Comparative Structural Analysis Of Industrial Buildings Designed With PEB And Tube Sections

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Abstract- *This study presents a comprehensive review of the structural performance, design considerations, and analytical approaches associated with Pre-Engineered Buildings (PEB) used in industrial warehouses, with specific attention to accidental loads. Industrial structures demand rapid construction, cost efficiency, and reliable performance under varying loads, making PEB systems a preferred alternative to Conventional Steel Buildings (CSB). The paper analyzes literature focused on the use of tapered members, prefabricated components, and tube sections that enhance structural efficiency, reduce steel consumption, and improve stability. Advanced software tools such as STAAD.Pro enable accurate modeling, load evaluation, and optimization of industrial frames, ensuring safe performance under dead, live, wind, seismic, and accidental loads. The review highlights that PEB structures offer 30–50% lighter framing, reduced foundation loads, shorter construction timelines, and better architectural flexibility compared with CSB systems. Additionally, sustainability advantages such as recyclability, reduced waste generation, and minimized carbon footprint strengthen the relevance of PEB technology in modern construction. Despite notable progress, research gaps exist in long-term durability, lifecycle sustainability assessment, and integration of smart monitoring technologies. Overall, this review synthesizes the advantages, limitations, and future prospects of PEB systems for industrial warehouse applications.*

Keywords- Pre-Engineered Building, Accidental Load, Structural Analysis, STAAD Pro, Sustainable Construction, Tube Sections.

I. INTRODUCTION

Industrial buildings play a vital role in supporting manufacturing, warehousing, logistics, and other large-scale operations, making their structural efficiency, safety, and cost-effectiveness crucial for modern infrastructure development. Over the past few decades, the construction sector has experienced a major shift from conventional steel buildings (CSB) to more optimized systems such as Pre-Engineered Buildings (PEB) and advanced steel tube sections. This transformation has been driven by the demand for faster construction, reduced project costs, enhanced sustainability, and improved structural performance under various loading conditionsincluding accidental and seismic loads.Pre-Engineered Buildings represent a significant advancement in steel construction technology. Unlike traditional structural systems where members are fabricated after detailed on-site design, PEB systems are fully designed, optimized, and manufactured in factories under controlled conditions. This approach allows for precision engineering, material optimization, and rapid assembly at the site, making PEB structures highly economical in terms of both time and cost. The use of tapered I-sections, cold-formed Z and C sections, and lightweight components further reduces steel consumption while maintaining adequate strength and stability. Consequently, PEB has become a favorable option for large-span industrial warehouses, commercial facilities, utility structures, and infrastructure-supporting buildings.

At the same time, the adoption of tubular sections in industrial structures has increased because of their superior strength-to-weight ratio, aesthetic appearance, and improved resistance to buckling and torsional effects. Tube sections, when combined with PEB principles, offer improved design flexibility and enhanced performance under dynamic and accidental loads. Their application is particularly beneficial in high-rise industrial frames, long-span roofs, and structures requiring efficient load distribution.The integration of modern structural analysis software such as STAAD.Pro, ETABS, and advanced finite element tools has further revolutionized industrial building design. These tools allow engineers to analyze multiple load combinations, assess the behavior of tapered and tubular sections, evaluate bracing systems, and optimize structural configurations with high accuracy.In addition to their engineering advantages, PEB systems contribute significantly to sustainable construction practices. The use of recyclable materials, reduced on-site waste, lower carbon footprint, and adaptable structural components aligns with global efforts toward eco-friendly construction.This review aims to present a comprehensive discussion on the evolution, analysis, design strategies, comparative advantages, limitations, and emerging trends associated with PEB and tube sections in industrial construction. By synthesizing findings from past research, the paper highlights the growing relevance of PEB technology and advanced steel systems in achieving efficient, economical, and sustainable industrial infrastructure.

