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Comparative Study of Pre-Engineered and Conventional Steel Structures with Crane Load

Noopur Pal[1], Prof. Rakesh Patwa[2], Dr. Savita Maru[3]
[1]*M.E. Student, Department of Civil Engineering, Ujjain Engineering College, Ujjain (M.P.), India*
[2, 3]*Professer, Department of Civil Engineering, Ujjain Engineering College, Ujjain (M.P.), India*

Abstract: Industrial buildings are generally constructed using either Pre-Engineered Building (PEB) systems or Conventional Steel Building (CSB) systems depending on design requirements and economy. Although both systems are commonly used, their behavior changes when crane loads are included, because crane loads add extra vertical and horizontal forces that affect member design and total steel requirement. In this study, a comparative analysis of PEB and CSB industrial structures with crane loading has been carried out using STAAD.Pro software by adopting identical geometric configurations and relevant load combinations including dead load, live load, wind load, seismic load and crane load as per Indian Standard provisions. The main aim of this study is to compare the steel tonnage of the two structural systems and to examine their displacement and internal force behavior. The results show a clear difference in steel usage and force distribution between PEB and CSB. The PEB system uses steel more efficiently because of its optimized and tapered sections
Keywords: Pre-Engineered Building (PEB), Conventional Steel Building (CSB), Crane Loading, Steel Tonnage, Structural Analysis, STAAD.Pro, Industrial Structures

I. INTRODUCTION

Industrial development has increased the demand for structural systems that can support large spans, greater heights, and heavy operational loads. Steel construction has become a preferred choice for such applications because it offers high strength, faster construction, and flexibility in design. In industrial practice, two commonly adopted structural systems are Pre-Engineered Buildings (PEB) and Conventional Steel Buildings (CSB). In Pre-Engineered Building systems, structural members are generally designed as built-up sections with varying depths along their length to match the bending moment distribution. The depth of the section is increased in regions of higher bending moment and reduced where the moment demand is lower, leading to more efficient material utilization. Since the moment of inertia (I) of a section is directly related to the cube of its depth ($I \propto d^3$), even a small change in depth significantly affects the flexural stiffness and load-carrying capacity of the member. In contrast, Conventional Steel Buildings commonly use prismatic rolled sections with constant depth throughout the span, which may not always provide optimum material distribution. As a result, tapered sections used in PEB systems can achieve better structural efficiency and reduced steel consumption while maintaining required strength and serviceability limits.

The key features of PEB include :

- Efficient material utilization
- Lightweight structural system
- Factory-controlled fabrication
- High Strength to Weight Ratio
- Faster construction
- Economical for large spans

The key features of CSB include :

- Strong and rigid structural framework
- Flexibility in on-site modifications
- Better resistance to heavy concentrated loads
- Suitable for heavy load applications
- High structural stability and robustness
- Easy availability of standard sections in the market

The main objective of this study is to compare 17 m high PEB and CSB industrial structures designed with crane loading. The purpose is to study how both systems behave under the same loading conditions and to observe the difference in their steel requirement. Through this comparison, the study aims to understand which structural system is more efficient and practical for industrial buildings with crane facilities.

II. ANALYSIS AND 3D MODELING OF THE STRUCTURE

The 3D models of the 17 m high PEB and CSB industrial buildings were created using STAAD.Pro software. Both structures were modeled with the same plan dimensions and structural layout to ensure a fair comparison. The models included columns, rafters, purlins, bracing members, and crane-supporting elements.

Table 1: General Data Used for the Analysis of the Structure

Constraint	Data Used for All Models
Type of structure	Industrial steel structure with crane
Structural systems	Pre-Engineered Building (PEB) and Conventional Steel Building (CSB)
Bay configuration	48 M (6 M @ 8 Bays)
Rafter span	12 M
Column height	17 M
Roof configuration	1:10
Column sections	Tapered Built-up Sections (PEB) and Prismatic Rolled Sections (CSB)
Rafter sections	Tapered Built-up Sections (PEB) and Prismatic Rolled Sections (CSB)
Crane system	Overhead Travelling Crane
Crane capacity	20 MT
Crane loads considered	Vertical Wheel Load, Horizontal Surge force, Impact load
Modulus of elasticity	2×10^5 N/mm²
Support conditions	Fixed at column base
Load combinations	Dead load, Live load, Wind load, Seismic load, Crane load and their combinations
Analysis type	Linear static analysis
Output parameters	Axial Force, Shear Force, Bending Moment, Support Reactions, Weight, Utilization Ratio

