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Design Optimization of Steel Structures through Internal Stress Diagrams of Low-Rise Buildings

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Abstract- Steel has high strength to mass ratio. This is the reason to used steel in construction industries against heavy loading. Generally, Hot rolled section & cold formed sections are used in steel buildings. But, the loading effects through-out the member (Beam/Column) in not same, that is why these sections are not recommended and to attain optimum use of steel the tapered sections are to be used. In this study, a building with 24 m width, 126 m length and 9 m Eave height is selected for study. The loading is applied according to MBMA-2006 and Design is done as per AISI-ASD Design code. In addition to that, 2 different 3D Frames having 7m and 9m of Bay Spacing's are selected for steel building. At these two Bay spacing's, the building is analyzed by STAAD.pro, which is a well-known software for structural analysis. A comparative study is made for Base Reactions, Eave Moments, Horizontal deflection, Vertical deflection and Weight of Steel required for the building. The results indicate that the building designed by following the internal stress diagrams gives Less values of Base Reactions, Horizontal deflection and Steel Weight of building as compared to building designed at maximum values of Shear and bending moments, which make it comparatively economical. In addition to that the results shows that while following the internal stress diagrams the segment length of 1.5m to 3.5m gives most economical results.

***Keywords*-** Design Optimization, Steel Structure, Low-Rise Building

Introduction

Steel has high strength to mass ratio. This is the reason to used steel in construction industries which require large clear span. There covering material could be GI Sheets, PU panel, brick masonry or concrete walls etc. These walls are non-load bearing yet able to withstand lateral forces caused by seismic activity or wind. The design of steel buildings generally includes the design of structural elements including primary columns and rafters/trusses, secondary purlin, girts, sheeting, diagonal bracing etc. Hot rolled section, welded plate sections, cold formed sections, corrugated sheets, rods, cables are the materials generally used in steel buildings. Steel buildings are classified into conventional steel buildings (CSB) and Pre-engineered buildings (PEB) depending upon the design concept [1] [2].

The paper presented a comparison between pre-engineered building (PEB) and conventional steel building (CSB) design. In this study, 2 different 2D Frames were selected for each pre-engineered building and conventional steel building. By varying the tributary width and wind speed, the frames were analyzed by a software of structural analysis i.e., STAAD pro (V8i).

The design concept of PEB is to use only the required depth of member that is needed at that particular spot depending upon the bending moment. This results in the tapered sections throughout the span of the building. The tapered shape is obtained by the built-up members. Standard hot-rolled sections, cold-formed sections, corrugated sheets, etc. are also used along with the tapered sections, as described in different studies [2, 3]. The use of tapered sections results in reducing the cost of the building by cutting off unnecessary steel. Conventional steel buildings (CSB) consist of a truss system supported by steel columns. The selection of a truss type depends on the span and pitch of the roof. Generally, fink-truss is used for a large pitch, Pratt-truss is used for medium pitch and Howe-truss is used for smaller pitch. Lighting in steel buildings can be provided through skylights or wall lights and for more lighting, a north truss roof can be used [1].

The selection of the truss depends on the following, i.e., roof slope, transportation, fabrication, geometry of the building, climatic conditions. Trusses normally used standard hot rolled section connected together using gusset plates [1, 4].

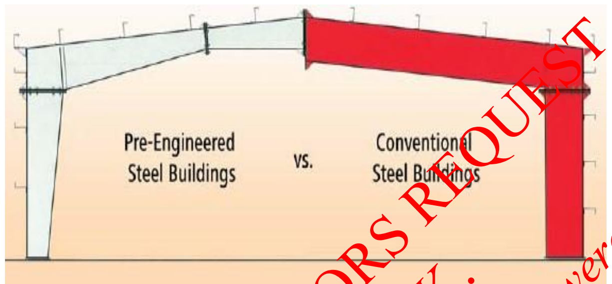

Figure 1: Pre-Engineering Building vs. Conventional Steel Building

The pre-engineered buildings (PEB) have been observed to be the most efficient economical and advantageous system particularly for the single-story system as compared to convention construction systems. Steel is the basic material that offers low cost, flexible in design, ductile and adaptable in different conditions and recyclable. Steel comes in variety of different shapes and colors, which makes it the most versatile and reliable construction material available. This means that we can achieve rapid installation of the structure with minimum energy, thus making a PEB sustainable. Infinitely recyclable, steel is a material that reflects the imperatives of the sustainable development. Steel is more common in the construction of single-story industrial structures rather than in tall buildings because of economy and serviceability problems.

