iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** III **Month of publication:** March 2025

DOI: https://doi.org/10.22214/ijraset.2025.67844

Analysis of Steel and Aluminum for Industrial Shed Construction: Structural, Environmental, and Economic Perspectives

Tejas Dilip Tipale[1], S. P. Raut[2], Amol Jadhav[3]
Department Of Civil Engineering, Yeshwantrao Chavan College Of Engineering, Nagpur, India
Sectional / Junior Engineer, Public Works Department, Nagpur

Abstract: The present paper reports and compares the performance of steel and aluminum in the construction of industrial sheds with respect to their material properties, structural behavior, costs, and environmental impacts. The objective of this study is to analyze the merits and demerits of each material in performance, durability, and sustainability so that informed recommendations can be made regarding the selection of that material most applicable for different construction requirements. Some of the key findings show that while steel, with its much higher strength, is best suited to large structures that need to carry weight loads, it will need constant maintenance because it rusts.

Aluminum, on the other hand, possesses better resistance to corrosion, weighs far less than steel, and as such, is only applicable to smaller or coastal structures; it also costs more in the initial phases.

This study also analyses the cost-effective aspect in which steel is more upfront cheap; however, aluminum, at first expensive, is long-lasting and hardly needs maintenance. Furthermore, both are recyclable and aluminum has less carbon footprint during its production phase.

This paper concludes that the selection of the material should depend on specific project requirements, environmental conditions, and life-cycle costs. Future studies should look into hybrid material approaches and further improvements in sustainability practices.

Keywords: Aluminum, Construction, Corrosion, Durability, Steel, Sustainability

I. INTRODUCTION

A. Overview of Industrial Sheds and Their Significance in Construction

They are large structures whose purpose is primarily storage, manufacture, warehousing, and other industrial processes. Industrial sheds are indeed important structures for manufacturing, logistics, agriculture, and construction industries.

It can cater to diverse operational needs from assembly lines to massive open storage areas, designed to provide large areas or spaces for operations. [1] Several factors must be addressed in the building of the shed, including load-bearing capacity, durability, safety, and functionality.

Designwise, simple yet effective forms and wide spans, large roof areas, and minimizing interior supports characterize industrial sheds. This ensures that usable space and structural integrity are maximized.

The materials that can be used in constructing industrial sheds significantly impact the overall performance, longevity, and cost efficiency of a building [2]. Among the many materials available, steel and aluminum are still commonly used because of their high strength, flexibility, and durability.

B. Importance of Material Selection in the Design and Construction of Industrial Sheds

The nature of these materials considers the performances of the industrial shed in terms of making costs and the service life possible for industrial sheds.

There have to keen specifications for the material regarding its required strength and resistance to environmental factors such as corrosion and extreme temperatures, along with the overall structural performance of the materials. Preferred materials are steel and aluminum as they possess very beneficial characteristics. Each material has its properties with which they are characterized to suit specific applications [3].

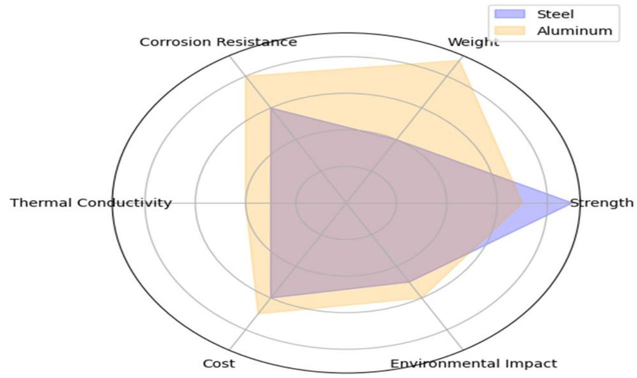

Fig. 1. Comparison of Steel and Aluminum for Industrial Shed Construction

Steel has a high tensile strength and load-bearing capacity, making it suitable for architecturally large structures for carrying heavy loads. It can also fit into any design as it easily shapes itself into many sizes and shapes according to the structural need. Steel has a high tendency to undergo corrosion, especially in humid or coastal environments, which further adds up to the maintenance requirements to increase the lifespan of steel.

