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Analysis of Pre-Engineered Buildings with different types of bracings – Using STAAD Pro Connect

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Abstract: Every year 1.86 billion metric tons of steel produced and the construction industry accounts to half of its consumption. Steel is an extremely versatile material that is not only easily available, cheap and easy to work with but also 100 % recyclable. This property of steel makes it a very viable solution to the ongoing environmental problems and even a better alternative to the conventional building materials. There are various types of steel available in the industry. It includes hot rolled steel sections that are already manufactured at certain pre-determined sizes. The properties of the hot rolled sections are already studied and readily available as tables. The other type of steel section is cold form steel which is differentiated by the process of production. The last and most commonly used type of steel section is the structural steel. Structural steel is prefabricated according to the design requirements of the project.

Pre-Engineered Steel Building System is broadly accepted across the world as a competent alternative to conventional steel buildings. Pre-Engineered Buildings (PEB) are a type of steel structures that can be constructed easily and quickly. Pre-Engineered Buildings are nothing but steel buildings in which surplus steel is evaded by tapering the sections as per the necessity of bending moment. Though it has many advantages, it is not widely used in India due to the lack of awareness. In Conventional steel structures, both the time and cost will be more, thus making it uneconomical. Thus, in pre-engineered buildings, the complete design is done and the detailed drawings are sent to the factories, and where the elements and members are pre-fabricated and then transported to the construction site. As they are already pre-fabricated according to the design the erection process will only take 2 to 6 weeks depending on the immensity of the project. Pre-Engineered Buildings have bolted connections and later can also be reused after dismantling. It is the most affordable and flexible building system ideal for any low or high rise industrial, institutional or commercial applications. The other advantages include low cost, environment friendly, easy erection, aesthetic appeal, flexibility and high durability. All these advantages make it the most suited after construction practice in the world. In India, Pre-Engineered & Pre-Fabricated building industry is growing swiftly. The paper involves analysis of the Pre-Engineered Building with different types of bracing and finding the most economical bracing. It also includes achieving economy by tapering the sections based on the bending moments.

Keywords: Steel, Structural Steel, Pre-Engineered Buildings, Bracing systems, Bending moments, STAAD Pro Connect

1. INTRODUCTION

Steel is one of the widely used building materials. It is versatile, cheap, easily available, easy to work with and also recyclable up to 100 percent (Mehendale et al. (2016)). This property of steel makes it one of the most sought out building materials. With many types of steel being manufactured, structural steel and hot rolled steel are the widely used materials for construction (Mehendale et al. (2016)).
Traditionally, the Conventional Steel Buildings are constructed using standard hot rolled sections from product manufacturers. They may be of I, Angle, Channel or Pipe sections that are available as standard sections in the market (Mehendale et al. (2016)). The structural detailing design is carried out according to the available sections in the market. This not only reduces efficiency, but also increases the cost of the project. The

"Pre-Engineered Steel Buildings" are first designed and based on the bending moments on the element, they are tapered to achieve efficiency. Based on the design detailing, the elements are manufactured in the factories. Every project is unique and therefore the fabrication of the elements varies from one project to another. The comparison below is intended to introduce and inform engineering design groups of the pre-engineered steel building concept, its high versatility and practicality, and its disadvantages to Designers and Contractors pre-engineered steel building concept is widely used in the United States, as well as in many of the industrialized countries Sub-Systems include anchor bolts, structural framing, insulation, roof and wall cladding, mezzanines or floor including steel floor decking, windows, doors, ventilation systems, canopies, overhangs and facias. Pre-engineered steel buildings can be used for permanent installations from around 400 square feet (36 square meters) upwards, for one story and two storey construction.

