Structural Performance of Pre Engineered Building: A Comparative Study

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Abstract: Technological advancement has greatly aided in improving quality of life through variety of new products and services. Pre Engineered Building (PEB) is among such technological advancement in the structural engineering. PEB concept provides optimum design, good aesthetic view, fast rate of construction and reduction in erection time. PEB satisfies a broad range of custom design needs and applications. This methodology is adaptable not only because of its high quality pre-designing and prefabrication, but also of its flexibility. In the current study, the comparison has been made on the structural performance of multiple bay system with different wind zones [Locations: Vijayawada and Hyderabad]. Analysis and design have been carried out using STAAD.Pro software. The structural performance of pre-engineered building has been assessed through the shear force (SF) and bending moment (BM) magnitudes. Based on the output of SF and BM of pre-engineered components through Staad. Pro analysis, the geometrical properties of pre-engineered sections have been decided. Results concludes structure weight located in Vijayawada is 11.04% higher than that of the structure in Hyderabad.

Keywords: Pre-Engineered Building, wind zones, shear force, bending moments, STAAD.Pro

1. Introduction

Steel is naturally ductile and versatile, it is the material of choice for construction. The steel industry is expanding very fast in almost every country. A number of technologies, systems, and products are developed in the construction industry, the PEB concept is one of them. The main concept in the PEB is geometry of frame matches the shape of bending moment diagram. As a result, slender tapered frame elements are used. To achieve this configuration, built-up tapered I sections are used. This leads to the optimisation of the material usage thereby reducing the weight of the structure. Use of PEB structure has been limited to Northern America and Mid East till 1990’s after which outspread to Asia and Africa regions. The PEB construction concept has now gained widespread acceptance and commercial success. International contractors and designers who earlier only stipulated conventional steel construction, now begun to specify the approach towards PEB. No other building technique match PEB when it comes to speed and value form excavation to occupancy. Pre-engineered building has many advantages which made the PEB industry’s explosive growth in recent years. The advantages include: Reduction of construction time, Lower cost, Flexibility of expansion, large clear spans, Quality control. Low maintenance, seismic reliability, architectural versatility, environment friendly. Components of PEB are Primary members and secondary members. Columns, Rafters, Base plate, Crane Girder, Bracings and...
Mezzanine floor comes under primary members. Purlins, Girts, eave gutter, sag rods etc. comes under secondary members. PEB are installed with various structural accessories like canopies, sliding doors, gutters, louvers, turbo ventilators etc. Pre-engineered buildings are typically low-rise structures. Some of the applications of Pre-engineered buildings are Industrial Buildings and Workshops, warehouses, supermarkets, indoor stadiums, outdoor stadium with canopies, Aircraft Hangers etc. Kalesha, et al. (2020) made study on PEB technique. They concluded that effective sizes in PEB structures are smaller than CSB structures so PEB is low-cost. The weight of PEB is almost about 50% or less compared to the steel used in conventional steel structures. Kiran et al. (2014) analyzed and designed an industrial structure according to the Indian standards, IS 800-1984, IS 800-2007 and also by referring MBMA-96 and AISC-89. They concluded that loading as per Indian codes is greater than MBMA code and also observed that in industries most of the projects are done with AISC/MBMA. Aditya et al. (2016) done comparative study between Conventional Steel Building (CSB) and PEB. PEB structures are 25 % low consumption of time and 30% lighter than CSB. They conveyed that PEB structures can be easily designed by simple design procedure. PEB structures have huge benefits than CSB in economy, speed of construction & simple erection. Hence they concluded that PEB has wide scope in India however less preferred. Sharma (2007) made analysis, design and comparison of Pre-Engineered industrial building with the CSB by mainly comparing the bending moments at different sections. Result concludes even though PEB give clear spans, it weighs minimum 27% - 30% low compared to CSB. Darshana (2012) compared the PEB design by IS 800 and AISC codes. And observed that calculation of wind coefficient using MBMA/AISC is much simplified as compared to IS code. Deflection limits of IS codes are higher than deflection limits of by MBMA/AISC. Thakar et al. (2013) Comparative study of PEB by varying depth of width and spacing of structure. They concluded that as spacing of portal increased steel consumption is decreased by primary members and increased for secondary members.

2. Description of the Pre Engineered Structure

An industrial PEB located at different locations such as Vijayawada and Hyderabad with same structural configuration details have been analysed and designed according to Indian Standard Codal provisions using STAAD. Pro software, comparison study has been made.