Aluminum, as opposed to steel, is absolutely lightweight compared to these superior defense mechanisms from corrosion. Its suitability therein is found in conditions of high humidity or exposure to corrosive elements, making it an alternative material for such locations. It has superior energy efficiency, being better thermally insulated and, thus, mostly chosen in buildings that prioritize energy conservation. But aluminum is known to possess high initial material costs compared to those of steel. It also cannot bear as much load compared to steel, which makes it necessary for some heavy-duty applications to avoid its use. Fig. 1 provides a view of comparison difference based on some key factors such as strength, weight, corrosion resistance, thermal conductivity, cost, and environmental impact between steel and aluminum [4]. An ideal way could be to show these features in a side-by-side bar chart or radar chart to allow readers immediate performance comparison of these materials on different attributes.

Choosing materials does not necessarily influence the build's physical and mechanical properties but also the environmental effects. Aluminum as sustainable material qualifies both as recyclable and a lesser emission in production; hence, it is becoming a favorite choice among eco-friendly projects, especially when steel is preferred. Steel is recyclable too. However, it has relatively higher environmental incidences than aluminum during production.

C. Objectives of the Comparative Study Between Steel and Aluminum Members

This research effort is oriented toward a comparative analysis of steel and aluminum as construction materials for industrial sheds. The intention of this analysis is to evaluate both the specific and general strengths and weaknesses of the materials from different angles, including structural integrity, cost-effectiveness, environmental friendliness, and sustainability.

The first objective of this research work is the mechanical comparison of steel versus aluminum, in particular with reference to strength, weight, and applied external forces, such as temperature variation, wind, and seismic loads. The study of the bearing capacity and performance of any material is essential to determine suitability in formulating various industrial types of sheds which are subjected to high loads or heavy environmental conditions.

Another goal of this study will be the economic consideration of steel versus aluminum in industrial shed construction. This factor considers initial materi- als expenses, fabrication, and maintenance costs throughout the entire serviceable life until use. Generally, upfront cost is smaller in steel benefit, but due to very high potential corrosion, maintenance cost will be very important. Upfront cost of aluminum is more, but much of the savings in maintenance and longer life because they are not easily damaged by environmental deterioration. This research also delves into assessing the thermal and corrosion behaviour of both steel and aluminium across a range of environmental conditions-factors including thermal conductivities, expansion indices and moisture and chemical resistances, which play essential roles in predicting the long-term durability and performance of industrial sheds. Because of aluminium's superior corrosion resistance and better insulation properties in some specific regions, it would be a more attractive option, whereas steel would be decided as the best option for regions that are more heavy-duty load-bearing. This research study would also cover the impact on the environment caused by the use of steel and aluminum. While steel can still be recycled, it will not be as eco-friendlier as aluminum since that will have a lesser carbon footprint during production and being recycled.

Sustainability becomes an increasingly relevant aspect in the construction industry today; hence, an understanding of such will go a long way in making responsible choices when it comes to materials used.

In summary, this study will focus on the following objectives:

1) To compare the properties of steel and aluminum in terms of strength, weight, and load carrying capacity.
2) To assess the economic impact between steel and aluminum, which includes initial costs, maintenance over a lifetime, and life cycle costs.
3) To determine the thermal and corrosion resistance of steel and aluminum under several environmental parameters.
4) To ascertain the sustainability of steel and aluminum with regard to recyclability, carbon footprint, and energy consumption involved in their production.
5) To guide in material selection based on specific needs for industrial shed construction.

II. MATERIAL PROPERTIES

When comparing steel and aluminum in construction, understanding their mechanical and physical properties, advantages, and limitations is essential for selecting the most suitable material for specific applications. Additionally, factors like cost, availability, and environmental impact play a crucial role in the decision-making process.

