Pre-engineered Buildings as sustainable structures – A review

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Abstract— **A pre-engineered building is one that has been pre-designed and fabricated at a factory in accordance with the standards and codes, as well as the loads that will be operating on the frame. These buildings are designed using simulations done in a modelling software. The primary idea behind PEB is that the geometry of the frame corresponds to the shape of the bending moment diagram and that the process includes predesigning and prefabrication. The application of pre-engineered buildings idea to low rise structures is highly affordable and quick, and the construction of the buildings may be achieved with great speed. In recent years, numerous efforts have been made in the area of sustainability. Pre-Engineered buildings are one such innovation that came about in the construction industry in the past few decades. Pre-Engineered Building is the modern technology of construction of steel buildings in a more sustainable and cost-effective manner. It aims to make optimal usage of the steel sections, hence reducing the wastage of steel. This also means there is reduced carbon emission. Due to the reduction weight of steel, there is a natural reduction in the cost of the structure as well as the construction time of the structure. Pre-engineered buildings also have more advantages in structures spanning great distances. In this study, a review of the PEB structures is done to understand the design principles of PEB structures and its applications have been discussed. Further advantages of PEB over conventional steel buildings are compared. Components and design codes and procedures used for design and construction of PEB are studied.**

Keywords— PEB, steel structures, sustainable construction, cost effective.

I. Introduction

One of the areas of particular interest for construction researchers has been the most lightweight design of buildings in order to obtain lighter and cheaper sections. Steel was chosen as an alternative construction material owing to its superior ratio of strength-to-weight, expansion flexibility, ability to be recycled, freedom of design in component size, ability to span for longer distances without intermediate supports and improved seismic resistance capabilities. The growth of the Pre-Engineered Steel Industry reinforced the concept of minimal weight design of steel structures. The term 'pre-engineered buildings' first appeared in the 1960s. Several elements, such as developing technology that was continually expanding the maximum clear-span capacities of metal structures, made this time notable in the history of metal buildings.

A pre-engineered building is one that has been pre-designed at a factory using modelling software and simulation in accordance with the standards and codes, as well as the loads that will be operating on the structure, prior to the manufacturing of the building's components. The components are then manufactured in the factory in accordance with the specifications, and the structure is constructed on-site. Wastage of steel is reduced as a result of the optimized design of the steel sections based on the bending moment requirements. As a result, the most effective way to minimize steel's carbon footprint is to utilize less of it, which is where PEB technology comes in. Figure 1 shows the various components of a PEB steel construction.

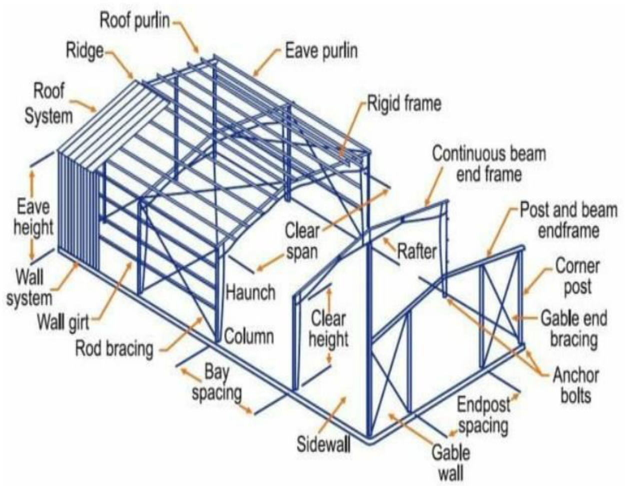

Fig. 1. Components of a Pre-Engineered building.

PEBs main frames can also be constructed in various configurations to suit the purpose of the structure. They can be single span, multiple spans, multiple gable, lean-to or single slope structures. An example of these main frames is shown in Figure 2.