The power tool for computerized structural engineering STAAD Pro is the most popular structural engineering software product for 3D model generation, analysis and multi-material design. It has an intuitive, userfriendly, visualization tools, powerful analysis and design facilities and seamless integration to several other modeling and design software products. The software is fully compatible with all Windows operating systems.(Zende et al. (2013))

The objective of this project is to optimize the PreEngineering Building according to the bending moments and to find the most economical bracing system. Two types of bracing systems such as Cross bracings and Chevron Bracings are compared in this paper. The most economical bracing system was found based on the steel take off taken from the STAAD Output data.

Atwal et al. used the Indian and ASTM and Euro codes to compare the weight of a Pre-Engineered Building and found that Pre-Engineered Buildings vastly designed using American codes had a significantly lesser weight of 23.97% as compared to IS 800:2007. This conclusion was arrived purely on the weight of the steel used in the building. The Euro Code also had a lesser weight of 27.08% concluding that American Code is the economical of all.

Patil et al. (2017) compared a PEB with a conventional steel building and concluded that PEB weighs lighter than CSB and the PEB can be designed and executed rapidly. Since it is pre-engineered, the connection details and design are also lesser and the construction is rapid. Support reaction is much lesser in PEB when compared to the CSB. The cost of the structure was also lesser in PEB than CSB because of the lighted sections. Kumar et al. studied an industrial structure and analyzed it according to the Indian standards, and also referring Euro codes and ASTM codes. In this study, a structure with various length and height is considered to carry out analysis & design for in two dimensions and found that American Code yielded a lighter section out of Indian and Euro codes.

Chavan et al. (2014) studied to determine the economic significance of hollow structural sections (HSS) in comparison to open sections. To better appreciate the relevance of cost effectiveness, this study was carried out to establish the percentage economy attained using hollow structural sections (HSS). The method utilised to attain the goal comprised a comparison of different profiles for various combinations.

STAAD PRO CONNECT

STAAD Pro CONNECT Edition includes a new Ribbon-Based Graphical User Interface. All the STAAD Pro V8i tools commands are available in STAAD Pro CONNECT Edition, but through the Ribbon, the tools are organized in a very logical, workflowbased layout.

STAAD Pro CONNECT Edition includes a new Physical Modeling Workflow. Through the Physical Modeler, structural elements can be modelled as they will be physically constructed, allowing the user to model elements such as girders, multi-story columns, and slabs/walls quickly and accurately. (STAAD Pro V8i includes an Analytical Modeling Workflow only.)

Through the STAAD Pro CONNECT Edition Physical Modeler, we can transfer data between STAAD Pro, ISM (Integrated Structural Modeler), and a BIM application to increase the productivity in creating accurate construction documents. Structural members, such as beams/columns/braces, concrete walls, and concrete slabs can be transferred into the STAAD Pro Physical Modeler from ISM and from ISM into the STAAD Pro
Physical Modeler.

2. MODELLING

2.1. *Introduction*

The span of the Pre-Engineered Building, bay spacing, eave height and total height of the Pre-Engineered Building is finalized and modelled in STAAD Pro connect. Two types of bracings namely the chevron bracings and the Cross bracings were provided in separate

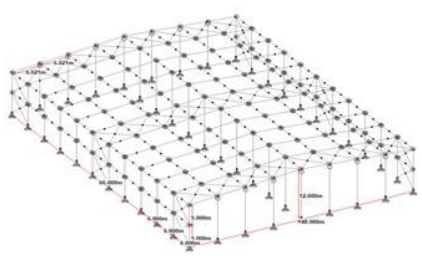

Figure 1: 1Dimensions of the Pre-Engineered Building

STAAD Pro files. Structural steel such as Tapered I sections were provided for the rafters and columns. Hot rolled sections were provided for beams and bracing systems. The span of the structure is 48 m. The eave height and total height of the building is 10 m and 12 m respectively. The total length of the building is 66 m with 11 bays and each bay being 6 m long. All the dimensions can be found in Fig. 1.