A. Mechanical and Physical Properties of Steel and Aluminum

Steel is used widely in construction because of its strength, durability, and versatility. It possesses mechanical properties such as high tensile strength, which may range from 250 MPa to 2000 MPa depending on the specific grade of steel. Steel has high resistance to fatigue, which makes it highly recommended for use in structural applications subjected to dynamic loads. The modulus of elasticity of steel is about 200 GPa, which contributes to its rigidity and strength under stress [15].

$$\sigma = E \cdot \varepsilon \qquad (1)$$

where σ is the stress, EEE is the Young's modulus, and ε is the strain.

As a solid rule, the density of steel remains typically around 7.85 g/cm³. This is dense enough for high strength and weight, which can be disadvantageous in some applications, mainly where weight reduction is important. Aluminum, on the other hand, is synonymous with being lightweight. Its tensile strength usually varies between 70 MPa to 700 MPa according to alloy types [16]. While aluminum strength is lesser than steel, it is also much lighter (2.7g/cm³). Aluminum can increase strength to a certain limit through various alloying such as with copper, manganese, or silicon, thus making them applicable where both low weight and strength are required. The Young's modulus for aluminum would approximately equal 70 GPa, lower than that of steel but qualifying for most structural applications.

B. Advantages and Limitations of Each Material

1) Steel Advantages

- The strength-to-weight ratio of steel is very good, making it possible to achieve thinner sections for structural elements.
- Steel suits many environments and can be formed into complex shapes for numerous applications.
- Steel can be recycled again and again without any compromise in quality and thus qualifies as an environment-friendly material.

2) Steel Limitations:

- In fact, steel is much heavier than aluminum, which means it can lead to higher transportation costs and complications in handling large-scale constructions [17].
- If steel is not coated or treated properly, it tends to rust in extreme environmental conditions.

3) Aluminum Advantages:

- The low density of aluminum allows to transport and to handle costs decreased by labor time and supports the possibility of large constructions without compromising strength [18].
- Aluminum has naturally an oxide layer, which protects it from further corrosion, and as such, is applicable for use in marine environments.
- The lightweight property of aluminum can translate into energy savings in the structures it builds, especially in transportation and aerospace industries.

4) Aluminum Limitations:

- Aluminum's tensile strength is less than steel, thereby making it a poor choice for applications that require high load bearing capacity [19].
- Aluminum tends to cost more than steel because of production costs and raw material costs.

C. Cost, Availability, and Environmental Impact

Steel is far more common and relatively cheaper than aluminum, as the price of steel ranges between $500 and $1,500 per ton depending on the type and market conditions, while an aluminum price that ranges from $2,000 to $3,000 per ton makes it more expensive, though it is gradually decreasing with the advancements in extraction and recycling technologies [20].

TABLE I. COMPARATIVE PROPERTIES OF STEEL AND ALUMINUM

Property	Steel	Aluminum
Tensile Strength (MPa)	250 - 2000	70 - 700
Young's Modulus (GPa)	200	70
Density (g/cm^3)	7.85	2.7
Corrosion Resistance	Moderate (needs treatment)	High (self-protecting)
Cost ($ per ton)	500 - 1500	2000 - 3000
Recyclability	100%	100%

Steel making is said to have a greater carbon footprint compared to the other processes for environmental implications, taking into consideration the very energy-intensive processes involved in extracting iron from ores. Aluminum production, however, is very much energy-fueled; in recent years, recycling technologies have improved greatly, thereby reducing emissions. Aluminum is said to be recyclable, and up to 95% energy can be saved when recycled aluminum is used instead of the commonly used raw material.

