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# Comparative Study of Pre-Engineered Buildings Based on Codal Provisions and Design Practice

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**ABSTRACT:** Current design practices of Pre-Engineered Building (PEB) structures of steel are lacking in order to follow basic codal provisions, which results in serious damages of structure by different member failures and loss of money and lives. The current study is based on various case studies, observations and parametric studies of PEB structures. There is a common practice to ignore basic clauses during design of PEB structures in order to achieve economy and leaving structure under designed and unsafe. Also, in existing structures sometimes designer becomes ignorant to adopt corrective measures to make structure safe. Therefore, this work is a step to highlight basic clauses to be followed in PEB design and suggest remedies for existing PEB structures to make them safe through visual inspections, software analysis and checks. In this study, few sites are chosen for case studies from Indore city (M.P.) India, which are investigated thoroughly by visual inspections, by preparing data sheets and to model the structure on software platform. Further, the modelled structures are analysed, designed and checked for their sustainability under various load combinations using IS800:1984 and IS800:2007. Based on analysis results, various observations are made and compared with code based permissible limits. The parameters which lacks in code based values are noted and remedial measures are suggested to rectify structural problems to make them safe.
**Keywords**: Pre-engineered building, stiffeners, thickness, web, flange, IS800:1984, IS800:2007, failure

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## I. INTRODUCTION

Pre-engineered building (PEB) is designed by a PEB supplier or PEB manufacturer which is fabricated using best suited inventory of raw materials available that can efficiently satisfy a wide range of structural and aesthetic design requirements. Within some geographic industry sectors these buildings are also called pre-engineered metal buildings (PEMB) or, as is becoming increasingly common due to the reduced amount of pre-engineering involved in custom computer-aided designs, simply engineered metal buildings (EMB).

Recently the use of PEB structures is increased due to being efficient in terms of economy, aesthetics, and safety. Current design practices of PEB structures of steel are lacking in order to follow some basic codal provisions, which results in serious damages of structure by different member failures and loss of money and lives. Therefore, in this study few sites are chosen for case studies from Indore city (M.P.) India, which are investigated thoroughly by visual inspections, by preparing data sheets and to model the structure on software platform. The modelled structures are analysed, designed and checked for their sustainability under various load combinations using codal provisions from IS800:1984 and IS800:2007. The observations from the case studies are highlighted and remedial measures are discussed which are often being ignored by supplier and/or designer in order to achieve economy.

## II. DATA COLLECTION AND VISUAL INSPECTION AT SITES

Based on site visits and structural drawings available, data collection of frames of PEB structures are done and some general observations based on visual inspection of existing PEB structures are highlighted as under. The data collected of all existing frames below viz. Table 1 are designed as per IS800:1984. These frames are reanalysed following all codal provisions and found that some clauses are not as per IS800:1984 therefore, some remedial measures are suggested and further these frames are compared with IS800:2007 codal provisions and differences in design are calibrated.

**Table 1** Frame details collected from sites

| | **Frame 1** | **Frame 2** | **Frame 3** | **Frame 4** |
|---|---|---|---|---|
| Frame Span | 15.0 m | 25.0 m | 30.0 m | 40.0 m |
| Height of Frame | 10.0 m | 10.0 m | 10.0 m | 10.0 m |
| Frame Spacing | 6.5 m | 6.5 m | 6.5 m | 6.5 m |
| Column Web | (350/900) x 5 mm | (350/900) x 5 mm | (350/1100) x 6 mm | (350/1100) x 6 mm |
| Column Flange | 188x8 mm | 166x6 mm | 166x8 mm | 250x10 mm |
| Rafter Web | (750/400) x 4 mm | (950/450) x 5 mm | (1050/710) x 4 mm | (1220/700) x 6 mm |
| Rafter Flange | 188x6 mm | 166x6 mm | 166x6 mm | 215x10 mm |

Observation No. 1: As shown in Fig.1 below, it is observed that MS rods or single pipe or single angle is used as bracing member with higher slenderness ratios for tensile forces. It is found that the slenderness ratio of such members is beyond code based limit of 350.

**Fig.1** MS rod used as column bracing

Observation No. 2: It is observed that flange and web thicknesses are below code based minimum thickness limits resulting in warping of column and rafter web plates during erection under self-weight (Fig.2).