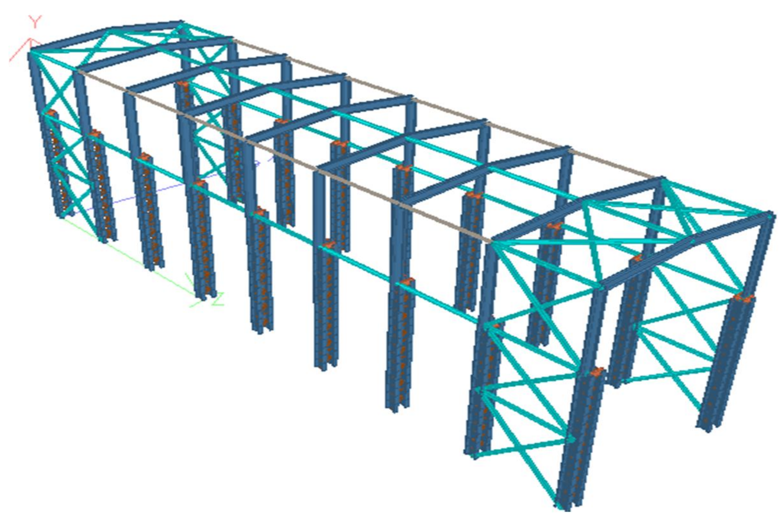

Fig. 1 : 3D view of CSB Structure

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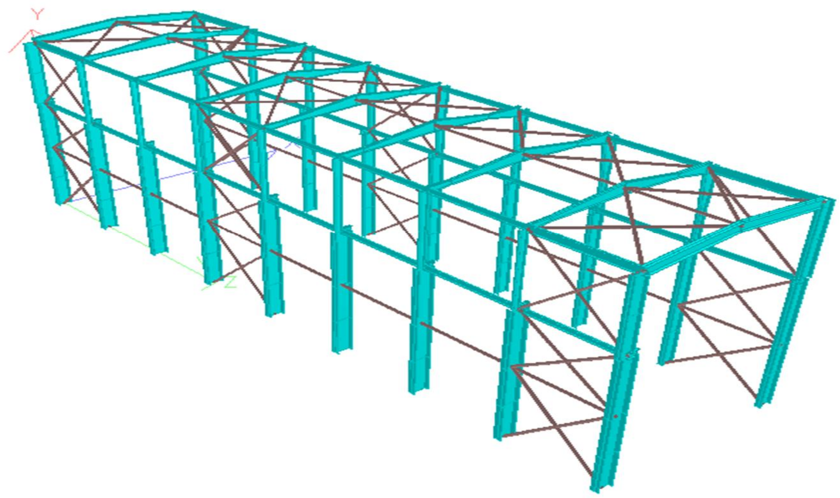


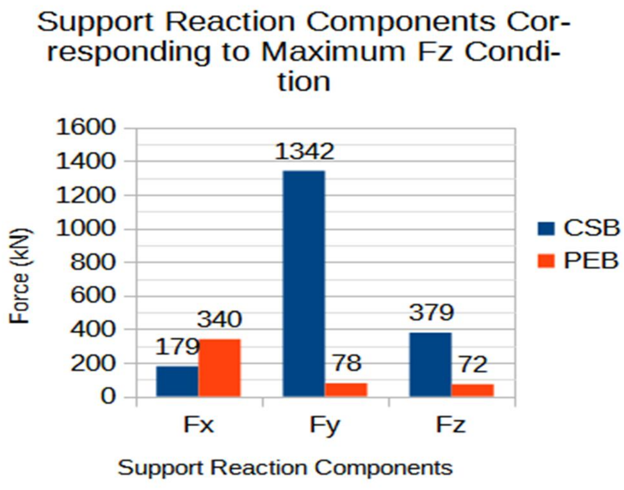
Fig. 2 : 3D view of PEB Structure

III. RESULT AND DISCUSSION

As shown by the results discussed below, the Pre-Engineered Building (PEB) system develops higher internal forces compared to the Conventional Steel Building (CSB) system. This is mainly because PEB uses tapered and optimized sections, which are designed to efficiently resist varying bending moments and shear forces along the span. Due to this design approach, the PEB structure experiences higher bending moments, axial forces, shear forces but lower support reactions under the same loading conditions. These higher force values indicate that the members are actively participating in load transfer and are designed closer to their capacity. On the other hand, the CSB structure shows lower internal force except the support reaction values and also lower utilization ratios, which means that many of its members are not fully utilized and more material is used than structurally required.

