Grenze International Journal of Engineering and Technology, June Issue

Comparative Analysis of Structural Performance and Sustainability in Pre-Engineered Buildings: A Review of American and Indian Guidelines

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***Abstract*—PEB is an abbreviation for pre-engineered buildings, and this modern construction technique is cost- effective as well as efficient in building faster as compared to traditional methods. Here, a review is presented for understanding the comparative effectiveness between PEB systems according to American standards (AISC, ASCE) and Indian standards (IS 800, IS 875). The study endeavors to analyze the differences in structural performance, material specifications, design settings, and construction practice between the PEB guidelines originating from both countries. The main finding of the study `states that \"whereas the American guides mandates higher safety factors along with full- blown quality control measures, thus improving load capacities and robustness highly; the Indian codes are could well be more readily adaptable to local conditions but leaves much to be desired in terms of quality assurance and material standards.\" "Case studies have shown comparative advantages wherein PEBs designed with American standards portray quite superb structural performance besides having very stringent inspection protocols." On the other hand, Indian guidelines constitute practical solutions for building techniques to work within the type of material and conditions available in the region and thus could be improved upon more with higher stringent quality control and upgraded material specifications. This review highlights the overall areas where continuous and regular evaluation and updating of codal guidelines are necessary to incorporate emerging technologies and field performance data for efficiency and better performance of structures and integrity of PEBs worldwide.**

***Index Terms*— AISC, ASCE, IS 800, IS 875, Pre-Engineered Buildings, structural performance.**

I. INTRODUCTION

A. Definition and Significance of Pre-Engineered Buildings (PEBs)

Pre-Engineered Buildings (PEBs) are those buildings whose design and construction are technology integrated and engineered to produce these peculiar types of buildings. These types of buildings differ from conventional buildings that require extensive local site construction and customization. In essence, they are either manufactured or substantially constructed in a controlled environment. By designing and prefabricating components (including beams, columns, and panels), the components can adhere relatively precisely to the specification and undergo a quality control process.

Grenze ID: 01.GIJET.11.2.231_20

The materials are thus taken into the construction site for assembly [1].
There are various strategic advantages associated with PEBs. First, their modularity and simplified assembly contribute matrix construction speeds that save time and thus cost [2]. They are therefore attractive to both the private and public sector. Secondly, PEBs provide an opportunity for flexibility and adaptability in design, ranging from warehouse and industrial complex configuration to commercial buildings and sports stadiums. Precision manufacturing also entails improved quality and increased uniformity in performance, thus enhancing safety and longevity.

II. Literature Review

The evolution of codal guidelines for pre-engineered buildings (PEBs) in the USA and India always shaped construction engineering. Initially, the focus was towards conventional construction methods; however, with the advent of PEBs, new standards and codes were developed and put in place to ensure safety and efficiency as well as a green environment. In such developments, much relied on the US Metal Building Manufacturers Association (MBMA) and the American Institute of Steel Construction (AISC).

A. Key Studies and Findings

Much research has taken place on the American and Indian guidelines of PEBs in terms of strengths and weaknesses of both approaches. The structural performance assessment of PEB systems under general loading conditions by Krishna and Raju (2023) was done through analysis using STAAD Pro [5]. The study shows that the concept of PEB optimizes designs while keeping the integrity of economics intact and emphasizes the role of tube cross sections as well as Indian Standard Medium Weight Beam 350 for specification of the column and rafter sections. Chhajed and Mulay (2020) conducted a comparative study of both Indian and international codes and concluded that there are remarkable differences in total tonnage and deflection criteria [6]. The study thus indicates the requirement for international standards to be localized for end suitability to a specific region.
In addition, Paudel, Maulana, and Prayuda (2024) evaluated the seismic vulnerability of residential buildings in Nepal-nonregular vertical structures were found to be highly vulnerable. This research emphasizes the need for localization of seismic activity in PEB design [7]. Bharadwaj and Singh (2024) provided proof of using GRIHA parameters and BIM tools in sustainable green construction practice, integrating PEBs to sustainable designs in environmental resilience.