2.1 Structure details

The structural configuration for multiple bay system for different wind zones have been presented in Table 1.

| Location    | Vijayawada | Hyderabad |
|-------------|------------|-----------|
| Length      | 70 m       | 70 m      |
| Width       | 75 m       | 75 m      |
| Eave Height | 5 m        | 5 m       |
| Bay spacing | 10 bays @ 7 m bay spacing | 10 bays @ 7 m bay spacing |
| Basic wind speed | 50 m/sec | 44 m/sec |
| Seismic zone | III       | II        |

2.2 Load calculations

The Dead Load (DL), Live Load (LL) and Wind Load (WL) calculations are done as per IS code and presented as follows:
2.2.1 Calculation of Dead load according to IS 875 (Part 1)-1987

In addition to self-weight, we must account for imposed dead loads caused by secondary elements such as roof sheeting, purlins, and so on.

- Weight of purlin: 5 kg/m²
- Weight of sheeting: 5 kg/m²

Total Dead load: 5 kg/m² + 5 kg/m² = 10 kg/m²: 0.1 kN/m²

Dead load = 0.1 x 7 (Bay Spacing = 7 m)
= 0.7 kN/m

2.2.2 Calculation of Live load according to IS 875 (Part 2)-1987

All loads that the structure is subjected to during erection, maintenance, and use during its lifetime are considered live loads.

As per Table 2 of the IS: 875 (Part 2)-1987(Imposed loads on various types of roofs)

Live load = 0.75 kN/m²
= 0.75 x 7 (Bay Spacing = 7 m)
= 5.25 kN/m

2.2.3 Calculation of Wind load according to IS 875 (Part 3)-2015

Basic wind speed ($V_b$)

Design wind speed ($V_z$) = $V_b$ x $K_1$ x $K_2$ x $K_3$ x $K_4$ (Clause 6.3)

Where, $K_1$ = probability factor (risk coefficient)
$K_2$ = terrain roughness and height factor
$K_3$ = topography factor
$K_4$ = importance factor for the cyclonic region

Design wind pressure $P_z = 0.6 V_z^2$ (Clause 7.2)

Design wind pressure $P_d = K_d x K_a x K_c x P_z$ (Clause 7.2)

Where, $K_d$ = wind directionality factor
$K_a$ = area averaging factor and
$K_c$ = combination factor

Wind load on individual members,

$F = (C_{pe} - C_{pi}) x A x P_d$ (Clause 7.3.1)

Where, $C_{pe}$ = external pressure coefficient,
$C_{pi}$ = internal pressure coefficient,
$A$ = surface area of structural element or cladding unit,
$P_d$ = design wind pressure

Various wind load cases

Wind Load 1 (WL 1): Wind direction towards Right
Wind angle = 0°
+0.5 internal pressure coefficient

Wind Load 2 (WL 2): Wind direction towards Left
Wind angle = 0°
+0.5 internal pressure coefficient

Wind Load 3 (WL 3): Wind direction towards Right
Wind angle = 0°
-0.5 internal pressure coefficient

Wind Load 4 (WL 4): Wind direction towards Left
Wind angle = 0°
-0.5 internal pressure coefficient

Wind Load 5 (WL 5): Wind direction towards Right
Wind angle = 90°
+0.5 internal pressure coefficient

Wind Load 6 (WL 6): Wind direction towards Left
Wind angle = 90°
-0.5 internal pressure coefficient

Final wind coefficients (C_{pe}-C_{pi}) for various wind load cases for Vijayawada location shown in Tables 2 and 3.

**Table 2 Final wind coefficients for Vijayawada location**

|       | WL1 | WL2 | WL3 | WL4 | WL5 | WL6 |
|-------|-----|-----|-----|-----|-----|-----|
| **Left Column** | 0.3 | -1.1 | 1.3 | -0.1 | 0.3 | 1.3 |
| **Rafter** | -1.375 | -1.375 | 0.9 | 0.9 | -1.2 | -0.2 |
| **Right Column** | -1.1 | 0.3 | -0.1 | 1.3 | -1.1 | -0.1 |

\[
F = (C_{pe} - C_{pi}) A P_d
\]

Table 3 Final wind loads for Vijayawada location

|       | WL1 | WL2 | WL3 | WL4 | WL5 | WL6 |
|-------|-----|-----|-----|-----|-----|-----|
| **Left Column** | 3.045 | -11.165 | 13.195 | -1.015 | 3.045 | 13.195 |
| **Rafter** | -12.705 | -12.705 | 8.316 | 8.316 | -11.088 | 1.848 |
| **Right Column** | -11.165 | 3.045 | -1.015 | 13.195 | -11.165 | -1.015 |

Final wind coefficients (C_{pe}-C_{pi}) for various wind load cases for Hyderabad location shown in Tables 4 and 5.