**Fig.2** warping of column and rafter web plates during erection

Observation No. 3: Invariable deflection in girts and purlins is observed at sites, reason may be section is under designed and deflection limits are not followed as per code based limits (Fig.3).

**Fig.3** deflection in top girt

Observation No. 4: The live load assumed for design of PEB structure is less (as mentioned in structure drawing of one of sites during data collection) i.e. 0.58 kN/m$^2$ however, as per IS-875 (part-2) the live load for non accessible roofs shall be 0.75 kN/m$^2$.

## III. LOAD CALCULATIONS AND ANALYSIS OF FRAMES UNDER CONSIDERATION

The frames data collected above are modelled in design software STAAD-Pro and analysed under various load cases and there combinations.

### A. Dead Load

Calculation of dead load as per IS: 875 (Part I):1987
Self Weight of frame = Calculated as per software
Weight of Sheeting = 0.08 kN/m$^2$
Weight of Purlin = (0.05 kN/m) / 1.4m = 0.0357 kN/m$^2$
Total Dead Load = 0.116 kN/m$^2$
UDL on Rafter @ 6.5m Spacing = 0.116 kN/m$^2$ * 6.5m = 0.754 kN/m

### B. Live Load

Calculation of live load as per IS: 875 (Part II):1987
Live Load on Rafter = 0.75 kN/ m$^2$
UDL on Rafter = 0.75 kN/m$^2$ * 6.5m = 4.875 kN/m

### C. Wind Load

Calculation of wind loads as per IS: 875 (Part III):2015
Basic Wind Speed ($V_b$) = 39 m/sec
Design Wind Speed ($V_z$) = $V_b * k_1 * k_2 * k_3 * k_4$
Probability Factor ($k_1$) = 1.0 (For All General Buildings and Structures)
Terrain Height and Size Factor ($k_2$) = 0.91 (Height = 10m ; Category 3)
Topography ($k_3$) = 1.0
Importance Factor ($k_4$) = 1.0 (For Cyclonic Region)
Therefore, $V_z$ = 39 * 1.0 * 0.91 * 1.0 * 1.0
= 35.49 m/sec

Wind Pressure ($P_z$) = $0.6 * V_z^2$
= 0.6 * 35.49$^2$
= 0.755 kN/m$^2$
Design wind pressure ($p_d$) = $K_d * K_a * K_c * P_z$
$K_d$ = 0.9 (Wind Directionality Factor)
$K_a$ = 0.8 (Area Averaging Factor)
$K_c$ = 1.0 (Combination Factor)

Minimum $p_d$ = 0.7 * $P_z$
= 0.7 * 0.755
= 0.53 kN/m$^2$

Final, $p_d$ = 0.755*0.9*0.8*1.0
= **0.54 kN/m$^2$**

Roof Slope = 1:10 Therefore, $\theta = 5.71^0$

**D. Internal Pressure Coefficient (Cpi) –**
$C_{pi} = \pm 0.2$ (For Wall Opening 0-5 %)

**E. External Pressure Coefficient (Cpe) –**
Taken from Table 5 of IS875 (Part III):2015

## IV. RESULTS OBTAINED AND REMEDIAL MEASURES FOR FRAMES ANALYSED

As stated above, all four frames are analyzed considering all load cases and their combinations mentioned above. The existing frames constructed at sites are found deficient (viz. Table 2) with respect to codal clauses of IS800:1984 for which they were designed, hence remedial measures for those frames are suggested to make them structurally safe. Apart from this, all frames are also designed using IS800:2007 codal provisions and differences in their weights are compared.

