



# Comparative Study Of The Design Of A Pre-Engineered Building Having Multiple Cranes With And Without Laced Columns

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## ABSTRACT

*Pre-Engineered Buildings (PEBs) are widely used in modern industrial construction due to their advantages in terms of faster construction, reduced material usage, and overall economy. These structures are designed using standardized components and are highly efficient for large-span buildings. In industries where heavy crane systems are involved, structural performance and stability become critical design considerations. Therefore, selecting an appropriate column system is essential to ensure safety, serviceability, and cost-effectiveness of the structure. In the present study, a comparative analysis is carried out for a PEB structure. The structure is modeled and analyzed using STAAD.Pro software in accordance with IS 800:2007 provisions. Two configurations are considered: one with conventional rigid columns and the other with laced columns. Various parameters such as bending moment distribution, horizontal displacement, vertical deflection, utilization ratio, steel consumption, and overall project cost are evaluated to assess structural performance. The primary objective of this study is to address the need for an economical and efficient structural system for crane-supported industrial buildings. Conventional rigid frames often lead to higher steel consumption and increased cost, especially for large spans and heavy crane loads. Hence, this study investigates whether the use of laced columns can improve load distribution, reduce material usage, and enhance structural efficiency while satisfying all serviceability and safety requirements as per code provisions. The results of the study indicate that the laced column system offers significant advantages over the conventional frame. The steel consumption is reduced from 11,584 kg to 10,530 kg, resulting in a saving of 9.09%. The horizontal displacement decreases from 99.86 mm to 56.499 mm, showing an improvement of 43.36% in lateral stability, while vertical deflection remains within permissible limits. The utilization ratio improves from 0.952 to 0.988, indicating better material efficiency. Furthermore, the total project cost reduces from ₹3.17 crore to ₹2.88 crore, leading to a saving of approximately ₹28.8 lakh (9.09%). Hence, it can be concluded that laced column systems are structurally efficient, safe, and more economical for PEB structures with multiple crane systems.*

**Keywords:** Pre-Engineered Buildings, Laced Columns, Crane Load Structures, Structural Efficiency, Cost Optimization.

## I. INTRODUCTION

### 1.1 INTRODUCTION TO PRE ENGINEERED BUILDINGS:

Pre-engineered Building (PEB) is designed and or PEB fabricated using best suited inventory of raw materials available from all sources and manufacturing methods that can efficiently satisfy a wide range of structural and aesthetic design requirements.



The designs were ready-made but the building components were either ready-made or manufactured against specific orders. These buildings were pre-designed or 'pre-engineered' into standard sizes, spans, bays and heights, and use standard details for fixing cladding, roofing, gutters, flashing, windows, doors etc., taking advantage of industrial practices of mass production of components economically.



**Fig 1.1: A PEB structure**

In other words a pre-engineered building (PEB) is designed by a PEB supplier or manufacturer, using sophisticated design software which takes into account the strength and thickness of available steel, the building loading criteria like wind resistance, snow loading, seismic zone, and a host of other loads that the building may be subjected to. In addition to the design integrity, the corrosion resistance of the steel materials used is of great importance. The building components are manufactured to exacting standards so assembly at the site is not hampered. Today's PEBs can efficiently satisfy a wide range of structural and aesthetic design requirements. Ideally, the available material inventory is added to the software database and the software selects the appropriate materials for optimum design. It does include the flexibility to specify the preferred material thickness and mechanical properties.

Steel is the material of choice for design because it is ductile and flexible. Steel members have high strength per unit weight and the properties of the steel members mostly do not change with time. Also addition and alteration can be made easily steel structures. Historically, the primary framing structure of a pre-engineered building is an assembly of I-shaped members, often 2 referred as I beams. In pre-engineered buildings, the I-beams used are usually formed by welding together steel plates to form the I-section. The I-beams are then field-assembled (e.g. bolted connections) to form the entire frame of the pre-engineered building. Some manufacturers taper the framing members (varying in web depth) according to the local loading effects. Larger plate dimensions are used in areas of higher load effects. In conventional steel building, hot rolled sections are used. The size of each section is selected on the basis of maximum internal stress in the member. Frames of pre-engineered building are according to bending moment diagram. Thus the BM is maximum at mid span and at fixed support. Thus at maximum BM the depth of section is large and depth is reduced depending on BM. Cold formed Z and C-shaped members as secondary structural elements to fasten and support the external cladding.