1.2 Concept of PEB

The concept of Pre-Engineered Buildings (PEB) has emerged as a transformative approach in the construction of steel structures, driven by the need for faster, economical, and efficient building systems. A pre-engineered steel building refers to a structure that is fully designed and fabricated in a factory-controlled environment, shipped to the site in a completely knocked-down (CKD) condition, and assembled using nut-and-bolt connections. This prefabrication strategy ensures precision, reduces on-site labor requirements, and significantly cuts down the overall construction time. In its simplest definition, "pre-engineered" denotes any structural component that is manufactured prior to its arrival at the building site, thereby ensuring standardized quality and ease of erection.The PEB concept originally relied on off-the-shelf, ready-made designs, but with advancements in technology, customized and project-specific solutions have become increasingly feasible. Modern PEB systems are engineered into standard spans, bays, and heights, utilizing uniform detailing practices for roofing, cladding, gutters, flashings, doors, and windows. This standardization facilitates mass production, resulting in substantial savings in material and labor costs. Moreover, the fabrication of components in automated facilities enhances accuracy, minimizes wastage, and ensures consistent quality compared with conventional site-fabricated structures.

Although PEB systems are widely used in industrial and non-residential construction globally, their adoption in India began only in the late 1990s with economic liberalization and the entry of multinational corporations. The Indian PEB manufacturing sector currently has an estimated capacity of 6.0 lakh tons annually, expanding at a compound growth rate of 25–30%. Despite this rapid progress, India still lags behind global standards in aesthetic development and advanced structural design practices. However, domestic manufacturers are increasingly investing in modern technologies to bridge this gap.The demand for PEB systems in India is driven by rising construction needs in residential, commercial, institutional, industrial, and infrastructure sectors. Modern structures are becoming taller, lighter, and more complex, necessitating efficient systems that do not compromise on functionality. In the ongoing economic competition among steel, concrete, and other materials, steel remains attractive due to its recyclability, strength, and speed of construction. Yet, India's per capita steel consumption remains low at 42 kg compared with China's 270 kg, indicating substantial potential for growth. Only 10% of national steel production contributes to construction, and PEB accounts for merely 0.5 million tons.Projections indicate that with increasing steel production and efforts by organizations such as BIS and INSDAG, steel-intensive construction could rise significantly, with PEB demand expected to reach 2.2 million tons. Thus, the PEB industry in India is poised for major expansion, supported by technological innovations, sustainable construction needs, and widespread acceptance across nonconventional sectors.

Fig 1: Pre-Engineered Building.

Pre-Engineered Buildings (PEBs) are cost-effective and versatile alternatives to conventional structures. Before selecting a supplier, it is important to define the purpose of the building—whether commercial, industrial, agricultural, or residential—as this determines the design, size, and cost. PEBs come in various types, including warehouses, manufacturing plants, and agricultural structures. Key considerations include overall dimensions, roof style (regular or upright), installation site conditions, and customization options such as size, color, and functionality. Proper planning ensures that the PEB meets both functional requirements and budget constraints.

II. LITERATURE REVIEW

The literature review examines previous studies on Pre-Engineered Buildings (PEB), highlighting advancements in structural efficiency, material optimization, and design practices. It compares PEB with conventional steel systems to understand performance, cost benefits, and suitability for industrial applications.