**Table 2** Codal provisions of IS800:1984 for which frames are found deficient

| Clause | Description | Frame 1 | Frame 2 | Frame 3 | Frame 4 |
|---|---|---|---|---|---|
| Clause 3.5 | Geometrical properties: Flange thickness $t_f = (b_f*\sqrt{f_y})/256$ | 6.9 mm Required | OK | OK | OK |
| Clause 3.8 | Minimum thickness of any member: Not accessible for cleaning = 8.0 mm Accessible for cleaning = 6.0 mm | 6.0 mm Required | 6.0 mm Required | 6.0 mm Required | OK |
| Clause 3.7 | Slenderness ratio = 350 | NB-80 or equivalent section required | NB-80 or equivalent section required | NB-80 or equivalent section required | NB-80 or equivalent section required |
| Clause 6.7.3 | For Web depth: $(d_1*\sqrt{T_{va,cal}})/816$ and $(d_1*\sqrt{f_y})/1344$ but not less than $d_1/85$ | Column web $d_1/85 = 7.35$ Rafter web $d_1/85 = 6.76$ | Column web $d_1/85 = 7.64$ Rafter web $d_1/85 = 8.23$ | Column web $d_1/85 = 8.52$ Rafter web $d_1/85 = 10.3$ | Column web $d_1/85 = 8.52$ Rafter web $d_1/85 = 11.3$ |

Based on results above (Table 2), following observations are made and remedial measures suggested as under:

1. Clause 3.5: Flange thickness provided for Frame 1 is less than required, which need to be strengthen. However this clause satisfies all other frames.

Remedial Measure: As the plate size shall be 2.0 mm greater than the weld size, therefore extra 4.0 mm thick plates need to be welded on flanges.

2. Clause 3.8: Minimum thickness of member required accessible for cleaning is 6.0 mm, Frame 1, Frame 2 and Frame 3 has thicknesses of 5 mm or 4 mm in column webs and/or rafter webs which is less than minimum required. Frame 4 fits well for this clause.

Remedial Measure: As the plate size shall be 2.0 mm greater than the weld size, therefore extra 4.0 mm thick plates need to be welded on flanges.

3. Clause 3.7: Bracing member required as per design is NB-80 or equivalent, however MS rods are provided at sites which are not acceptable.

Remedial Measure: MS rods need to be replaced with the designed section.

4. Clause 6.7.3: This clause checks the requirement of stiffeners in webs; here it is found that all frames lacks to satisfy this clause having lesser web depth to thickness ratios. For Frame 1 and Frame 2, 8-10 mm thicknesses are required and for Frame 3 and Frame 4, 10-12 mm thicknesses are required in column and/or rafter webs.

Remedial Measure: Extra plates (4.0 mm thick minimum) need to be welded on webs for its full depth to make them stiffened webs. Alternatively, stiffeners need to be provided as per provisions mentioned in IS800:1984.

## V. COMAPRISON OF FRAME SECTIONS DESIGNED AS PER IS800:1984 AND IS800:2007

It is seen up to this stage that existing frames at sites designed as per IS800:1984 does lacks to fulfill some codal provisions due to ignorance of some codal provisions to achieve economy which are important to be adopted as per safety considerations. Here an attempt is made to design column and rafter sections of all frames considered above if the codal clauses would have followed for frames as per IS800:1984 and also if IS800:2007 would have been followed. The sections thus designed are tabulated below and their weights are compared to have a basic idea for cost evaluations.

**Table 3** Section details and weight of frames provided at site

| | Frame 1 | Frame 2 | Frame 3 | Frame 4 |
|---|---|---|---|---|
| Column Web | (350/900) x 5 mm | (350/900) x 5 mm | (350/1100) x 6 mm | (350/1100) x 6 mm |
| Column Flange | 188x8 mm | 166x6 mm | 166x8 mm | 250x10 mm |
| Rafter Web | (750/400) x 4 mm | (950/450) x 5 mm | (1050/710) x 4 mm | (1220/700) x 6 mm |
| Rafter Flange | 188x6 mm | 166x6 mm | 166x6 mm | 215x10 mm |
| Weight of Frame, Kg | 1461 Kg | 1769 Kg | 2561 Kg | 4188 Kg |

**Table 4** Sections and weight of frames after remedial measures

| | Frame 1 | Frame 2 | Frame 3 | Frame 4 |
|---|---|---|---|---|
| Column Web | (350/900) x 9 mm | (350/900) x 9 mm | (350/1100) x 10 mm | (350/1100) x 6 mm |
| Column Flange | 188x8 mm | 166x6 mm | 166x8 mm | 250x10 mm |
| Rafter Web | (750/400) x 8 mm | (950/450) x 9 mm | (1050/710) x 10 mm | (1220/700) x 6 mm |
| Rafter Flange | 188x10 mm | 166x6 mm | 166x6 mm | 215x10 mm |
| Weight of Frame, Kg | 2180 Kg | 2657 Kg | 3587 Kg | 4188 Kg |