2.2. *Rafters and columns*

The Rafters are the important element in a PreEngineered building. The load from the roofing sheet is transferred onto the rafters through the purlins. Each rafter is connected in the transverse direction by several beam members that have moment releases at the end. This moment release will ensure that the load acting onto the beams are directed to the rafters and thus maintain less amount of load on the beams. This mechanism helps to optimize the structure effectively, because of the control that is established due to the isolation of the forces. The rafters can be broadly distinguished as main rafters and gable rafters. The gable rafters are constituted of lighter sections due to the relatively less amount of load acting on the bay. The main rafters are usually heavy sections that act as the main skeleton of the building.

The columns can also be broadly distinguished as main column, corner column, wind column and middle column. The main columns are connected to the main rafters and they transmit the load from the main rafters to the foundation. The corner columns are usually the heaviest of the columns due to various types of load acting on it. The wind columns are the columns that are placed against the wind direction in the longitudinal direction. The wind columns transfer the wind load to the bracing system adjacent to it

2.3. *Bracing system*

Two types of bracing systems namely the cross bracings and chevron bracings are compared in this paper.

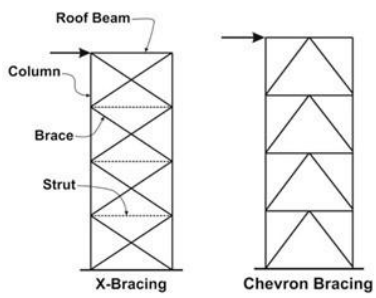

Figure 2: Types of bracings in the Pre-Engineered Building

The bracing system is provided at three locations in the Pre-Engineered Building. They are provided at the end bays and at the middle bay. The bracing system ensures that the wind load acting on the building in the transverse direction is transferred effectively to the rafter members. The two types of Bracing systems used in the PEB are demonstrated in Fig.2.

2.4. *Beams*

Beams are modelled in STAAD pro as transverse members running longitudinally throughout the structure. They are modeled in such a way that the loads are transferred to the columns effectively. Only beams are modelled in STAAD Pro and they are provided with moment releases at the start and end. This process of releasing the moment at the ends and the start reduced the net load acting on the beams. The beams also transfer the load in the particular bay directly to the rafters and to the columns. This behavior ensures that lesser amount of section is sufficient for the beams as most of the loads are transferred to the columns

2.5. *Purlins, girts and Eave Gutters*

The purlins, girts and Eave gutters are the transverse members running longitudinally along the structure. The purlins and girt members transfer the load from the roof sheeting to the beams below. They are provided at equal spacing to ensure uniform distribution of load. The dead load due to the purlins, girts and eave gutters are calculated separately and uploaded to STAAD Pro. This approach not only simplifies the modelling of the structure but also reduces the time taken to run analysis. Apart from dead load, the live load due to the presence of water in the eave gutter is also taken into account during calculation of loads. The purlin loads are calculated.

3. LOAD APPLICATIONS

3.1. *Dead load*

Dead load comprises of self-weight of the structure, weights of roofing, purlins, girt members, sag rods, bracings and eave gutters. Dead load varies from structure to structure based on the roofing materials, purlins and the self-weight. This load is applied as a uniformly distributed load over the rafter while designing the structure by PEB concept. The weight of the roofing sheet, flange braces, sag rod, purlins along with the collateral loads are calculated and applied as UDL on the rafters. The self-weight of the girt members is applied as UDL onto the column members. Half of the total load is assigned to the gable end columns and rafters. The self-weight of the eave gutter and eave strut are applied as point loads on the columns.

3.2. *Live load*

According to IS: 875 (Part 2) – 1987, the live load for a roof with no access is 0.75 kN/m^2, with a drop of 0.02 kN/m^2 for every one degree of roof slope over 10 degrees. The total evenly live load operating on the PEB structure's main rafter was determined to be 4.5 kN/m^2. This load is applied as a uniformly distributed load over the rafter while designing the structure by PEB concept. Apart from the live load on the roof, the live load due to water on the Eave gutter should also be taken into account. This is calculated by taking into account the surface area of the gutter, density of water and by spacing.