**The Indian Scenario:** Pre-engineered metal buildings were introduced in India in the mid-1990s. This rapidly growing industry has enormous growth potential in India. As mentioned earlier, the economics and speed of pre-engineered metal buildings is much superior to the traditional concrete and masonry structures that dot the Indian landscape. Steel buildings are typically safer than the conventional masonry structures, especially in earthquakes because steel structures do not collapse. The safety of steel buildings is more readily visible if the steel building is properly designed, bolted and diagonally braced. The concrete structures rely on "fixed bracing" meaning they



often do not have diagonals as bracing but depend on the connection of the column to the foundation, concrete slabs for floors, and the roof. The strength of concrete buildings depends on the proper mixing of concrete which is generally done at the site and unscrupulous contractors can get away with less than specified cement content or lower slab thickness.

India has quickly embraced the modern PEB design software; the two main types of software used are MBS and STAAD PRO. While MBS is more user friendly and has virtually unlimited potential and design flexibility, the STAAD PRO software requires more manual inputs. From the software availability perspective, the Indian PEB industry is fully tuned to world standards. However, as will be described later, the Indian PEB manufacturers are not using the software for optimum designing and are restricting the true potential of the MBS software. In India, most PEB projects are managed by Consultants who may be architects or engineers. They drive the project and are responsible for the architectural design, structural integrity, and costs. Not all consultants are well versed in the structural design aspects of PEBs. Given that PEB's were introduced in India in the mid-1990s and its long history and experience with conventional masonry construction, many consultants feel comfortable in applying the design criteria of

Conventional construction technology to steel buildings. This practice denies the deployment of the true benefits of the PEB technology.

## 1.2 OBJECTIVES OF STUDY

1. To compare pre-engineered building (PEB) models with multiple crane systems using conventional columns and laced columns, in order to identify the most cost-effective design. The study evaluates material consumption, fabrication efficiency, and overall structural economy.
2. To analyse and compare the lateral (horizontal) and vertical deflections of PEB structures under crane loads and other design loads. The aim is to ensure that both configurations satisfy serviceability criteria and structural performance requirements.
3. To optimize the structural members by examining bending moment diagrams and redistributing material where required, such that the utilization ratio is lesser than 1. This helps in achieving an efficient design with improved load-carrying capacity and reduced material wastage.

## 1.13 SCOPE OF STUDY:

This study focuses on the most economical building system by comparing a PEB building with laced column & without laced column. The study aims to assess the effectiveness of these systems in controlling steel tonnage weight, horizontal & vertical deflection, utilization ratio, & optimizing the frames as per bending moment diagram. Using Staad.pro V22.12, incorporating appropriate material properties, loads & Design parameters. Indian Standard (IS) Codes will be followed for load definitions, wind speed, seismic zone, & design parameters. By comparing the steel quantity with & without laced columns the study seeks to identify the most economical PEB structure. The findings from this study are expected to contribute to improved understanding of how laced columns can reduce the weight of the PEB structure.

## II. LITERATURE REVIEW

Pre-Engineered Buildings (PEBs) have gained significant popularity in industrial and infrastructure projects due to their structural efficiency, cost-effectiveness, and rapid construction. With the increasing demand for industrial



sheds accommodating heavy material handling systems, the incorporation of multiple overhead cranes has become common. Such buildings are subjected to complex load combinations involving dead load, live load, crane loads, impact loads, and lateral loads due to wind and seismic effects.

In this context, the selection of an appropriate column system plays a vital role in ensuring structural safety and economy. Conventional solid columns and laced columns are widely used in industrial buildings, especially where large axial loads and bending moments are present. This chapter presents a comprehensive review of previous research related to PEBs, crane load behavior, and the structural performance of laced columns, with emphasis on comparative studies.

Several researchers have investigated the structural behavior and advantages of pre-engineered buildings over conventional steel structures.

**Noopur Pal et al. (2026)** Noopur Pal et al. explored Comparative Study of Pre-Engineered and Conventional Steel Structures with Crane Load in the International Journal for Research in Applied Science and Engineering Technology (IJRASET). The study focused on industrial steel buildings subjected to crane loading using STAAD.Pro with Indian Standard load combinations. The authors modelled structures considering dead load, live load, wind load, seismic load, and crane load to evaluate structural performance. The results showed that crane loads significantly increase axial forces and bending moments in columns and beams. It was observed that horizontal surge forces and impact loads govern the design of crane-supporting members. The study concluded that PEB structures are more economical due to optimized tapered sections. However, the study considered only general crane loading and did not analyze multiple crane interaction effects. This indicates a research gap in multi-crane PEB systems with different column configurations.”