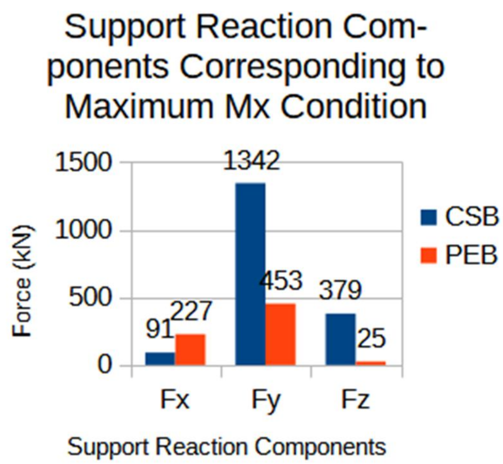
The PEB system proves to be more efficient than the CSB system, especially for industrial buildings with crane loads. This is because PEB members are proportioned based on actual force distribution, leading to better material optimization, reduced foundation sizes and reduced overall steel tonnage. Although the forces are higher in PEB, the structure remains within permissible limits and performs safely. Therefore, the PEB structure provides more structural efficiency and economic advantage compared to the conventional CSB structure for the given loading and design conditions.

1) Support Reaction Distribution for Governing Fz Load Combination



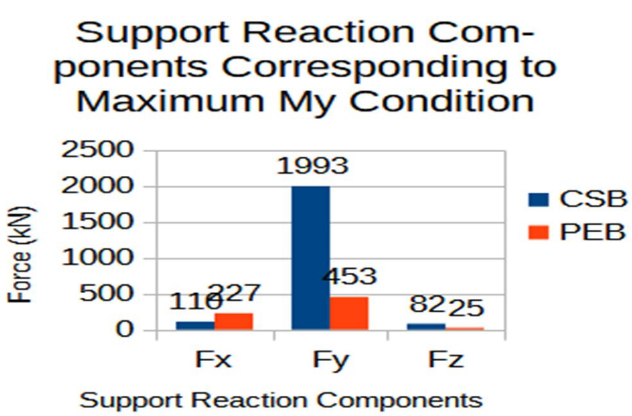
As shown in the figure, under the maximum Fz load condition, the CSB structure develops support reactions of 179 kN in Fx, 1342 kN in Fy, and 379 kN in Fz. In comparison, the PEB structure shows 340 kN in Fx, 78 kN in Fy, and 72 kN in Fz. It is clearly observed that CSB carries much higher vertical (Fy) and lateral (Fz) reactions, whereas PEB shows a higher value only in the Fx direction. The reason is given in commencement of result and discussion section above. This difference occurs because the PEB system is more flexible and optimized, which helps in reducing overall support reactions.

2) Support Reaction Distribution for Governing Mx Load Combination



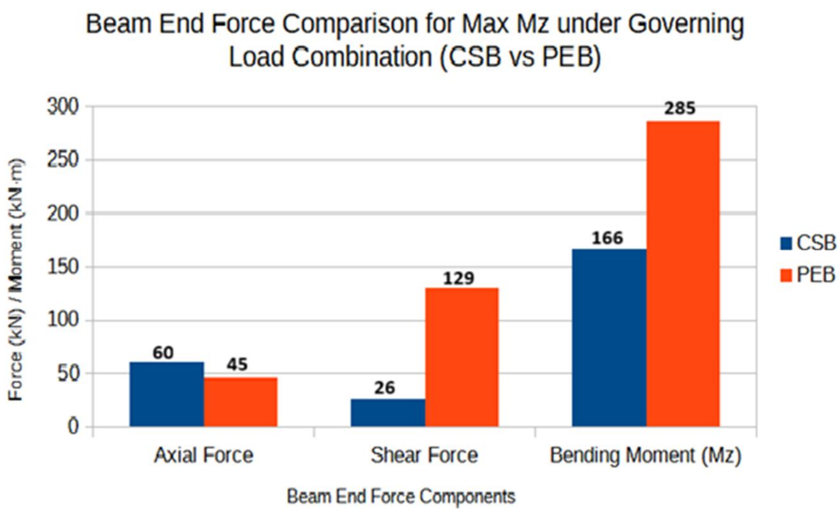
As shown in the figure, under the maximum Mx load condition, the CSB structure develops support reactions of 91 kN in Fx, 1342 kN in Fy, and 379 kN in Fz. In comparison, the PEB structure shows 227 kN in Fx, 453 kN in Fy, and 25 kN in Fz.
It is observed that CSB carries significantly higher reactions in the Fy and Fz directions, whereas PEB shows a higher value only in the Fx direction. The reason is given in commencement of result and discussion section above. This difference occurs because the PEB system is more flexible and optimized, which helps in reducing overall support reactions.