The pre-engineered buildings (PEB) consist of main moment resisting frames connecting laterally secondary frames to the resist lateral forces. Secondary framing consist of purlins girts, eave struts, sag rods, flange braces and diagonal bracing. The purpose of secondary framing is to transfer the exterior loads to the main frame and eventually to the foundations. Bracing are important component of PEB buildings, because they provide lateral stability to the buildings by transferring longitudinal wind pressure to the column bases. The majority of structures that made in steel are generally low rise structured and normally used as cold storage in ware house, steel plant, automobile industries, garages and large thermal power stations. Ordinary steel structures typically require large clear span which are not economically achievable using other constructions techniques [5]. In construction industry, long span and column-free structures are very essential and pre-engineered building have fulfilled these requirements through its diverse design related to pre-fabrication and pre-casting [6]. There are many advantages in using PEBs such as, flexibility of expansion, reduced cost, less construction time, large clear spans, best quality control, less maintenance, energy efficient wall and roof systems, architectural diversity, [7], good strength, corrosive resistance, no residual oils, reduced energy loads etc. [6].

1 Materials & Methods

A building having dimension 25x100x10 m was selected and analyzed for both type of systems i.e. PEB & CSB. In this study, 16 different 2D Frames were selected for each pre-engineered building and conventional steel building. The software used was STAAD pro, which is universally accepted for such uses and purposes of the structural analysis program. Pinned supports were considered for both of the buildings. The Dead, Live, Wind-load were in according with MBMA-2006 (Metal Building Manufacturers Association-2006) and Seismic load were in accordance with UBC-1997 (Uniform

Building Code-1997). AISI-ASD (American Iron & Steel Institute-Allowable Stress Design) and MBMA-2006 (Metal Building Manufacturers Association-2006) protocols were adopted as design code and for load application respectively.

Following load combinations were taken: Dead + Live; Dead + Live + Wind/Seismic and Dead + Wind/Seismic.

Different parameters were selected depending upon the structural configuration of both types of frames. The parameters included were:

1. Base reactions
2. Moments at eave
3. Horizontal displacement at eave
4. Vertical displacement at ridge
5. Steel take off.

2 Results & Discussions

2.1 Base Reactions

Both the structures are analyzed for different parameters as mentioned above. The first parameter selected is base reactions. For this purpose, pin supports are considered for both the frames. The base reactions after the analysis are plotted on a graph as shown below.

Figure 2: Comparison of Base Reactions at 7.1 Bay Spacing

The value of horizontal components of the reaction is negligible as compared to vertical component, so only the vertical components have been plotted in the graphs.

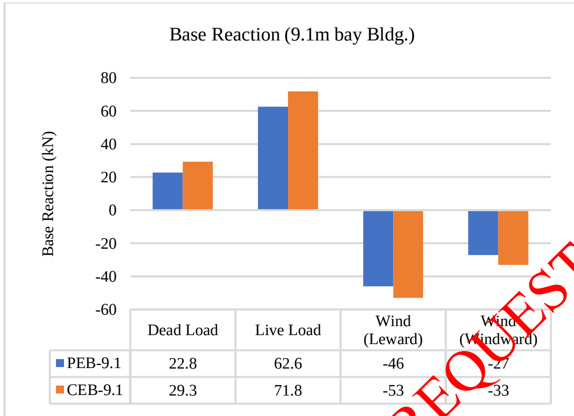

Figure 3: Comparison of Base Reactions at 9.1 Bay Spacing

The above analysis shows that the support reaction in PEB is on average 16 % lesser as compared to CSB system Lesser supports reaction means lighter foundations and hence reduction in the cost of footings.

2.2 *Moments at Eave*

The shear and bending moments of both the PEB and CSB are summarized in the graph as shown. It has been observed that that the shear and bending forces in PEB are less as compared to CSB that put impact on the weight of material required.

Figure 4: Comparison of Moment at Eave for CSB and PEB Frame

By comparing above graphs, the trend of difference in bending moment's values at eave is significant. On average the bending moments values in PEB are 24 % greater compared to CSB. The steel in PEB is provided in tapering based on the bending moments along the sections that make PEB economical.

2.3 *Horizontal Displacement at Eave*

The horizontal displacements at eave have also been studied and plotted in a graphical form as shown in the graph below.

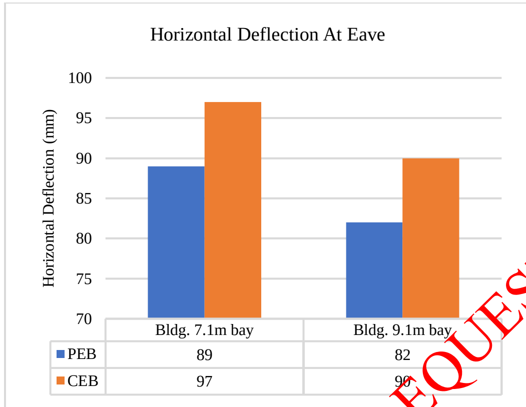

Figure 5: Comparison of Horizontal Deflection at Eave for CSB and PEB Frame

It has been observed that horizontal deflection at eave in PEB is less than by CSB by 20 %. Significant difference in horizontal deflection makes the PEB frame more serviceable and safer with respect to design point of view.