2.1 Review of Previous Studies on Pre-Engineered Building (PEB) Systems

Bhaskar (2022) presented a comprehensive review of pre-engineered steel buildings, emphasizing their advantages in structural efficiency, cost reduction, and rapid construction. The study highlighted advancements in fabrication technology and discussed how PEB systems support sustainable, large-span industrial structures compared with conventional steel building practices.**Venkatesh and Jayanthi (2021)** analyzed pre-engineered steel truss buildings using structural software and demonstrated significant savings in material usage and construction time. Their results showed that optimizing frame spacing and geometry in PEB systems provides improved structural performance and cost-efficiency compared with traditional steel truss configurations.**Pantheeradi and Abraham (2022)** conducted a comparative study between pre-engineered buildings and conventional steel buildings using STAAD Pro. Their analysis revealed that PEB structures require less steel, reduce overall project cost, and perform efficiently under various loading conditions, making them a practical alternative to conventional systems.**Patel and Sharma (2015)** examined the design and analysis of a PEB portal frame, showing that factory-fabricated components and tapered sections significantly improve performance and reduce material consumption. Their findings confirmed that PEB portal frames achieve faster installation and structural optimization compared with conventionally designed steel portal systems.**Subashini and Valentina (2015)** compared industrial buildings designed using PEB and conventional methods. Their study reported that PEB structures deliver substantial benefits in weight reduction, fabrication speed, and cost savings. The authors concluded that PEB offers superior efficiency for long-span industrial applications requiring rapid and economical construction.**Shaik Kalesha (2020)**carried out an analytical study on pre-engineered buildings using STAAD Pro and highlighted their efficiency in terms of cost, time, and sustainability. The study explained how prefabricated components reduce construction duration and material wastage while improving structural performance. PEB systems were shown to offer better architectural flexibility, reusable materials, and eco-friendly construction practices. Overall, the research emphasized the superiority of PEB technology over conventional steel structures in modern construction.**Deepti D. Katkar (2018)**compared conventional steel frames with pre-engineered steel truss systems for an industrial building using STAAD Pro V8i. The study demonstrated that PEBs offer faster construction, reduced weight, and cost efficiency, particularly for long-span structures. Prefabrication and standardized detailing improved accuracy and reduced overall construction time. The research concluded that PEB technology provides substantial advantages over traditional steel construction, supporting its increasing adoption in India's rapidly growing industrial infrastructure sector.**N. Roopesh (2020)**examined the design of PEB systems for gas-insulated substations that require large clear spans and fast installation. The study highlighted the limitations of concrete structures in such applications and emphasized steel's superior ductility, recyclability, and flexibility. By utilizing prefabricated components produced parallel to site work, PEBs drastically reduced construction duration. The research confirmed that PEB systems offer better structural optimization and economic benefits than conventional steel buildings in specialized industrial applications.

2.2 Studies on Modern Innovations in Geotechnical, Structural, and Seismic Engineering

Kangmin Lee (2022)analyzed the performance of helical piles using finite element modelling in PLAXIS 2D, addressing their increasing use in dense or environmentally sensitive construction zones. The study demonstrated how these piles offer improved load-carrying capacity, ease of installation, and flexibility compared with traditional piling systems. By examining soil–pile interactions and critical spacing and embedment ratios, the research provided valuable insights into the design and optimization of helical piles for various soil conditions.**Ahmed M. Elsayed (2021)**introduced a multi-objective optimization model for steel building layouts, focusing on reducing cost and embodied energy using genetic algorithms. The study optimized beam configurations, deck thickness, and slab design while adhering to architectural constraints. Results demonstrated that sustainable design integration can significantly lower environmental impact without compromising structural efficiency. The research highlighted the importance of combining structural optimization with energy considerations in modern steel building design.**Baduge (2022)** reviewed cutting-edge applications of AI, ML, and deep learning in Construction 4.0, covering areas such as architectural visualization, material optimization, structural analysis, automation, safety monitoring, and building health management. The study emphasized technologies like BIM, Digital Twins, IoT, and smart vision systems. Findings revealed that AI-driven tools significantly enhance accuracy, productivity, and sustainability across the entire building lifecycle, promoting a more efficient and technologically advanced construction industry.**Kim and Christopher (2022)** synthesized current practices related to seismic analysis, design, and retrofitting of built environments. Their review explored building behavior during earthquakes, rehabilitation methodologies, and modern design codes. Case studies of non-conforming school buildings demonstrated effective retrofit strategies. The study emphasized the importance of updated structural standards, ground-motion considerations, and robust seismic detailing to enhance building safety and resilience.