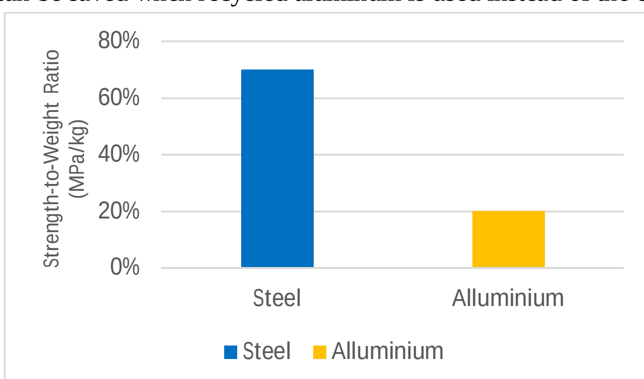

Fig. 2. Comparison of Strength-to-Weight Ratio of Steel and Aluminum

The graph along fig. 2 elaborates a comparison between steel and aluminum in terms of their weight-to-strength ratios. Although steel has generally higher strength than aluminum, the lightweight property of aluminum makes it suitable for specific applications [21]. It is thus clear that the selection as to whether steel is used or aluminum depends on the specific requirements of a particular project. Steel is superior to aluminum in terms of strength and durability, while aluminum has better qualities in lightweight applications and in benefiting from ideal corrosion resistance. Both are sustainable and recyclable materials, thus making them apt for environmentally friendly construction.

III. STRUCTURAL DESIGN CONSIDERATIONS

Material selection directly relates to the response of the structure under various different loads in structural design. Steel and aluminum each possess their inherent characteristics, which indeed affect the behavior of these materials under different loading conditions. This section focuses on important considerations in design, such as types of load, cross section properties, and connection detailing for both materials.

A. Load Considerations

Live load : The effect of these variable loads can be visualized as being due to the occupancy, movable furniture, and other temporary items. For instance, a live load of about 2 to 5 kN/m will be imposed per meter square, depending on the usage of the building.

Dead Loads: These types of loads are permanent and consider the weight of the structure itself, and these are much static like weight of beams, columns, floors and other items payload in it. The overall dead load will also generally differ among structures according to the type of materials used, whether steel or aluminum [22].

Wind Loads: Wind effect is multidimensional based upon the heights of the buildings, the site location, and the exposure category to wind. For a calculation of wind load; [23]:This equation is used:

$$F_{wind} = 0.613 \cdot C_p \cdot A \cdot V^2 \qquad (2)$$

where F_{wind} is the wind force, C_p is the wind pressure coefficient, A is the projected area, and V is the wind speed.

Seismic Loads: The earthquake forces are dynamic forces, not only depending upon the height of the building but also on its location and design. It can be calculated using the following formula: [24]:

$$F_{seismic} = W \cdot S \cdot I \qquad (3)$$

where $F_{seismic}$ is the seismic force, W is the weight of the building, S is the seismic response factor, and I is the importance factor.

B. Cross-Sectional Properties and Member Dimensions

Steel and aluminum possess differing cross-sectional characteristics that relate to their behavior under loading. For both materials, one major factor in resisting bending is the moment of inertia (I). The rectangular section has then moment of inertia expressed as [25]:

$$I = \frac{b \cdot h^3}{12} \qquad (4)$$

where b is the base width and h is the height of the section. Steel sections, being stronger, allow for smaller dimensions to resist similar loads compared to aluminum.

The comparison here is that in any case, the cross-section of the aluminum beam may be larger than that of a comparable steel beam for supporting the same bending moment due to the inferior strength-to-weight ratio of aluminum. These materials properties should also be borne in mind in the design of cross-sectional dimensions as this will lead to efficiency and cost-effectiveness in construction.

C. Connection Detailing and Joint Design

The design of connections and joints between members is vital in the overall stabilization of a structure. Steel and aluminum connections tend to differ somewhat in their detailing:

1) Steel Connections: Generally, such connection types will have bolted or welded joints. Moreover, steel extremely weldable has the ability to establish strong rigid connections applicable to high shear and tensile resistance [26].
2) Aluminum Connections: Compared to steel, aluminum is much less weldable, and bolted connections are necessary. Since the fatigue resistance of aluminum is lesser than that of steel, special considerations must be made in the case of dynamic loading conditions.

Making proper detail about connection maintains the force transfer from member to member, hence maintaining the whole structure stable. Typical moment of inertia shown in Figure 3 is between steel and aluminum structural sections. Steel allows smaller and lighter members to resist similar bending stresses compared to aluminum, due to its higher moment of inertia [27].