**Nerlekar & Radhika (2024)** Harshad Nerlekar and K. L. Radhika explored Analytical Study of Pre-Engineered Building Subjected to Lateral Loads in the Journal of Propulsion Technology. The study focused on seismic and lateral load behavior of PEB structures using IS 800:2007 provisions. The authors analyzed different bracing systems and roof configurations to evaluate structural performance. The results indicated that diagonal bracing systems provide better stability and reduced displacement. It was observed that optimized PEB configurations reduce steel consumption significantly. The study concluded that PEB systems are efficient for industrial buildings. However, crane loads and their interaction effects were not considered. This highlights a research gap in analyzing PEB structures under crane and multi-crane loading conditions.”

**Varshitha et al. (2024)** M. Varshitha et al. explored A Comparative Study of the Pre-Engineered Building and Conventional Steel Building focusing on steel quantity and efficiency.

The study compared PEB and conventional systems based on steel take-off and fabrication methodology. The authors analysed structural performance under standard loading conditions. The results showed that PEB structures reduce steel consumption by approximately 20–30% compared to conventional steel buildings. It was observed that prefabrication improves construction speed and reduces labour requirements. The study concluded that PEB systems are more efficient and sustainable. However, crane loads and industrial dynamic effects were not considered. This highlights a research gap in crane-supported PEB structures.”

**D. S. Pawar et al. (2023)** D. S. Pawar et al. investigated A Comparative Study on Pre-Engineered Building and Conventional Steel Structures in Mathematical Statistician and Engineering Applications. The study focused on



comparing PEB and conventional steel structures based on parameters such as design efficiency, structural weight, cost, construction time, and performance. The authors analysed industrial building configurations and evaluated their behaviour under standard loading conditions. The results showed that PEB structures are significantly lighter and more economical than conventional steel buildings. It was observed that prefabrication reduces construction time and improves quality control. The study concluded that PEB systems are highly suitable for long-span industrial applications. However, crane loads and dynamic industrial effects were not considered. This creates a research gap in evaluating PEB systems under crane-supported conditions.”

### III. METHODOLOGY

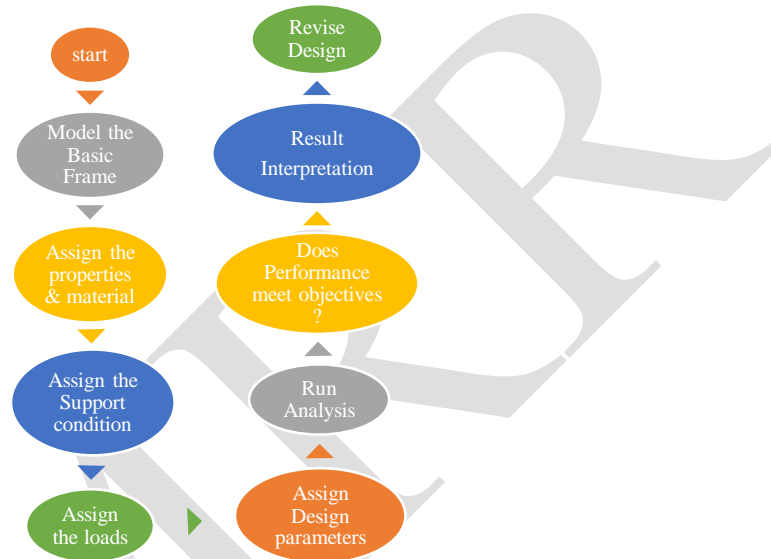
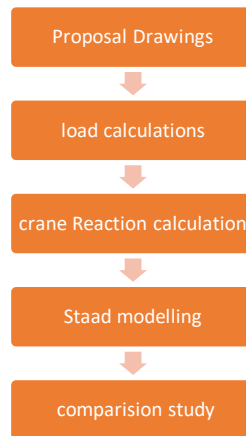


Fig. 2.1 Study of PEB and Conventional System

The methodology adopted in this study involves the analytical comparison of Pre-Engineered Building (PEB) frames with conventional rigid columns and laced columns under identical loading and geometric conditions. A typical industrial building with multiple crane systems is selected, and two structural models are developed using STAAD.Pro software. The structures are analyzed as per relevant Indian Standards, considering dead load, live load, wind load, seismic load, and crane loads. Design parameters such as bending moment, shear force, displacement, deflection, and utilization ratio are evaluated for both configurations. The steel quantity is calculated to assess material efficiency, followed by cost estimation based on prevailing Indian construction rates. The results obtained are compared to study structural behavior, serviceability performance, and economic feasibility. Graphical representations are used to clearly present the comparison. Based on the analysis, conclusions are drawn to identify the most efficient and economical structural system.