Research Gap

The reviewed literature demonstrates the considerable advantages of Pre-Engineered Buildings (PEBs) over conventional steel structures in terms of cost reduction, rapid construction, material efficiency, structural optimization, and sustainability. Numerous studies have validated the performance of PEBs under various load conditions using structural analysis software, highlighting the benefits of prefabrication, tapered sections, and optimized frame geometry. PEBs are particularly suitable for long-span industrial applications and specialized facilities, offering faster installation and reduced material consumption compared with conventional steel systems.However, despite extensive research on structural performance and cost-effectiveness, several gaps remain. Most studies primarily focus on comparative analyses of material usage, cost, and construction speed, while limited attention is given to holistic sustainability metrics, such as lifecycle energy consumption, carbon footprint, and recyclability. Although some research considers seismic and wind load performance, comprehensive investigations on long-term structural resilience and durability of PEBs in diverse environmental conditions are scarce. Furthermore, while emerging technologies such as AI, ML, and digital twins are being applied in Construction 4.0 for optimization and monitoring, their integration into PEB design, predictive maintenance, and real-time performance assessment remains underexplored. Additionally, the majority of studies are limited to theoretical modeling and simulation, with insufficient field validation or large-scale experimental studies evaluating practical challenges of PEB implementation.Therefore, future research should address these gaps by incorporating sustainability assessment, long-term durability studies, and smart technology integration into PEB design and construction. Such investigations would provide more comprehensive guidelines for optimizing PEB systems while promoting eco-friendly, resilient, and efficient industrial infrastructure solutions.

III. METHODOLOGY

The present study focuses on a comparative analysis of Pre-Engineered Building (PEB) industrial sheds and conventional steel (CST) sheds. The objective is to evaluate the structural performance of PEBs in comparison to traditional designs, particularly in terms of support reactions, axial forces, and overall efficiency.

The methodology is divided into several stages:

1. **Model Validation:**

Initially, a reference industrial shed is developed and validated by analyzing the support reactions and axial forces in each structural member. This ensures that the modeling and analysis approach is accurate before conducting comparative studies.

2. **Proposed Models for Comparative Analysis:**

For the purpose of comparison, six different industrial shed models are considered:

- **Model 1:** Conventional steel (CST) industrial shed with 3 bays, each 8 m in width and a span of 12 m.
- **Model 2:** CST industrial shed with 9 bays, each 8 m in width and a span of 12 m.
- **Model 3:** PEB industrial shed with 3 bays, each 8 m in width and a span of 12 m.
- **Model 4:** PEB industrial shed with 9 bays, each 8 m in width and a span of 12 m.
- **Model 5:** PEB industrial shed with 3 bays, each 8 m in width and a span of 12 m.
- **Model 6:** PEB industrial shed with 3 bays, each 8 m in width and a span of 12 m, including cross bracing for enhanced stability.

3. **Analysis Procedure:**

Each model is analyzed under identical loading conditions to evaluate critical structural parameters such as support reactions, axial forces, bending moments, and deflections. Comparisons are drawn between conventional CST sheds and PEB sheds to identify differences in material efficiency, structural stability, and cost-effectiveness.

4. **Evaluation and Comparison:**

The results obtained from each model are compared to determine the advantages of PEB systems over conventional designs. Particular attention is given to the effect of bay numbers and cross bracing on structural performance. This allows for a comprehensive assessment of the suitability of PEBs for industrial applications.

This detailed methodology ensures a systematic and thorough comparison between PEB and conventional industrial shed designs, providing insights into structural efficiency, material optimization, and potential cost benefits.This methodology provides a structured approach to evaluating the advantages and limitations of PEB sheds compared to conventional CST designs, enabling a detailed comparison in terms of structural behavior and material utilization.

IV. RESULTS AND DISCUSSION

This study presents the analysis outcomes of CST and PEB industrial sheds, comparing structural performance, support reactions, and axial forces. The discussion highlights differences in efficiency, stability, and material usage, emphasizing the advantages of pre-engineered building designs.