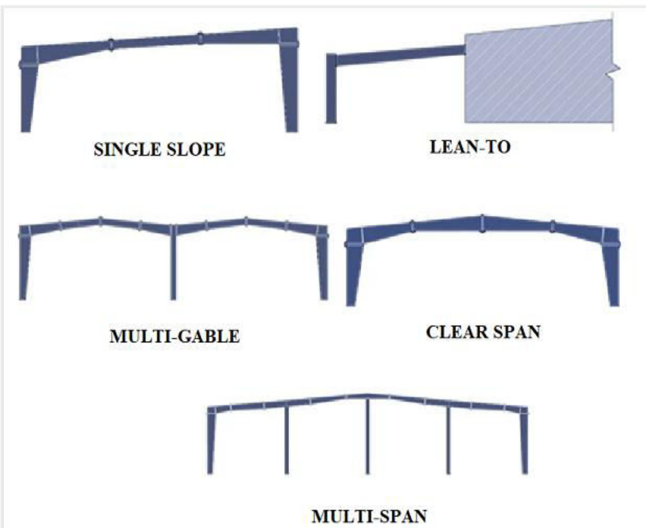

Fig. 2. Different types of PEB main frames.

PEBs may span up to 100-120m without any intermediary supports, allowing them to be utilised for auditoriums, indoor stadiums, gymnasiums, swimming pool enclosures, aircraft hangars, industrial structures needing enormous continuous expanses, greenhouses, and so on. A big column-free area allows for greater flexibility in the placement of partition walls in the case of residential or commercial units, allowing the structure to be reused as needed.

Table 1 shows the comparison of Pre-Engineered buildings (PEB) with a conventional steel buildings (CSB) in which PEB holds a clear upper hand as compared to a CSB.

TABLE I. COMPARISON OF PEB WITH CSB.

Parameter	Pre-Engineered Building (PEB)	Conventional Steel Building (CSB)
Weight of construction	Owing to the use of tapered sections and cold-formed channels, the cost is around 20-50% cheaper than CSB.	Because they use traditional hot-rolled sections and channels, they are heavier than PEB.
Design procedure	Efficient and fast. Basic design standards are used (AISC, MBMA, IS 800). Easily designed on design software.	More time is required as each CSB must be designed from scratch as per requirement.
Time for delivery	About 6–10 weeks for an 800 MT project.	About 24–30 weeks for an 800 MT project.
Foundation design	Minimal in weight, simple and straightforward.	Heavy and extensive.
Simplicity of erection	Less complicated and faster.	Complex, slow and demands extra energy.
Seismic Resistance	PEB excels over CSB owing to its lighter frame and superior structural performance.	Seismic resistance is lesser as compared to PEB.
Overall Cost	Costs approximately 35% cheaper in comparison.	Greater expense per square metre.
Structural Performance	Generally results in a better performance.	Each structural member is designed independently which impacts the overall structural performance of the CSB.

II. LITERATURE REVIEW

Z. Darshana (2012) examined the design of a PEB according to Indian and American standards and compared the results achieved by both standards. The findings showed that the live load taken in MBMA is less than that taken in IS code. It was observed that when compared to the IS code, the computation of wind coefficient using MBMA was substantially simpler. It was discovered that the IS code had larger deflection limits than the MBMA code, which led to a more conservative design in IS codes than the MBMA/AISC code [1].

Md. U. Saleem, Z. A Siddiqi and H. J. Qureshi (2013a) used standard steel hot-rolled sections as well as pre-engineered cold formed and tapered sections to analyze and design a prototype steel industrial building. The findings revealed that PEB constructions were lighter, had a greater structural efficiency and were less expensive than traditional steel buildings. In the primary and secondary frames, it was observed that hot rolled sections demonstrated lower deflections and sway [2].