3) Support Reaction Distribution for Governing My Load Combination



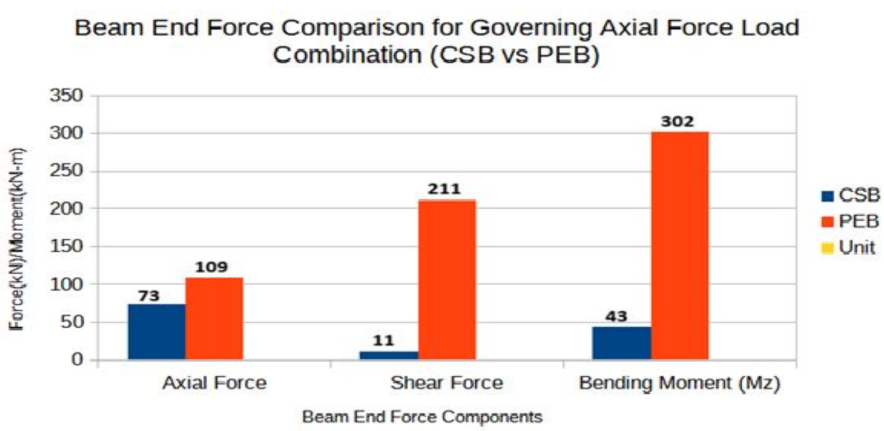
As shown in the figure, under the maximum My load condition, the CSB structure develops support reactions of 110 kN in Fx, 1993 kN in Fy, and 82 kN in Fz. In comparison, the PEB structure shows 227 kN in Fx, 453 kN in Fy, and 25 kN in Fz. It is clearly observed that CSB carries a significantly higher vertical reaction (Fy), with a difference of about **1540 kN** compared to PEB. CSB also shows a higher Fz value, while PEB has a higher reaction only in the Fx direction. Overall, CSB attracts much larger support forces under the maximum My condition. The reason is given in commencement of result and discussion section above. This difference occurs because the PEB system is more flexible and optimized, which helps in reducing overall support reactions.

4) Beam End Force Comparison for Governing Bending Moment Load Combination



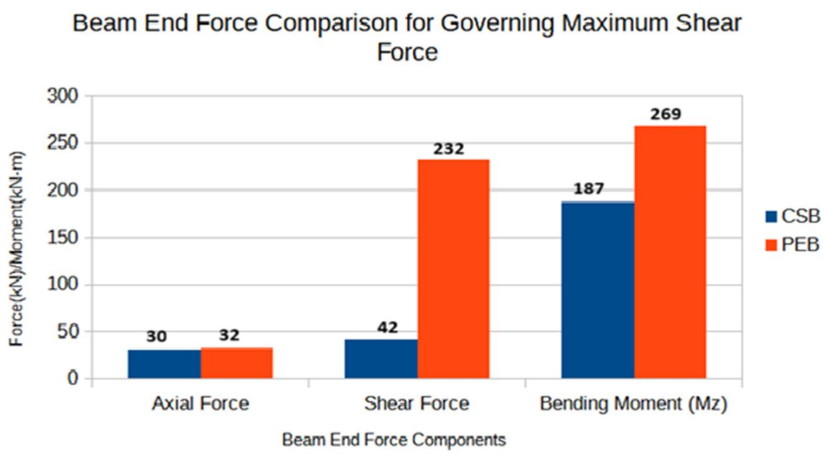
As shown in the figure, for maximum Mz under the governing load combination, the CSB beam end forces are 60 kN axial force, 26 kN shear force, and 166 kN·m bending moment (Mz). In comparison, the PEB beam shows 45 kN axial force, 129 kN shear force, and 285 kN·m bending moment (Mz). It is observed that CSB has slightly higher axial force, whereas PEB develops significantly higher shear force (by 103 kN) and bending moment (by 119 kN·m). The reason is given in commencement of result and discussion section above. This difference mainly arises because PEB transfers more bending effect to the joints, while CSB spreads it more uniformly through the member, leading to lower beam end forces.