B. Gaps in the Literature

Notwithstanding the considerable research into pre- engineered buildings (PEBs), many gaps still exist. For instance, very few studies consider long-term performance and durability of PEBs in given environmental conditions. Most of the existing studies are oriented to immediate performance characteristics (load-bearing capacities and deflections) and do not take into account long-term problems like corrosion and material fatigue [8]. The other sub-gap identified is that the effect of locality climatic conditions on PEB performance is not well researched. A few studies can be compared where PEBs perform under different states in India that have largely varying climatic conditions [9]. Thirdly, while the sustainable design practices are emerging, the literature does not have well-equipped frameworks that integrate PEBs with holistic sustainability measures, including energy efficiency, water management, and carbon footprint metrics [10].

III. Comparative Analysis

A. Design Loads

Loading requirements are among the primary factors considered in both American and Indian codes as they relate to ensuring structural safety of Pre-Engineered Buildings (PEBs). While the general idea is similar for the requirement of a particular load in reliability and safety terms, there also exists a little dissimilarity between the loads considered and the load combinations. ASCE 7-16, Minimum Design Loads and Associated Criteria for Buildings and Other Structures, specifies the variety of loads that should be considered. The loads may include dead, live, wind, and snow loads among others as permanent static loads, temporary dynamic loads, seismic loads, or others [16]. Often the design load combinations are based upon Load and Resistance Factor Design (LRFD) method and Allowable Strength Design (ASD) method, which has safety factors for load effects for high safety. One sets out the load types in Indian standards such as IS 875-Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures: dead loads, live loads, wind loads, snow loads, and so on. IS 1893, Criteria for Earthquake Resistant Design of Structures, spells out guidelines for seismic loads. Most Indian codes employ safety factors, unlike the LRFD approach, which is more considering statistical arguments.

The most significant difference is the magnitude of loads and safety factors that pertain to them. American standards tend to keep more conservative load factors that correspond to a larger variety of environmental conditions and higher uncertainty levels concerning load effects [17]. For example, the ASCE 7 assigns a wind load factor of 1.6, while IS 875 lists 1.5 as its default. The same trend is observed for seismic load factors, as ASCE 7 uses much more complicated response coefficients than IS 1893.

B. Material Specifications

First, indicate the grade or material specifications needed for a PEB: the material spec defines the standard of structural performance and reliability throughout the life of the structure.

The United States set out guidance such as that promulgated by the American Institute of Steel Construction to itemize various grades of steels for structural components, such as ASTM A992 under wide-flange shapes, ASTM A36 for plates, and angles. These grades have high yield strength, are tough, and are matched with stringent quality controls to guarantee the uniformity of material [18].

There are guidelines for India too, which are summed up in IS 2062, Hot Rolled Medium and High Tensile Structural Steel. These specifications include the grades of similar iron and steel but differ somewhat in the compositions and mechanical properties. For instance, IS 2062 E350-grade steel can possibly be equated to ASTM A572 Grade 50 but has a bit different chemical and mechanical specifications.

C. Design Principles

The design principles and methodologies match philosophy opposing the guidelines. American standards indeed have much emphasis on performance and intensity to make room for flexibility in design and creativity, especially AISC 360 standards. It supports the LRFD method, which is further defined as a load effect multiplied by load factors and compared against factored resistance-a probabilistic measure of safety. The standards promulgated in India like IS 800 read, 'General Construction in Steel-Code of Practice.'" Such codes are generally prescriptive in character, demanding specific design rules and guidelines. Most popularly known as Allowable Stress Design (ASD), actual loads are compared to allowable stresses with built-in safety factors. This easy approach does not consider several uncertainties and variations considered in an LRFD approach. A comparison of the design principles between the standards is shown in Table I [19].

TABLE I. COMPARISON OF DESIGN PRINCIPLES BETWEEN THE TWO STANDARDS

Aspect	American Standards (AISC, ASCE)	Indian Standards (IS 800, IS 875)
Design Method	LRFD, ASD	ASD, Limit State Design
Safety Factors	Higher (reflecting higher uncertainties)	Lower (more deterministic approach)
Load Combinations	More complex, reflecting multiple load cases	Simpler, with standard load combinations
Flexibility in Design	High (performance-based approach)	Moderate (prescriptive approach)

D. Construction Practices

Construction practices and quality assurance protocols form the most important ingredients requisite for successful implementation of the PEB projects. Construction and installation methods in the US are very standardized and extremely controlled. Much more has been stated in the AISC "Code of Standard Practice for Steel Buildings and Bridges," which provides extensive procedures for fabrication, erection, and inspection. This also has very explicit tolerances for the fabrication, erection, and alignment of members, assuring a high level of precision and quality.