Md. U. Saleem, H. J. Qureshi and Z. A Siddiqi (2013b) investigated the optimal unbraced length of thin steel sections subjected to the effects of compression and bending. A narrow range of webs were chosen where the web slenderness was kept constant at a web depth of 800mm and flange thickness of 12mm, the built-up sections were analyzed by varying the slenderness ratio of flange from 4.00 to 16.00. It was found that increasing the unbraced length ratio reduced the section's overall capacity [3].

G. S Kiran, A. K. Rao, and R. P. Kumar (2014) conducted an analysis and design of an industrial structure in accordance with Indian and American codes, and the structure's economy was examined in terms of its weight. It was observed that the IS codes considered a higher value of horizontal loads like surge and barking loads as well as a greater impact allowance, while there was similarity in the consideration of vertical loads like crane impact load allowance. It was concluded that one of the main reasons to use the American code for PEB structures is that it presents a more economical structural design than the Indian Code [4].

Md. U. Saleem and H. J. Qureshi (2018) looked into the working of PEB steel constructions and established a comparison with conventional steel buildings in terms of weight of the frames, sway or lateral displacements, and vertical displacements. The study concluded that PEB steel frames outperformed conventional steel buildings in terms of economy and weight of construction. [5].

Md. U. Saleem, N. Khurram, H. J. Qureshi, Z. A.Kazmi, Z. A Siddiqi (2018) investigated the optimized slenderness for web and flange for built-up sections used in construction PEB. Based on the observations, it was understood that sections with smaller unbraced length ratios and subjected to higher loads should be designed with compact flanges with flange slenderness 11.0 to achieve a better economy, and sections with to larger unbraced length ratios should be designed with flange slenderness 14.0 [6].

S. Kalesha, B.S.S. R. Reddy, and D. C. K. Jagarapu (2020) performed manual seismic and wind analysis and investigated the design ratio difference between a pre-engineered building and a standard steel frame construction. According to the findings of the study, PEB structures are more cost efficient than traditional steel frame buildings because the effective sizes of the structural components of PEB structures are lower. PEB buildings are roughly 35% cheaper than traditional steel frame constructions due to the reduction in the amount of steel required for construction [7].

L. Sharma, N. Taak, and P. K. Mishra (2021) developed and compared a pre-engineered building to a typical steel building of the same configuration that previously existed. It was observed that the overall structural weight of the pre-engineered structure was reduced by 20 to 25% when compared to the conventional construction. This element influences the utilization of structural steel as well as the overall cost of construction of the structure, making it significantly more cost effective and sustainable. The study concluded that pre-engineered structures outperformed typical steel buildings when subjected to seismic forces due to their less weight and improved structural performance [8].

V. V. Sai, P. Poluraju and B. V. Rao (2021) examined the structural functioning of multiple bay systems in distinct seismic and wind zones, namely Hyderabad and Vijayawada. STAAD.Pro software was used for the analysis and design. The magnitudes of the bending moment (BM) and shear force (SF) were used to assess the structural performance of the PEB. The weight of the construction was 11.04% higher in Vijayawada in comparison to the weight of construction in Hyderabad, according to the research. The wind speed and seismic zone components were discovered to have an influence on the weights of the structures and on the and section sizes [9].

C. Kavitha, S. Suryaprakash, N. Lavanya, and S. Durgadevi (2021) used Staad.pro to design and analyze a pre-engineered industrial building spanning 30 m and having an eave height of 10 m with a slope of 10°. The study aimed to understand the structural behavior and to achieve an economic steel design by reducing the quantity of material and saving time during erection and construction. IS 800-2007 codes were used in the design. Loads such as dead load, live load, wind load, and seismic load were all taken into account in modelling. The findings of the base reaction, rafter moment, column moment, and displacement were recorded, and the study was used to produce a PEB that will be installed on site in accordance with the specifications [10].