5) Beam End Force Comparison for Governing Axial Force Load Combination



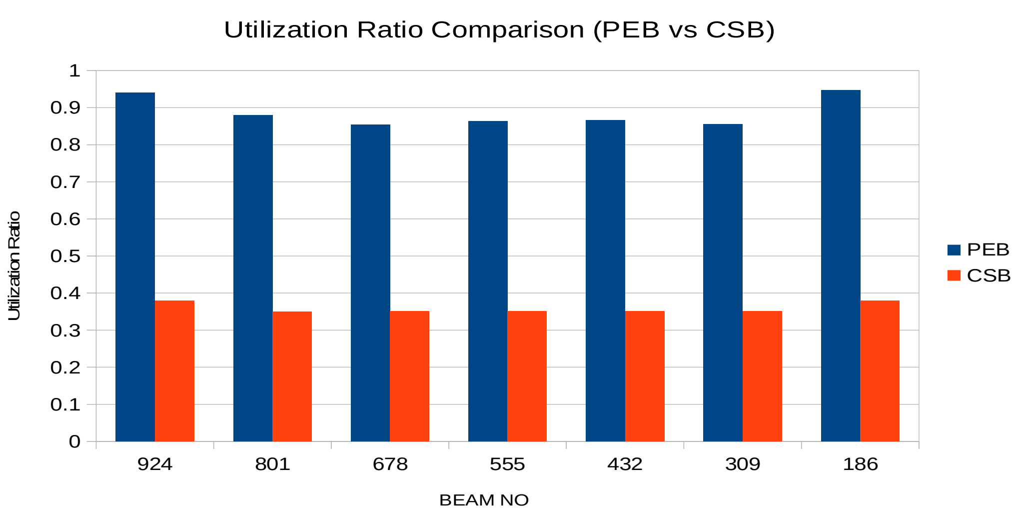
As shown in the figure, under the governing axial force load combination, the CSB beam end forces are 73 kN axial force, 11 kN shear force, and 43 kN·m bending moment (Mz). In comparison, the PEB beam shows 109 kN axial force, 211 kN shear force, and 302 kN·m bending moment (Mz). It is clearly observed that PEB develops significantly higher forces in all three components. The shear force in PEB is higher by 200 kN, and the bending moment is higher by 259 kN·m compared to CSB. The reason is given in commencement of result and discussion section above. This difference occurs because the PEB behaves more like a continuous rigid frame system, which converts axial effects into higher shear and bending moments at the connections.

6) Beam End Force Comparison for Governing Shear Force Load Combination



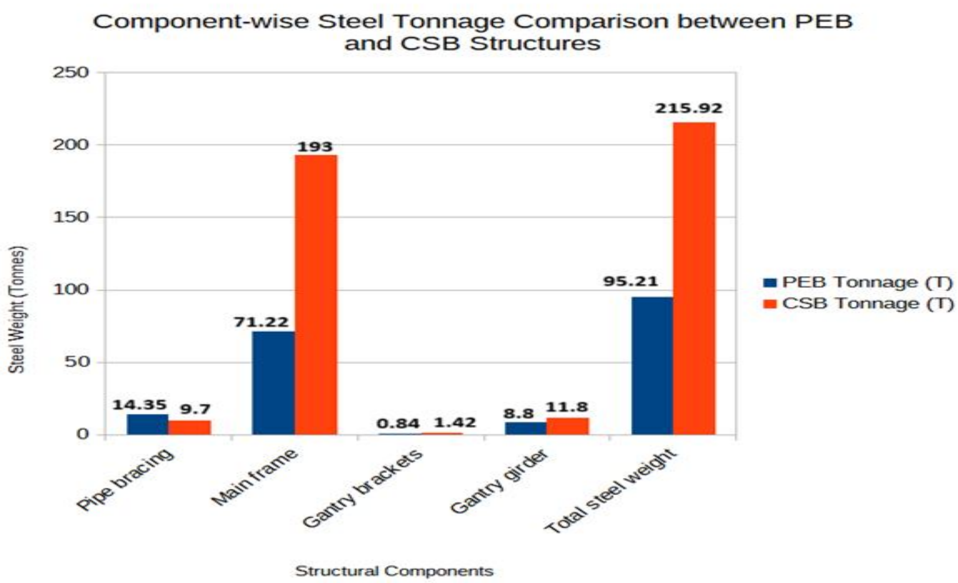
As shown in the figure, under the governing maximum shear force condition, the CSB beam end forces are 30 kN axial force, 42 kN shear force, and 187 kN·m bending moment (Mz). In comparison, the PEB beam shows 32 kN axial force, 232 kN shear force, and 269 kN·m bending moment (Mz). It is observed that axial forces are almost similar in both systems, but PEB develops significantly higher shear force (higher by 190 kN) and bending moment (higher by 82 kN·m) compared to CSB. The reason is given in commencement of result and discussion section above. The higher shear and bending in PEB occur because its rigid frame action and tapered sections transfer more force to the beam–column joints