4.1 Structural Analysis, Design, and Validation of an Industrial Truss

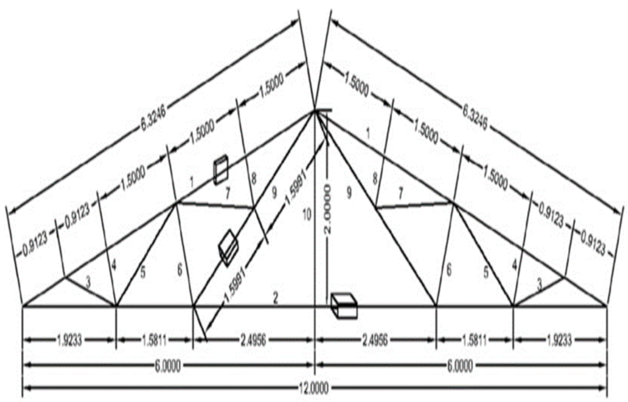

Fig.2: Structural Elevation of the Truss

Figure 2 illustrates the elevation of the industrial truss under study. The structural analysis considers various load effects in accordance with Indian Standards. Dead loads, live loads, wind loads, and accidental loads are applied as per IS: 875-1987, while seismic effects follow IS: 1893-2002 Part IV. Multiple load combinations are evaluated to simulate realistic service conditions, including: (1) dead load plus imposed (live) load, (2) dead load plus imposed load combined with wind or earthquake load and accidental load, and (3) dead load with wind or earthquake load including accidental load. This ensures comprehensive assessment of truss performance and structural safety.

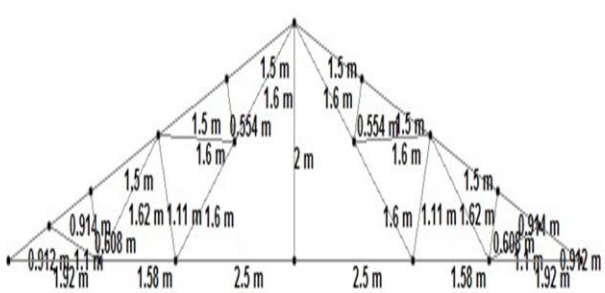

Fig 3: Dimensions of the industrial truss modeled in STAAD-Pro

The figure shows the detailed geometric dimensions of the industrial truss used for structural analysis in STAAD-Pro. The truss has a central height of 2 m with varying panel lengths and heights across the span. Panels on either side are symmetrically arranged, with lengths ranging from 0.554 m to 2.5 m and vertical heights from 0.608 m to 1.62 m. These precise measurements are essential for accurate modeling, ensuring correct calculation of axial forces, bending moments, and deflections under applied loads, and providing a reliable basis for comparison between conventional and pre-engineered shed designs.

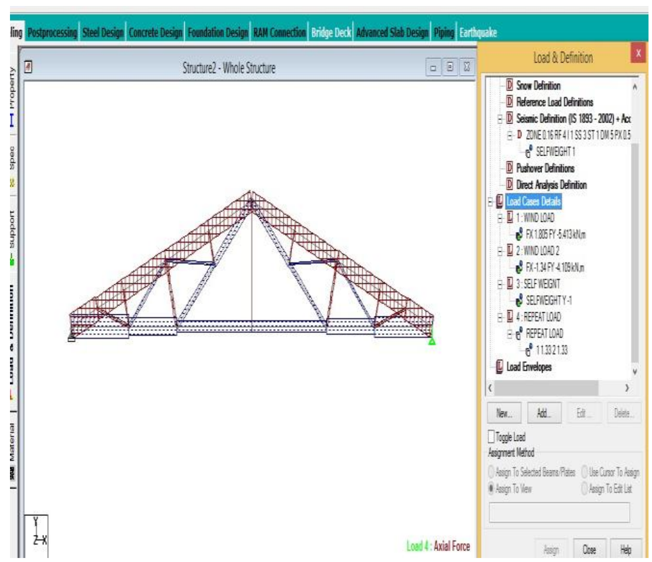

Fig 4: Axial Force

The figure shows the axial force distribution in a pre-engineered steel truss structure analyzed in STAAD-Pro. The axial forces represent the internal forces experienced by each truss member due to applied loads, including self-weight, wind, and live loads. Compression and tension members can be identified, with top chords typically under compression and bottom chords under tension, while web members experience a combination depending on load paths. The analysis indicates how forces are transferred from the roof to supports, ensuring structural stability. This information is crucial for selecting appropriate member sizes, optimizing material usage, and verifying that the structure meets safety and design standards.