3.3. *Wind load*

Wind load is calculated as per IS: 875 (Part 3) – 2016. For the Present work, the basic wind speed (Vb) is assumed as 39m/s. The wind load over the roof can be provided as uniformly distributed load. Wind load is calculated after taking into account the probability factor, terrain factor, topography factor, importance factor, wind directionality factor, Area averaging factor and combination factor.

Based on the dimensions of the PEB, the internal and external wind pressure co efficient were calculated and the consolidated pressure factors that will be acting on the structure based on the internal and external coefficients is found out. The wind load is calculated for four air flow conditions for rafters and columns.

101 : 1.5(DL+LL)
102 : 1.2 (DL+LL+WL (0+ CPI))
103 : 1.2 (DL+LL+WL (0- CPI))
104 : 1.2 (DL+LL+WL (90+ CPI))
105 : 1.2 (DL+LL+WL (90- CPI))
106 : 1.2 (DL+LL+ EQ X)
107 : 1.2 (DL+LL+ EQ Z)
108 : 1.5(DL+ WL (0+CPI))
109 : 1.5(DL+ WL (0-CPI))
110 : 1.5(DL+ WL (90+CPI))
111 : 1.5(DL+ WL (90-CPI))
112 : 1.5(DL+ EQ X)
113 : 1.5(DL+ EQ Z)
114 : 0.9 DL + 1.5 EQX
115 : 0.9 DL + 1.5 EQZ
116 : 0.9 DL + 1.5 WL (0+CPI)
117 : 0.9 DL + 1.5 WL (0-CPI)
118 : 0.9 DL + 1.5 WL (90+CPI)
119 : 0.9 DL + 1.5 WL (90-CPI)

201 : DL + LL
202 : DL + EQ X
203 : DL + EQ Z
204 : DL + WL (0+CPI)
205 : DL + WL (0-CPI)
206 : DL + WL (90+CPI)
207 : DL + WL (90-CPI)
208 : DL + 0.8 (LL+ EQ X)
209 : DL + 0.8 (LL+ EQ Z)
210 : DL + 0.8 (LL+ WL (0+CPI))
211 : DL + 0.8 (LL+ WL (0-CPI))
212 : DL + 0.8 (LL+ WL (90+CPI))
213 : DL + 0.8 (LL+ WL (90-CPI))

Figure 3: Types of load Combinations

3.4. *Seismic load*

The earthquake load was calculated as per IS 1893: 2016 Part I. The location of the project, zone factor, response reduction factor, importance factor, damping ratio and soil category were assigned to the STAAD Pro loading panel and the seismic force generated by the model was applied on the structure. Apart from seismic loads, the member weight and joint weights produced by the dead weight of the members were also added to the structure. Both wind load and seismic loads are calculated in STAAD Pro through load combinations.

3.5. *Load combination*

Load combinations were provided as per Indian standards for both strength and serviceability criteria of Limit state of design. A total of 19 load combinations were provided for Strength criteria and a total of 13 load combinations were provided for serviceability criteria. The Fig.3 shows the types of load combinations provided for the structure.

4. ANALYSIS AND DESIGN

4.1. *Analysis*

Analysis of the structure was done after enveloping the strength load combinations and serviceability load combinations together. After the analysis of the structure, the shear force, deflection, bending moments and the displacement reactions studied with high degree of precision and accuracy. It was found that the bending moment of the section in the columns increased gradually towards the eaves. This paved way to reduce the section at the bottom and thus reduce the cost. The other sections such as beams, rafters, bracing systems etc., were also studied in detail before proceeding to designing.