#### 3.1 FLOW CHART OF THE WORK:



**Fig 3.1: Flow Chart of the work**

**3.2 Building Data:**

Table 3.0: Data Required for the Design

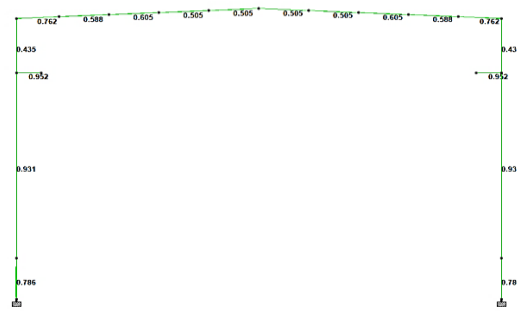
S.no	Variables	Rigid Frame	With laced column
1.	Building dimensions	29.10m(W)*67.50m(L)	29.10(W)*67.50m(L)
2.	Building height	20m	20m
3.	Live load	0.75 KN/m <sup>2</sup>	0.75 KN/m <sup>2</sup>
4.	Dead load	0.1 KN/m <sup>2</sup>	0.1 KN/m <sup>2</sup>
5.	Crane capacity	2-50MT	2-50MT
6.	Wind	50 m/sec	50 m/sec
7.	Seismic zone	IV	IV
8.	Laced column spacing	0	1.5m

**IV. RESULTS AND DISCUSSION**

The Pre-Engineered Building was designed with laced column & without laced column to check the most economical structure among the two. The two models were similar in geometry of the building, seismic zones, wind speed, column height, crane height & crane loadings but varied in column condition i.e. One is with laced column & another was rigid frame while the overall geometry, material properties, loading conditions & crane data remained constant.

**4.1 Results for Structure without Laced Column:**

**4.1.1 Utilization Ratio Check:**

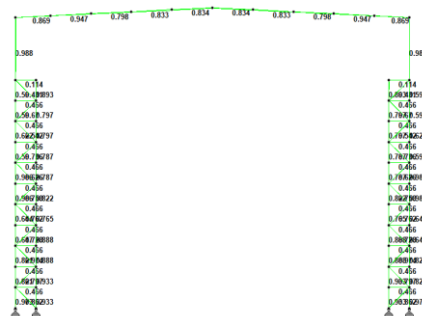


**Fig 4.1 Utilization/stress Ratio (<=1).**

Utilization ratio in a pre-engineered building (PEB) is defined as the ratio of the applied (factored) load effect on a structural member to its corresponding design strength, representing the extent to which the member’s capacity is being utilized. As per IS 800:2007, specifically Clause 5.4.1, the design requirement states that the design action must be less than or equal to the design strength, which is expressed in terms of utilization ratio as being less than or equal to 1.0. In the present analysis of the structure without laced columns, the utilization ratios obtained from STAAD are found to be less than 1.0 for all structural members. This indicates that each member satisfies the code requirement and is operating within its permissible strength limits. The results confirm that the selected sections are adequate to safely resist the applied loading conditions. The observed utilization ratios also reflect that the members have sufficient reserve strength, ensuring structural safety. However, certain members of Rafter/Beam (member 101 to 110) exhibit comparatively lower utilization ratios (ie from 0.762 to 0.505), indicating that they are not fully utilized and may be slightly conservative in design. This is generally expected in the absence of laced columns, where relatively stronger sections are adopted to maintain safety. The overall distribution of utilization ratios across the structure shows a consistent and stable design performance. Hence, the results validate that the PEB without laced columns meets the codal provisions and ensures safe structural behavior. The utilization ratio is less than 1 hence it’s safe as per the standards.

**Results for Structure WITH Laced Column:**

**Utilization Ratio Check:**



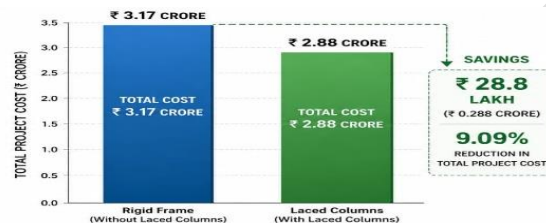
**Fig 4.2 Utilization Ratio (<=1).**

Utilization ratio in a pre-engineered building (PEB) is defined as the ratio of the applied (factored) load effect on a structural member to its design strength, indicating the efficiency of the member in resisting loads. As per IS 800:2007, specifically Clause 5.4.1, the design condition requires that the design action should be less than or equal to the design strength, which implies that the utilization ratio must be  $\leq 1.0$ . In the present study of the laced frame structure, the utilization ratios obtained from STAAD analysis are found to be less than 1.0 for all members,