**Table 5** Sections designed as per IS800:1984 and weight of frames

| | Frame 1 | Frame 2 | Frame 3 | Frame 4 |
|---|---|---|---|---|
| Column Web | (350/900) x 6 mm | (350/950) x 6 mm | (350/1100) x 6 mm | (350/1100) x 6 mm |
| Column Flange | 188x8 mm | 166x6 mm | 166x8 mm | 250x10 mm |
| Rafter Web | (750/400) x 6 mm | (950/450) x 6 mm | (1050/710) x 6 mm | (1220/700) x 6 mm |
| Rafter Flange | 188x10 mm | 166x6 mm | 166x8 mm | 215x10 mm |
| Weight of Frame, Kg | 1740 Kg | 2024 Kg | 2658 Kg | 4267 Kg |

**Table 6** Sections designed as per IS800:2007 and weight of frames

| | Frame 1 | Frame 2 | Frame 3 | Frame 4 |
|---|---|---|---|---|
| Column Web | (350/900) x 8 mm | (350/1000) x 8 mm | (350/1100) x 8 mm | (350/1220) x 10 mm |
| Column Flange | 215x12 mm | 280x16 mm | 320x16 mm | 350x20 mm |
| Rafter Web | (770/400) x 6 mm | (1050/600) x 8 mm | (1500/700) x 12 mm | (1300/800) x 10 mm |
| Rafter Flange | 200x10 mm | 300x16 mm | 330x16 mm | 350x20 mm |
| Weight of Frame, Kg | 2267 Kg | 4717 Kg | 6866 Kg | 9107 Kg |

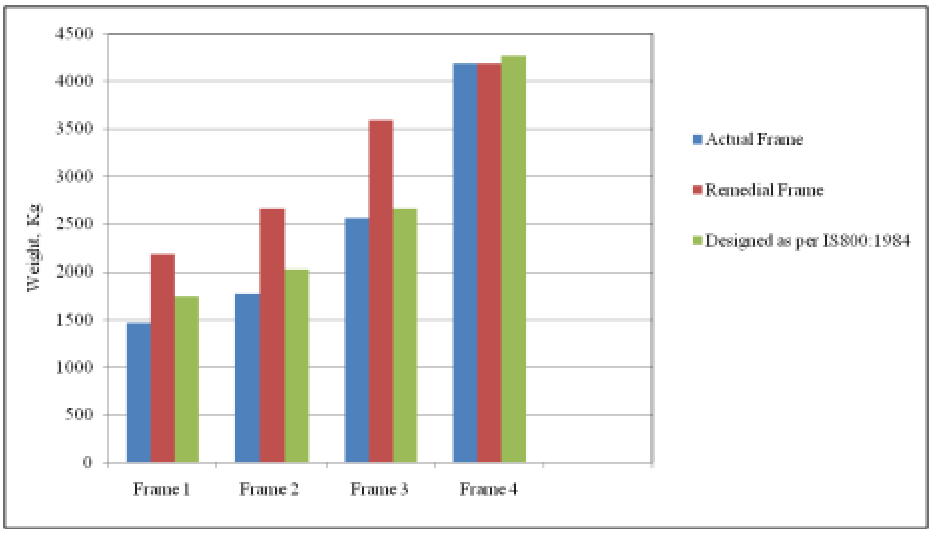


**Fig.4** Weight comparison of frames

## VI. CONCLUSION

This paper focuses on the importance of codal provisions for structural safety. As observed from this study in order to achieve economy PEB suppliers and/or designers become ignorant to adopt codal provisions completely which results in structural damages. Thereafter remedial measures are performed which makes structure more costly and heavy which exhibits loss of money and time. It is concluded from this study that, if the structure is designed following codal provisions from start it will have lesser weight instead of under designed structure with remedial measures. Although there is a provision for remedial measures to be adopted in structures for strengthening yet it involves loss of time, extra dead weights to foundations which are hard to get rectified.

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