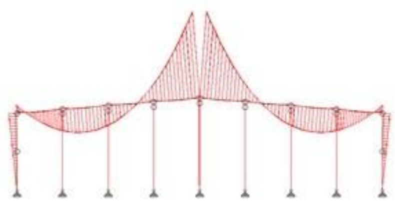

Figure 4: Bending moments of the Pre-Engineered Building

4.2. *Design*

Various parameters were included for the design of the Pre-engineered Buildings. The PEB was designed based on Limit State Method (LSM) using IS 800:
2007. The effective length factor for torsional buckling was provided separately in X,Y and Z directions based on the support conditions. The effective length itself was calculated according to the Purlin spacing and the estimated bending of the members between the purlins. The spacing of the purlins were 3 m. This led to the effective length to be calculated as 1.5 m. The effective length was calculated for every type of member such as middle columns, corner columns, wind columns, rafters and beams in X, Y and Z directions.

5. TAPERING OF THE SECTION

5.1. *Introduction*

One of the biggest advantages of Pre-Engineered Buildings is the ability to customize the section for every project. This allows the designer to observe and study the bending moment diagram after the analysis of the structure. The bending moment diagram as shown in Fig.4 can be used to taper the section. At the points of contra-flexure where there is zero bending moments, the section can be tapered down without compromising on the deflection or strength criteria. This process gives ability to cut off the excess section that may add up to the cost of the dead weight of the structure and thereby increasing the project cost.

5.2. *Tapering of the section*

The bending moment diagram is studied for all the sections and it was found that middle columns, gable end rafters and gable end columns had very less bending moments acting on them as shown in Fig 5 and thus they were provided with uniform cross section. The other

Figure 5: Tapering of rafters of the Pre-Engineered Building

columns had gradually increasing bending moments towards the eaves and thus the sections were provided accordingly.

The Main Rafters had prominent points of contraflexure which enabled the tapering of the section at various points and thus reducing the total amount of steel being used.

6. OPTIMIZATION OF THE SECTION

6.1. *Introduction*

One of the objectives of the project is to economize the section based on the bending moments. On top of tapering the section, STAAD Pro Connect provides the option to reduce the total amount of section used by a concept called utility ratio. Utility ratio is the ratio of Actual Load on member to the capacity of member, if it exceeds unity, then load on member will be greater than its capacity and member gets collapsed. With the help of utility ratio and the behavior of the structure, the optimization was done.

6.2. *Utility ratio*

The post processing mode of STAAD Pro connect allows the user to check the utility ratio of a member. It is the ratio of how much section has been used for the critical load case. The ratio of 0.5 means only half of the section has been used due to the given loading conditions. Usually, a utility ratio greater than 0.5 is desirable in order to achieve economy. Any ratio lesser than 0.5 will be uneconomical as more than half of the section is not being utilized by the structure.

The section properties were changed until at least 75 percent of the section members had a utility ratio greater than 0.5 to ensure both safety and economy. About 92

7. RESULTS AND DISCUSSION

1. The Steel Take off for Cross Bracings and cross bracings were found to be 1186 kN and 1413 kN respectively as indicated in Fig 6
2.

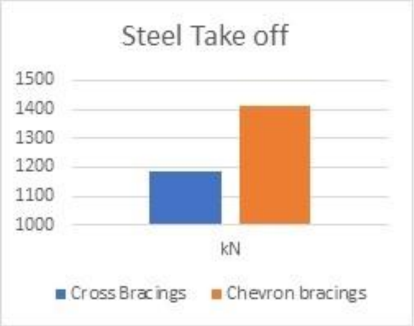

Figure 6: Steel take off of the Bracing system

3. Chevron Bracings demand almost 20 percent more material than Cross Bracings
4. Cross bracings can take more lateral load than the Chevron bracings for the same amount of section

8. CONCLUSIONS

From the analysis and results, the following conclusions can be made.

- Tapering of the rafters according to the Bending moment diagram does not affect the load carrying capacity of the structure.
- Cross bracings are more economical than chevron bracings
- Tapering of the rafters according to the bending moment diagram does not affect the load carrying capacity of the structure.
- The tapering of the sections according to the bending moment diagram does not affect the serviceability criteria of deflection.
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