confirming compliance with codal provisions. The utilization ratio of rafters/beams ranges from 0.947 to 0.798, indicating that these primary members are efficiently utilized and are closer to their design capacity without exceeding safe limits. The lacing members exhibit a utilization ratio of around 0.466, showing that they are well within their capacity and contribute effectively to the overall stability of the built-up columns. The comparatively lower utilization ratio of lacing members indicates that they are lightly stressed but adequately designed for their intended function. The results demonstrate that the load distribution in the laced frame system is more efficient, leading to better utilization of primary structural members. The variation in utilization ratios across different members reflects a balanced and optimized structural design. Overall, the obtained utilization ratios validate that the laced PEB frame is safe, code-compliant, and structurally efficient.

#### Cost Comparison Graph:



**Fig 4.3 Comparison of Overall Cost**

The graph illustrates the comparison of total project cost for PEB frames with and without laced columns. It is observed that the cost of the conventional rigid frame is ₹3.17 crore, whereas the cost reduces to ₹2.88 crore when laced columns are used. This results in a saving of approximately ₹28.8 lakh, corresponding to about 9.09% reduction in total cost. The reduction is primarily due to decreased steel consumption and improved structural efficiency. Hence, the laced column system proves to be more economical for industrial buildings with heavy crane loads.

#### V. CONCLUSION

The present study was undertaken to perform a comparative evaluation of a pre-engineered industrial building having multiple overhead cranes, designed with and without laced columns. The structural analysis and design were carried out in accordance with relevant Indian Standard codes such as IS 800:2007, IS 875 (Part 1 to Part 5), and IS 1893, considering the combined effects of gravity loads, wind loads, seismic loads, and crane-induced forces. Based on the analytical results and comparative assessment, the following conclusions are drawn:

- 1. Cost-Effective Structural System:** The total project cost for the rigid frame is estimated as ₹3.17 crore, whereas the cost reduces to ₹2.88 crore with laced columns. This results in a saving of approximately ₹28.8 lakh, corresponding to about 9.09% reduction in overall cost. Hence, laced column systems are identified as the most cost-effective solution for crane-supported industrial buildings.
- 2. Reduction in Material Consumption:** The study shows that the total steel requirement decreases from 11,584 kg in the conventional frame to 10,530 kg in the laced column frame. This results in a saving of 1,054 kg of steel, which is approximately 9.09% reduction. Therefore, laced columns provide an optimal solution for minimizing steel tonnage while maintaining structural safety.
- 3. Improvement in Lateral Stability:** The horizontal displacement analysis reveals that the frame without laced columns shows a maximum displacement of 99.86 mm, whereas the laced column frame shows only 56.499 mm. This indicates a significant reduction of approximately 43.36% in lateral displacement. Both values are within the



permissible limit of 133.33 mm as per IS 800:2007 (H/150). Hence, laced columns enhance the overall stability of the structure.

4. **Structural Efficiency and Member Utilization:** The utilization ratio comparison shows that the conventional frame has a value of 0.952, whereas the laced column frame reaches 0.988, which is closer to the allowable limit of 1.0. Therefore, laced columns provide a more optimized structural configuration.

5. **Optimization through Load Redistribution:** The bending moment behavior indicates improved load distribution in the laced column system due to the presence of lacing members. These members enable better force transfer and reduce stress concentration in individual elements. As a result, lighter and more efficient sections can be used without compromising structural strength. This leads to an optimized design with improved load-carrying capacity. Hence, laced columns contribute significantly to structural optimization.

6. **Overall Structural and Economic Advantage:** From the overall analysis, it is evident that the laced column system provides a balanced combination of strength, stability, and economy. It reduces steel weight by 9.09%, lowers cost by approximately ₹28–30 lakh, and improves lateral stability by 43.36%. This confirms that laced columns offer both structural and economic advantages over conventional systems.

#### **FUTURE SCOPE OF STUDY:**

While the present study provides valuable insights into the comparative performance of pre-engineered buildings with and without laced columns, several aspects remain open for further research. The following areas are suggested for future scope:

1. Dynamic Analysis of Crane Loads.
2. A detailed nonlinear seismic analysis, including pushover and time-history analysis, can be carried out.
3. The performance of laced columns may be compared with battened columns, tubular sections and composite columns to identify the most suitable column system for different industrial applications.
4. A comprehensive life-cycle cost assessment considering fabrication, erection, maintenance and dismantling can provide deeper insights into the long-term economic benefits of laced column systems.

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