**Table 4 Final wind coefficients for Hyderabad location**

|       | WL1 | WL2 | WL3 | WL4 | WL5 | WL6 |
|-------|-----|-----|-----|-----|-----|-----|
| **Left Column** | 0.3 | -1.1 | 1.3 | -0.1 | 0.3 | 1.3 |
| **Rafter** | -1.375 | -1.375 | 0.9 | 0.9 | -1.2 | -0.2 |
| **Right Column** | -1.1 | 0.3 | -0.1 | 1.3 | -1.1 | -0.1 |

\[
F = (C_{pe} - C_{pi}) A P_d
\]

Table 5 Final wind loads for Hyderabad location

|       | WL1 | WL2 | WL3 | WL4 | WL5 | WL6 |
|-------|-----|-----|-----|-----|-----|-----|
| **Left Column** | 2.12 | -7.78 | 9.19 | -0.707 | 2.12 | 9.19 |
| **Rafter** | -8.80 | -8.80 | 5.76 | 5.76 | -7.68 | -1.28 |
Load combinations for both strength and serviceability are as follows:

**Load Combination of Strength**

1. 1.5 DL + 1.5 LL
2. 0.9 DL + 1.5 EL/WL
3. 1.2 DL + 1.2 WL/EL
4. 1.2 DL + 0.6 WL/EL + 1.2 LL
5. 0.9 DL + 1.5 WL

**Load Combination of Serviceability**

1. 1.0 DL + 1.0 LL
2. 1.0 DL + 0.8 WL +0.8 LL
3. 1.0 DL +1.0 WL/EL

### 3. Analysis and Design of Pre-Engineered Buildings using STAAD.Pro

STAAD.Pro is a software that helps in the modelling, analysis, and design of structures. In comparison to manual techniques, STAAD.Pro gives accurate results. STAAD.Pro has been more successful for modelling, analysis, and multi-material design in 2D and 3D. It comes with intuitive, user-friendly visualisation tools, as well as powerful analysis and design capabilities with a variety of other modelling and design software products. The software consists of various country standards, including Indian standards. STAAD.Pro has been the tool of choice for analysing and designing in the world.

#### Considerations

1. Wind Load according to IS 875 (Part 3)-2015 for location Vijayawada is 50 m/sec, for Hyderabad is 44m/sec.
2. Internal Pressure Coefficient is considered as +/-0.5 (Since % of opening between 5-20%).
3. Column base considered as Pinned support.

#### 3.1 STAAD.Pro Procedure

Modelling the structure, applying properties, specifications, loads and load combinations, analysing and designing the structure are all part of the procedure. The front view and 3D View of warehouse have shown in Figures 1 and 2.
4. Results and Discussion

The pre-engineered building is analysed and designed using STAAD Pro. With different wind zones, output results are discussed in this section.

From the STAAD.Pro output, it is observed that Steel take off (total weight of steel) for the structure located in VIJAYAWADA is 1074.10 kN and Steel take off (total weight of steel) for the structure located in HYDERBAD is 955.51 kN.

4.1 Comparison of moments and shear forces

The BM and SF on typical frame for different locations are shown in the figures 4, 5, 6 and 7.
Figure 4 Bending moments on typical frame for Vijayawada location

Figure 5 Bending moments on typical frame for Hyderabad location

Figure 6 Shear Force on typical frame for Vijayawada location
5. Conclusion

Based on the results below shown conclusions are drawn

1. It is observed that the weight of structure located in Vijayawada is 11.04% higher than that of the structure in Hyderabad.
2. The section sizes of columns and rafters are less for the structure located in Hyderabad when compared to the structure located in Vijayawada. As the BM and SF are less for the structure located in Hyderabad.
3. The parameters that affect the structural weight and section sizes are Wind speed and Seismic Zone.

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