S. K. Sah, M. Z. Kangda, S. Sathe and N. Mate (2022) investigated the study and design of PEB structures, as well as numerous elements of PEB such as characteristics, configuration, and performance vs conventional steel structures. Section ratio limitations and PEB design standards are provided, as well as a design approach for PEB construction. According to the findings of the studies, when large, clear span, and speedy construction are necessary, PEB building is a superior and more cost-effective technology. It was also determined that extending the distance between the bays up to a certain limit lowered the weight of the structure but increased the weight further [11].

III. METHODOLOGY

A. Materials Used

Listed below are the several components of a PEB. Figure 2 shows the different types of sections used in a PEB. Fig. 2(a) presents a built-up section that is typically utilized as a beam or column, whereas Figs. 2(b), (c), and (d) display cold formed channel sections, cold formed Z-shape sections, and roof sheeting, respectively.

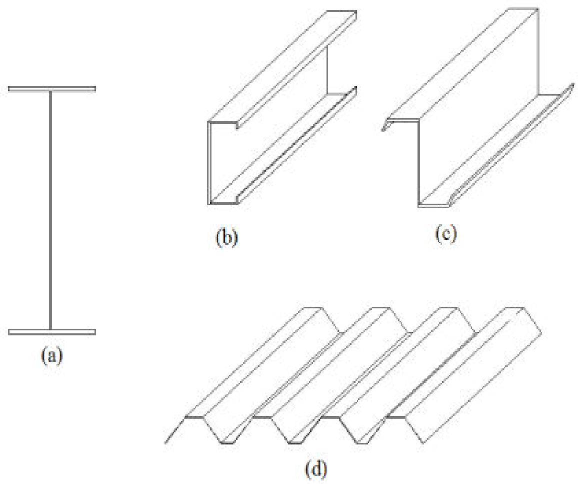

Fig. 3. Different types of sections used in a PEB.

1) *Primary structural members.*

These are the major load-bearing elements of the PEB rigid frame and are 'I' shaped members that are tapered or built-up using hot-rolled plates. Dimensions of the building, occupancy of the structure, slope of roof, desired column-free clear spans, acceptance of visible steel columns and proposed materials for roof and walls are all factors that impact main frame selection.

2) *Secondary structural members.*

The space between the main building frames is bridged by secondary structural components. Secondary structural components such as purlins for the roof, wall girts and eave struts at the intersection of the sidewall and the roof, are made from "Z" and "C" shaped cold-formed sections. Cold formed members do not require any cutting, welding, or grinding since the desired shape of these sections is achieved by directly pressing the steel coil in a pressing machine. Alternatively, these members can also be used as flange bracing for primary framing and contribute to the lateral load resisting system of the structure.

3) *Cladding/sheeting.*

This comprises roof and wall roll-formed profile sheets. These are ribbed panels of colour coated, galvalume, or galvanized steel.

4) *Miscellaneous.*

These include all functional construction elements such as mezzanine floors, crane runway beams for crane system, sag rods to restrict the movement of purlins and girts in the direction of its weak axis, anchor bolts to connect members to foundation, skylights, gratings, staircase, cage ladders or other strut & support pipes.

B. Design Procedure

The common practice of designing PEB is by using simulation softwares such as STAAD.Pro, ETABS, SAP2000, MBS although they can be designed manually as well. For the design procedure, the first step would be to assume the dimensions of the components of the structure.

Then the various loads imposed on the structure can be calculated as per the design codes followed for the load combinations. The structure is then analyzed for structural adequacy. Each component of the structure must be properly analyzed, and the most location that is most critical inside that section must be subjected to bending, axial, shear stresses and deflections. The deflection limits for different structural members should be within the allowable limits. Section sizes must be design-safe, and utilization ratios must be less than one. A value larger than one indicates that the member is overstressed, whereas a value less than one indicates the member's remaining reserve strength.

C. *Technical parameters for design*

Standards and codes used. In general, the design firms producing PEB structures use the American and Indian codes for design and load combinations as per the client requirements. Design codes generally used are IS:800, Metal Building Manufacturers Association (MBMA) and American Institute of Steel Construction (AISC).