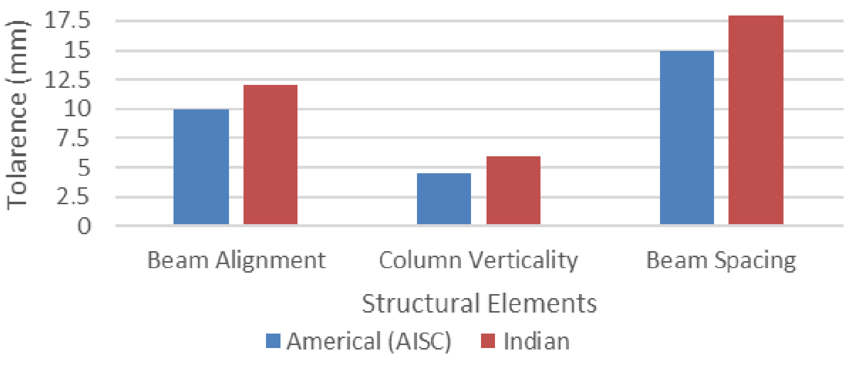

Figure 1. Tolerances and Inspection Requirements Comparative Construction

Construction practices in India are regulated by IS 7205 "Safety Code for Erection of Structural Steel Work" as well as IS 7215 "Tolerances for Fabrication of Steel Structures." Though these codes are fairly exhaustive in stipulating guidelines, the actual construction practices vary with the degree of industrial development and training of the workforce. Inspection requirements also vary; in the United States, inspection by third-party certification is often required by standard, while in India the dependence is towards in-house quality control. For instance, the AISC standards require regular inspections during fabrication and erection, including weld inspections and bolt torque tests. Again, while Indian standards are very comprehensive, they seldom insist on the same external supervision as in the case of the United States. Figure 1 shows a visual comparison of construction tolerances for major structural components like alignment (beams), vertical columns, and corresponding inspection types for relevant construction stages: fabrication, erection, and the final assembly [20].In total, both American and Indian guidelines provide very well-grounded comprehensive frameworks for the design, material specifications, and construction of PEBs. Still, what distinguishes them significantly is how they articulate such provisions. While American standards are more conservative performance-based with high safety factors and stringent quality control measures, Indian standards take the prescriptive approach, where specific design rules and practices focus on.

IV. Case Studies

A. Design Loads

A study comparing PEBs designed using ASCE 7-16 (American Standards) and IS 875 (Indian Standards) observed that the conservative load factors in ASCE 7-16 ensure higher structural safety. For instance:

- Case Example: A warehouse designed under ASCE 7-16 with wind load factors of 1.6 demonstrated 20% higher structural stability during hurricane-level wind speeds compared to a similar structure designed using IS 875, which has a default wind load factor of 1.5.
- Impact on Cost: While initial costs were higher due to additional material requirements, the structure required minimal post-disaster repair costs.
- Impact on Time: American standards allow for optimized structural components, enabling faster construction cycles.

B. Material Specifications

PEBs constructed with ASTM A992 steel grades exhibited 15% higher yield strength and better uniformity than those using IS 2062 E350-grade steel.

- Case Example: A factory structure in California using ASTM A992 reported lower maintenance costs and enhanced performance under seismic conditions compared to a counterpart in India constructed with IS 2062 steel.
- Cost Efficiency: The higher quality materials in American standards increase upfront costs by approximately 10–15% but reduce long-term operational and maintenance expenses.

V. Conclusion

The review discusses the major performance differences of American and Indian guidelines for Pre- Engineered Buildings (PEBs) as well as some similarities in those performances. However, the analysis reveals that despite ensuring structural strength and stability, the two guideline sets differ in their load-bearing capacities, material specifications, and design philosophies. American guidelines that include AISC and ASCE, on the contrary, emphasize stringent safety factors and a thorough process for inspecting things, whereas Indian guidelines such as IS 800 and IS 875 emphasize practicality and amenability to local conditions and materials.

PEBs under US design specifications will be much more resilient and stricter towards quality control, resulting in better performance under various environmental conditions when compared to Indian ones.

Even though Indian guidelines are good, they still have room for improvement in the form of better-quality assurance as well as advanced material specifications comparable to international specifications. To lend robustness and reliability in performance to PEBs, it is advisable to include stricter inspection processes and sophisticated specifications of materials in Indian codal guidelines.

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