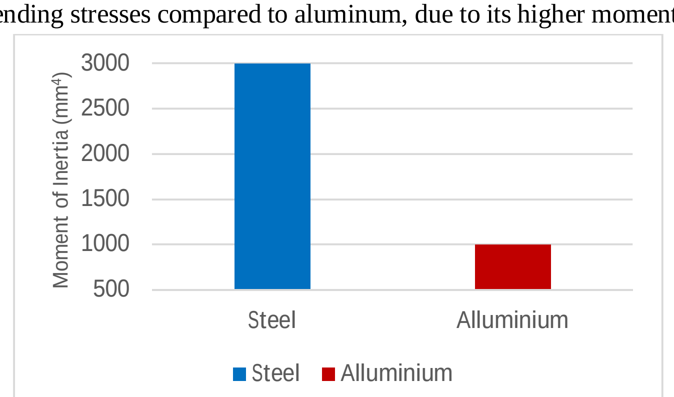

Fig. 3. Comparison of Moment of Inertia for Steel and Aluminum Sections

Moist overall considerations regarding structural design in steel and aluminum include a meticulous balance between load resistance, properties of materials, and connection design. While steel assures better strength and weldability, aluminum is weight-efficient and requires dimensions in connection details.

IV. ANALYSIS OF INDUSTRIAL SHED STRUCTURES

Shed structures are meant for large, open-span buildings and are designed to function as rigid and efficient installations. Steel or aluminum is the material, and its choice has an influence on design methodology and modeling techniques and also on structural behavior under various load conditions. This part addresses the comparison of design methodologies for sheds in steel and aluminum, finite element modeling (FEM) techniques, and structural behavior under different loads.

A. Comparison of Design Methodologies for Steel and Aluminum Sheds

One-dimensional design methodology basically goes into the process of decision-making regarding an appropriate material, cross-section-sizing, and member sizing to ensure stability. Furthermore, it is to ascertain if the design is stable under different types of loads. For example, the way of designing a shed in steel would be different from that of designing an aluminum shed because the mechanical properties of the materials differ, such as their weight.

Steel Sheds: It is the very high strength and stiffness of steel that allows members in minimal cross-sectional dimensions to be used. The limit state design method is usually adopted for the design of steel structures where safety factors are provided to check whether the structure is capable of withstanding the applied loads without failure. Strong and permanent joints are achieved with welded connections, which also favor steel attributes [[28].

Aluminum Sheds: Light but low in tensile strength compared to steel, aluminum causes buildings to have bigger cross sections than steel ones for the same load. The design of aluminum buildings generally revolves around joint quality through bolted connections as well as the consideration of the material's aspects on fatigue over time. The common design approach for aluminum is the allowable stress design method, wherein the stresses inside the materials are compared with the allowable values.

V. COST ANALYSIS

Cost analysis becomes so critical with respect to materials for construction of industrial sheds since it includes all expenses related to initial costs of the materials, cost of construction, and costs of long period maintenance and lifecycle. The material costs, fabrication costs, construction costs, and maintenance costs are compared here between different steel and aluminum structures.

A. Material Costs, Fabrication, and Construction Expenses

Steel: Steel is less liable-to cost per unit weight compared to aluminum. Normally, steel worth from $500 to $800 per ton can be acquired in different market conditions and widely depending on the steel grade. Steel structures are often prefabricated in the factories, which can sometimes reduce fabrication costs at construction sites [11]. However, steel generally requires corrosion protection (galvanizing or coating) that can enhance the material cost.

Aluminum: Aluminum is much more expensive than steel-often costing between $2,000 and $3,000 per ton. This means that it possesses lightweight characteristics that can cut down on costs of transportation and/or foundation-building. However, aluminum typically needs more complex methods of fabrication (such as bolting and specialized welding), which impose a penalty on the total cost of construction.

Total construction cost can be computed by the following equation [25] as:

$$C_{total} = C_{material} + C_{fabrication} + C_{construction} \quad (6)$$

where $C_{material}$, $C_{fabrication}$, and $C_{construction}$ represent material, fabrication, and construction costs, respectively.