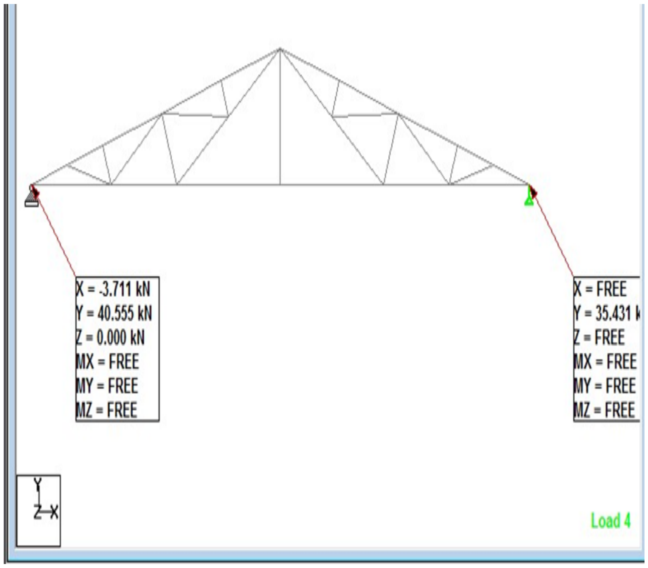

Fig 5: Support reaction

he supports reactions of the truss show that the left support, a pinned support, resists both vertical (Y = 40.555 kN) and horizontal (X = -3.711 kN) forces, while the right support, a roller support, resists only a vertical force (Y = 35.431 kN). Both supports allow free rotation (MX, MY, MZ = FREE), indicating no moment resistance. These reactions ensure equilibrium of the truss under the applied loads.

4.2 Assessment of Industrial Warehouse Operations

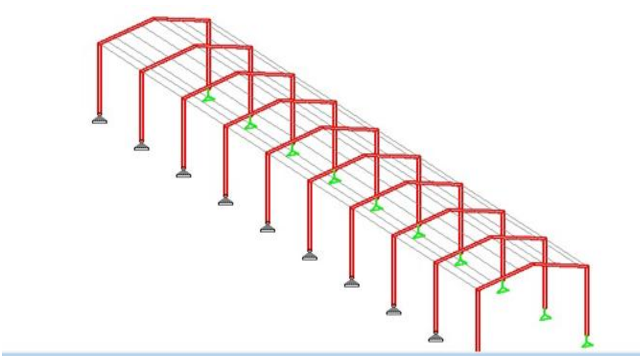

Fig 6: Staad Pro Generated PEB with 9 bays.

The figure illustrates the STAAD Pro-generated model of a single-storey industrial warehouse with nine bays. The structure spans a total width of 12 m with a total length of 72 m, each bay measuring 8 m. The eave height is 14 m, and the roof slopes are 5° for the Pre-Engineered Building (PEB) and 15° for the Cold-Formed Steel Building (CSB). The supports are pinned, allowing rotational freedom at the base. The 3D frame representation highlights the structural arrangement, bay divisions, and load path, serving as a reference for structural analysis and performance evaluation of the warehouse.