D. Load considerations.

Loads considered for the design of PEB structures are the same as used in general building structures. These are:

1) Dead loads.

These are the loads that are acting on the structure due to the self-weight of the components like purlins, sheeting used for wall and roof etc. Collateral loads such as load of solar panels, lighting, HVAC and other protection material may also be considered along with dead load.

2) Live Loads/Imposed loads.

Although there is no direct live load imposed on the roof, some amount is taken into consideration the weight of the workers for repair and installation purpose.

3) Wind Loads.

The Basic wind speed is to be considered according to the location of the structure being designed. Calculation of wind load on roof is to be done according to the Codal provisions.

4) Seismic Loads.

Earthquake loads influence the plan of structure in regions of incredible seismic movement. Base shear and design horizontal coefficient for the structure can be calculated as per formulas in the standard Codes used. The seismic load calculations depend upon the seismic zone, soil type, importance factor of the building amd response reduction factor. These parameters are obtained from the standards codes.

5) Other Moving Loads.

Other important loads that need to be considered in case the building is to be used for industrial purposes are EOT Crane load or Monorail etc.

E. *Combinations for loads.*

Standards and codes are used in order to consider the load combinations. Different load combinations are applied to the structure depending on the PEB layout. The loads will be affected according to the configuration of the main frame, wind zone, seismic zones. The load combinations mostly taken are from the American code MBMA/AISC or Indian code IS800-2007. load combinations as per IS875 and load combinations as. Table 2 shows the load combinations used in AISC and table 3 shows the load combinations used as per the IS.

TABLE II. LOAD COMBINATIONS ACCORDING TO AISC

Design for strength	**Design for Serviceability**
1.0DL + 1.0LL	1.0DL + 1.0LL
1.0DL + 0.75LL + 0.75WL/EL	1.0DL + 0.75LL + 0.75WL/EL
1.0DL + 1.0WL/EL	1.0DL + 1.0WL
0.6DL + 1.0WL/EL	1.0DL + 1.0EL

TABLE III. LOAD COMBINATIONS ACCORDING TO IS 800:2007

Design for Strength	**Design for Serviceability**
1.5DL + 1.5LL	1.0DL + 1.0LL
1.2DL + 1.2LL + 1.2WL/EL	1.0DL + 0.8LL + 0.8WL/EL
1.5DL + 1.5WL/EL	1.0DL + 1.0WL

IV. DISCUSSION

According to the research presented in this paper, studies in the area of pre-engineered buildings are mostly limited to the optimization of steel structures, cost reduction of the structure, comparison with a conventional steel building, and advantages over conventional steel buildings. Through these studies, it is observed that while PEBs are mostly only advantageous when the proposed construction has large column-free spans and the scope of such structures in residential and commercial sectors may be explored. There is also a need to study the seismic responses of these structures in detail. PEBs can be constructed faster and there is better quality control since the fabrication process is done in factories and assembled on site whereas in the case of conventional steel buildings, the fabrication is done on site and must be carefully monitored. This requires more human effort and hence is more time-consuming. PEBs also do not require the fabrication of complex trusses as in the case of CSBs. It is observed that PEB offers many benefits over a conventional steel building, and this has resulted in its adoption in the construction industry.

V. CONCLUSION

The use of optimized tapered sections in PEB results in the reduction of wastage of material. The structures thus obtained are about 20% to 25% lighter in weight and 30% to 35% less in expense. PEB is the future of sustainable construction as it provides both a lightweight and economical solution. While a more economical solution is obtained by using loads recommended in the MBMA, which is the major industry practice, it must be validated that these parameters are appropriate for Indian conditions. Since most PEB structures have pinned base supports due to the ease of installation, a comparison between the effectiveness of pinned and fixed supports can be studied in different load cases. There is also a scope for study of the effect of the different lateral resistance systems in PEBs.

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