B. Maintenance and Lifecycle Cost Comparison

Steel: Steel structures need constant maintenance against corrosion and rust mainly in hostile places, as coatings usually wear down over the years and thus require periodic reapplication. Maintenance costs of steel can average around 1-3 percent of the initial construction cost on a yearly basis.

Aluminum: The excellent anticorrosion properties of aluminum help minimize the maintenance costs considerably compared to steel. But because of impact and fatigue, aluminum is more vulnerable. The average maintenance costs of aluminum are generally about 0.5 to 1 percent of initial construction cost per year.

TABLE II. Cost Comparison of Steel vs. Aluminum for Industrial Sheds

Cost Factor	Steel	Aluminum
Material Cost (per ton)	$500 - $800	$2,000 - $3,000
Fabrication Cost	Lower, due to simple welding	Higher, due to complex joints
Construction Cost	Moderate	Higher due to intricate methods
Maintenance Cost (annual)	1-3% of initial cost	0.5-1% of initial cost

Steel can be easily fabricated at a lower initial investment, but aluminum in itself is made to benefit lightweight construction and lower maintenance needs in the entire lifecycle [33]. However, higher upfront costs must be considered before counting the entire lifecycle cost of aluminum usage.

VI. THERMAL AND CORROSION PERFORMANCE

These are the two factors, that is, thermal and corrosion performance, which are significant influences when choosing materials for an industrial shed for durability and structural integrity. Because steel and aluminum exhibit different behaviors in the aspects of thermal and corrosion performance, they suit different environmental conditions.

A. Thermal Conductivity and Expansion Characteristics

Steel: Steel is a material that has relatively high thermal conductivity (of about 50 W/m·K), enabling it to transfer heat very quickly. Such property is very much needed in countries that have very low winter temperatures and very high summer temperatures as it causes steel to expand and, subsequently, contract. CTE or Coefficient of Thermal Expansion has an approximate value of 12×10−6/°C12, thus, resulting in dimensional changes under the temperature fluctuations [34].

Aluminum: With respect to these parameters, compared to steel, having a thermal conductivity of about 205 W/m·K, aluminum thus becomes almost as effective in cooling structures designed to safeguard excessively transient thermal environments. The coefficient of thermal expansion, also called alpha, is approximately 23×10−6/°C, which is much greater than steel, thus meaning that with temperatures changing, such materials will expand significantly more.

The relationship between temperature change ($\varDelta T$) and dimensional change ($\varDelta L$) in materials can be described by the following equation [35]:

$$\Delta L = L_0 \cdot \alpha \cdot \Delta T \qquad (7)$$

where: ΔL is the change in length, L0 is the original length, α is the coefficient of thermal expansion, ΔT is the temperature change.

B. Durability and Corrosion Resistance

Corrosion is usually termed as the destructive process, Furthermore, it is mostly observed in steel near moist coastal regions, whereby one finds that the metal reacts with either oxygen and water to form iron oxide or rust. Therefore, one coats protective materials, for instance, the metallic structure, with coatings such as galvanizing, paints, and powder coatings. The rate of corrosion varies mostly upon environmental conditions and the types of protective coatings.

Naturally, aluminum can be supplied with an oxide layer when oxygen is added to it, and this gives it very good corrosion resistance. Since that is the case, it can perform well in moist environments or saltwater conditions, but it stands subjected to localized corrosion in the presence of galvanic reactions with other metals. Fig. 5 shows and describes the thermal expansion of steel and aluminum under the same temperature change; the results show that steel expands less than aluminum when compared with an equal distance. Aluminum is also defined by its much higher coefficient of thermal expansion. [36].