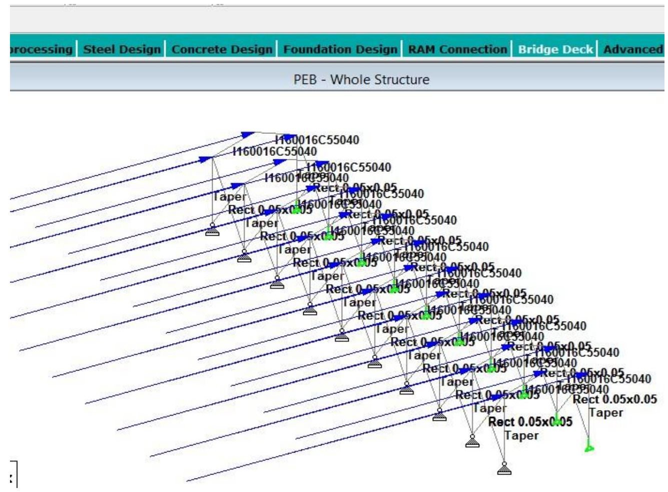

Fig. 7: Whole Structure View of the Industrial Warehouse (PEB Model)

The figure illustrates the complete 3D structural model of the single-storey Industrial Warehouse designed using a Pre-Engineered Building (PEB) system. The model shows tapered columns, rafters, and primary framing elements arranged across nine bays, each 8 m long, covering a total length of 72 m and a span of 12 m. The pinned supports, roof slopes of 5° (PEB) and 15° (CSB), and an eave height of 14 m are clearly represented, depicting the overall configuration and load path of the warehouse structure.

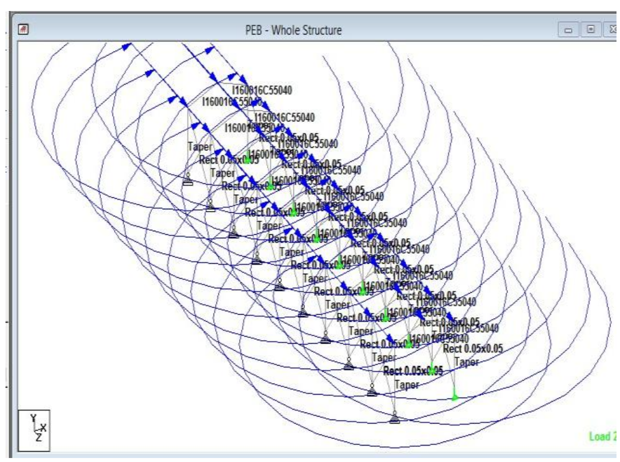

Figure 8: 3D Load Application View of the Industrial Warehouse (PEB Model)

This figure presents the 3D load application view of the Pre-Engineered Industrial Warehouse structure. The diagram illustrates the distribution of external loads, including roof loads and lateral forces, applied across the nine-bay system. The curved load contours represent the action of wind and roof loading over the 12 m span and 72 m total length. Tapered columns, rafters, and pinned supports are clearly shown, highlighting the building's structural behaviour under applied loads.

III. CONCLUSION

The studyclearly establishes that Pre-Engineered Buildings (PEB) represent a highly efficient, economical, and sustainable alternative to conventional steel construction for industrial warehouse applications. The ability of PEB systems to use optimized tapered members, factory-fabricated components, and lightweight structural sections leads to significant reductions in steel consumption, construction time, and overall project cost. Analytical tools like STAAD.Pro play a critical role in evaluating the structural behavior of PEB frames under various load combinations, including dead, live, wind, seismic, and accidental loads. These tools ensure accuracy in predicting axial forces, support reactions, bending moments, and deflections, supporting safe and performance-based design.PEB structures demonstrate superior performance in terms of material efficiency, stability, and ease of erection. Their inherent advantages—such as precise detailing, minimal on-site labor, reduced foundation loads, and faster installation—make them ideal for large-span industrial warehouses. Studies show that PEBs are up to 50% lighter and significantly more cost-effective than CSBs, while also offering enhanced architectural and functional flexibility. Sustainability benefits, including lower embodied energy, recyclability of steel, and reduced carbon emissions, further increase their suitability for modern industrial needs.However, the review identifies gaps in long-term performance assessment, lifecycle sustainability evaluation, and real-time monitoring of PEB structures. Future research should integrate advanced technologies such as AI, IoT, and digital twins to improve predictive maintenance, design optimization, and resilience against accidental events. Overall, PEB systems offer a robust, economical, and environmentally responsible solution that aligns with the evolving demands of industrial infrastructure.

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