 N/m^2
= 0.628 KN/m^2

3.2.4. Design wind loads:

Depending on the internal and external pressure co-efficients, four different wind load cases are considered in this study.
For Internal pressure co-efficient, two design conditions shall be examined in the case of the buildings where the claddings permit the flow of air with openings not more than about 5 percent of the wall area but where there are no large openings. Therefore internal pressure co-efficient of +0.2 and -0.2 are taken.

External pressure co-efficients are taken from table 5 of IS: 875 (part 3) – 1987 for roof and table 4 of IS: 875 (part 3) – 1987 for sides and gable end.

Final wind loads (kN/m) are as below in table 1:
Wind load case 1:
Wind angle=0, windward side+exhaust
Wind angle=0, leeward side+exhaust

Wind load case 2:
Wind angle=0, windward side+suction
Wind angle=0, leeward side+suction

Wind load case 3:
Wind angle=90, windward side+exhaust
Wind angle=90, leeward side+exhaust

Wind load case 4:
Wind angle=90, windward side+suction
Wind angle=90, leeward side+suction

Table 1. Final wind loads (kN/m)

Applied area of the building		WL1	WL2	WL3	WL4
Roof	Vertical windward	1.214	0.867	0.867	0.52
	Horizontal windward	-0.195	-0.139	-0.139	-0.084
	Vertical leeward	0.52	0.173	0.694	0.347
	Horizontal leeward	0.084	0.028	0.112	0.056
Side	Windward	0.439	0.791	-0.615	-0.264

	Leeward	-0.395	-0.044	-0.615	-0.264

Table 1(Continued)

Gable end	Windward	-0.703	-0.351	0.439	0.791
	Leeward	-0.703	-0.351	-0.264	0.088
Frictional drag	Windward and leeward	0.044	0.044	0.044	0.044

3.2.5. Load combinations:

For the present study, various primary loads are considered as given below.

(1) DEAD LOAD
(2) LIVE LOAD
(3) WIND LOAD 1
(4) WIND LOAD 2
(5) WIND LOAD 3
(6) WIND LOAD 4

For these primary loads, following are the combinations adopted for the analysis in both the concepts according to IS 800: 2007

(1) DL+LL
(2) DL+WL1
(3) DL+WL2
(4) DL+WL3
(5) DL+WL4
(6) 1.5DL+1.5WL1
(7) 1.5DL+1.5WL2
(8) 1.5DL+1.5WL3
(9) 1.5DL+1.5WL4

3.3. Analysis by Staad pro:

TheBending Moment Diagrams of the main frames of PEB and CSB by Staad pro are as shown in figure 2 and 3.

Fig.2. Bending Moment Diagram of Main frame for PEB

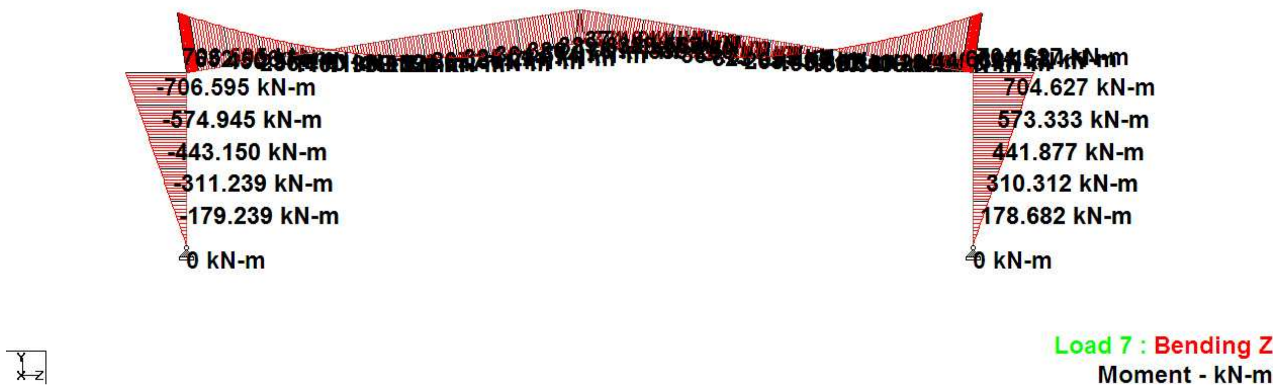

Fig.3. Bending Moment Diagram of Main frame for CSB

4. RESULTS AND DISCUSSION:

Using the software Staad pro, the structure considered was analyzed and designed using both the PEB and CSB concept and obtained results are summarized as below in table 2 with reference to figure 2 and 3.

Table 2.Summary of the results

Sl.no.	Parameter	PEB	CSB
1	Steel take off (kN)	1525	2410
2	Maximum moment (kNm)	670	705
3	Maximum shear force (kN)	326	414
4	Support reaction (kN)	155	197

5. SUMMARY AND CONCLUDING REMARKS:

The paper contains the analysis and design concepts of PEB and also makes a comparison of the PEB and CSB. The results obtained from the study together with the literature studies show that the Pre- engineered buildings are advantageous over conventional steel buildings. The various inferences made from the study are as follows.

(1) Steel take off :

It can be seen that PEB's reduce the steel used by 36% than that required for the CSB. This is the main factor for the cost reduction of the structure. Thus the material and cost savings can be done using PEB's.

(2) Moment and force:

The bending and shear force of PEB are lesser than the CSB which in turn reduces the material required for the structure. The steel is provided as per the bending moment obtained at a particular section.

(3) Support reaction:

Support reaction for PEB is lesser compared to CSB. Hence heavier foundations can be avoided and thus the cost is reduced due to lighter foundations in the case of PEB.

(4) Earthquake resistance:

The lighter tapered sections offer better resistance to earthquake forces than the heavy frames of CSB in the earthquake zones.

(5) Delivery of the material:

Delivery of PEB components is done in around 6 to 8 weeks where as in the case of CSB it is more than 20 weeks.

(6) Erection of the components:

The PEB components are manufactured before bringing it to the site and therefore easily erected using nut and bolts at the site. No field work is required which makes the process of erection simpler.

(7) Savings in cost:

Savings in cost for PEB can be done in many ways such as savings in material, providing lighter foundation etc. Also the PEB's are aesthetically pleasing at a lesser cost. Upto 30% cost reduction can be achieved using PEB.

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