2.4 Vertical Displacement at Ridge

The vertical displacements at eave have also been studied and plotted in a graphical form as shown in the graph below. Vertical deflection is the important parameter to study. Below graphs shows that defection at ridge in PEB is more as compared to CSB frames. In CSB the truss member is closely connected that make it more stable against vertical deflection at ridge. Deflection at mid span in both frames is low in as compared to ridge.

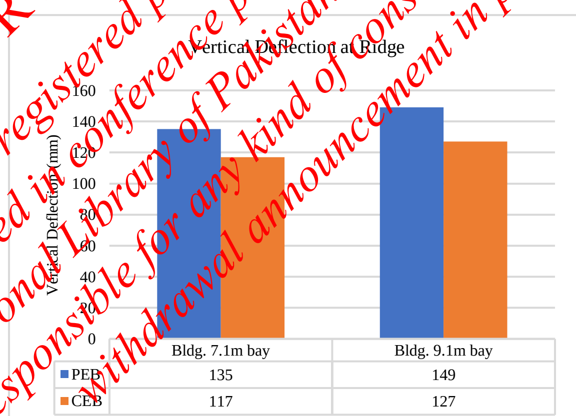

Figure 6: Comparison of Vertical Deflection for CSB and PEB Frame

Above graph shows that deflection trend is different at different loading. At wind speed 130 KPH the deflection in CSB 9 % less as compared to PEB. The deflection results show that PEB frame is lighter in weight as compared to CSB.

2.5 Steel Take off

The graph below shows the steel consumption of PEB frame and CSB frame. The amount of steel consumed by PEB is less as compared to CSB. This is because of the better design methodology of PEB in which the steel is provided depending upon the bending moments that are coming in the frame. This not only saves weight but also reduces the support reactions which in turn results in the lower foundation costs. However, in CSB this cannot be achieved as justified by the results below.

Figure 7: Comparison of Steel Take Off for CSB and PEB Frames

By changing load width, it is observed that the % age difference in weight reduction of PEB with respect to CSB almost remain same. At 7.1 m bay spacing the %age weight decrease is 30% and at 9.1 m bay spacing the PEB weight saving is almost 31 %. On average PEB saving is 30.5 % same as by varying wind speed.

2.6 Steel Take-off after making Segments

The graph below shows the steel consumption of PEB frame after making segments of a member. The graph shows that lesser the length of segment less will be the steel take-Off. The cost comparison is done by the assuming the fabricated steel rate at Rs. 200/kg.

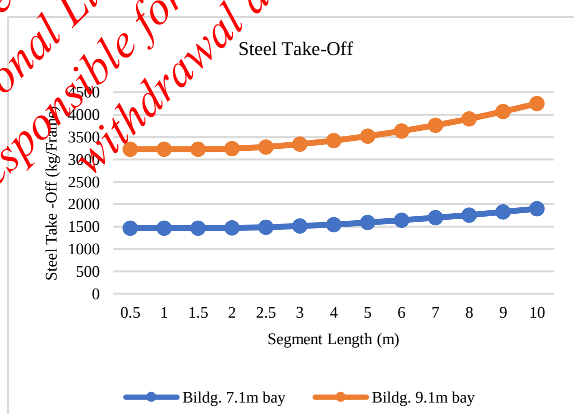

Figure 8: Steel Take-Off at different Segment Lengths

Figure 9: Cost Comparison at different Segment Lengths

The above Graphs shows that by decreasing the segment length the cost of structure decreases up to a certain limit. But after that cost increases rapidly. This is because of welding and erection charges.

3 Conclusions & Recommendations

On the basis of previous chapter, we can now easily conclude that Pre-Engineered buildings have numerous advantages over convention steel buildings.

In PEB system uses bending moments in order to calculate the depth of members this not only optimized the building but also reduced the base reactions. Decrease in base reactions results in reduction of footing sizes. This we cannot achieve in CSB. On an average base reaction of PEB are more than 16% lighter than CSB. The results have shown that the bending moments at Eave level in case of PEB is about 24% more than CSB. Because the connection at Eave is fully moment connection in case of PEB while in CSB the connection is pinned. Horizontal defection in PEB is lesser as compared to CSB. This means that PEB frame is more stable as compared to CSB frame. Thus, PEB is more serviceable. Vertical deflection in CSB is less simply because the members are braced together at regular interval while in PEB this is not the case. Future expansion in PEB is easier and faster as compared to CSB where it is more tedious and time taking. Earth quake resistance of PEB is better than CSB. This is because of its lighter weight. Erection of pre-engineered building is faster and efficient because it follows the same procedure in every project. In CSB

the erection procedure is different for different projects thus making erection process tedious. ASD method is more economical as compared to LRFD method when Live load to Dead load ratios is significantly high in PEB. Steel take off for PEB is more than 30.5% lesser as compared to CSB. The percentage increases with the increase in loading. Furthermore, the cost of PEB is much lesser as compared to conventional steel buildings based on the above analysis.

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