7) Utilization Ratio Comparison of Structural Members



As shown in the figure, the utilization ratio of PEB members ranges from approximately 0.85 to 0.95, whereas for CSB members it ranges only between 0.35 to 0.38 for all beam numbers It is clearly observed that PEB members are utilized much closer to their full capacity, while CSB members are under-utilized. The reason is given in commencement of result and discussion section above. PEB has a higher utilization ratio because its members are optimally designed and tapered according to force requirements, whereas CSB uses uniform sections that lead to higher material consumption.

8) Comparison of Steel Tonnage for PEB and CSB Structures



As shown in the figure, the steel tonnage for PEB is lower than CSB in most components. For pipe bracing, PEB uses 14.35 T, while CSB uses 9.7 T. In the main frame, PEB requires 71.22 T, whereas CSB requires significantly higher steel of 193 T. For gantry brackets, PEB uses 0.84 T compared to 1.42 T in CSB. Similarly, for the gantry girder, PEB uses 8.8 T, while CSB uses 11.8 T.

Overall, the total steel weight of PEB is 95.21 T, which is much lower than CSB's 215.92 T, showing that PEB achieves considerable material savings and is more economical in terms of steel consumption.

IV. CONCLUSIONS

A. Support Reaction

- The support reaction results clearly show that the CSB system develops significantly higher vertical reactions compared to the PEB system under all governing load conditions.
- Under the maximum Fz case, the vertical reaction (Fy) in PEB is approximately 95.9% lower than CSB.
- Similarly, under maximum Mx and My conditions, the vertical reactions in PEB are about 77% lower.
- The vertical component Fz in PEB is also consistently reduced by nearly 68–73% compared to CSB.
- The horizontal reaction (Fx) in PEB is observed to be about 90–110% higher than CSB across different load cases.

B. Beam End Force Behaviour

- Under the governing maximum Mz load combination, the bending moment at the beam end in the PEB system is 285 kN·m, compared to 166 kN·m in the CSB system. This shows that the PEB beam develops approximately 72% higher bending moment than the CSB beam.
- Under the governing axial load combination, the axial force in the PEB beam is 109 kN, compared to 73 kN in the CSB beam, which is about 49% higher. This indicates that the PEB member is carrying more axial action in addition to bending.
- Under the governing maximum shear condition, the PEB beam develops a shear force of 232 kN, which is approximately 5.5 times higher than the 42 kN observed in the CSB beam.

C. Utilization Ratio

- The PEB utilization ratios range between 0.85 and 0.95, whereas the CSB members remain around 0.34 to 0.38.
- On average, the PEB members are utilized approximately 2.5 times more than the CSB members.

D. *Steel Tonnage*

- The PEB system uses about 1.5 times more steel in bracing members, the CSB structure consumes substantially more steel in primary components.
- The main frame steel in CSB is approximately 2.7 times higher than that of PEB.
- Similarly, CSB uses about 1.7 times more steel in gantry brackets and 1.3 times more in gantry girders.
- Overall, the total steel consumption in CSB is nearly 2.3 times higher than in PEB.

V. FUTURE SCOPE

1) The present study focuses on a 17 m high industrial building with crane loading under specific geometric and loading conditions. Future work can extend this study by considering different crane capacities and varying building heights to understand their influence on structural performance and steel consumption.
2) The work can be extended further by considering dynamic analysis methods such as response spectrum and time-history analysis to study their behavior under seismic effects.
3) In addition, detailed study of connection behavior may provide better understanding of the actual structural performance and failure mechanisms of both systems.
4) A cost comparison including foundation design and construction time analysis can also provide a more comprehensive evaluation of PEB and CSB systems.

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