TABLE III. Thermal and Corrosion Properties of Steel vs. Aluminum

Property	Steel	Aluminum
Thermal Conductivity (W/m·K)	50	205
Coefficient of Thermal Expansion ($\times 10^{-6}$ /°C)	12	23
Corrosion Resistance	Moderate (requires coating)	High (naturally resists corrosion)
Corrosion Rate (in humid climates)	High without coating	Low, stable oxide layer

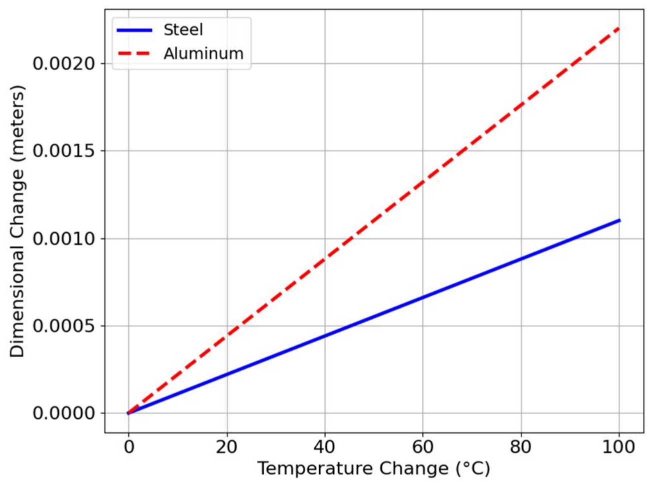

Fig. 4. The thermal expansion of steel and aluminum under the same temperature change

Steel provides acceptable strength; however, exposure to corrosion requires protection from coatings, especially in harsh environments. On the other hand, aluminum is the most expansive at temperature changes, but it possesses excellent corrosion resistance and is otherwise well suited for areas that are in constant high humidity or salt exposure situations.

VII. SUSTAINABILITY AND ENVIRONMENTAL IMPACT

When considering the construction of industrial sheds, it is important to keep in mind the sustainable and environmental impact of materials like steel and aluminum in decisions such as what materials to use, how much energy to consume, and compliance with green building policies.

A. Recyclability and Carbon Footprint

Steel is indeed very much recyclable: well over nine out of ten steel products are recycled upon the completion of their life functions. Steel production is an energy-intensive endeavor because of the extreme amounts of energy required in mining and metallurgic processing. Advances in recycling technology, along with the increased usage of recycled steel, tend to lessen the entire environmental impact.

Like steel, aluminum also possesses high recyclability, 75% of all aluminum ever produced still is in service today. Its production, however, indeed derives a lot of power and even most without raw bauxite ore, it already brings out a huge amount of electricity to make it. The energy-intensive smelting processing gives most to the carbon footprint of the process of aluminum production [16].

This gives information about the carbon footprint concerning the way steel and aluminum affect the environment, in a quantifiable manner, through the equation mentioned below [32]:

$$Carbon\ Footprint = (EnergyConsumption) \times (EmissionFactor) \qquad (8)$$

B. Compliance with Green Building Standards

Stainless steel and aluminum can be utilized in green buildings and environments compliant with standards such as LEED and BREEAM. Standards like these underline energy efficiency and recycled materials and establish guidelines for their operation. This allows for the construction of energy-efficient structures using steel and aluminum, which would considerably cut down carbon emissions and greatly improve overall environmental performance.

TABLE IV. Environmental Impact of Steel vs. Aluminum

Aspect	Steel	Aluminum
Recyclability	High (90% recycled content)	High (75% recycled content)
Carbon Footprint	High due to energy-intensive production	High due to energy-intensive production
Green Building Compliance	Can meet LEED, BREEAM standards	Can meet LEED, BREEAM standards

VIII. MODEELING AND ANALYSIS

A. Key Structural Design Aspects

1) Ford Manufacturing Facility located in USA, Michigan, is one Wall and Cladding: Brickwork up to 2.1m; 6.3m clad with materials for steel/aluminum for stability.
2) Roof Slope and Protection: 9.91° slope with GI sheets; aluminum resists corrosion without extra coating.
3) Purlin and Girt Spacing : 1.5m purlin and 2.1m girt spacing; aluminum's light weight allows cost-effective adjustments.
4) Support Conditions : Pinned supports; steel provides high stability; aluminum reduces foundation load.

B. Design Deatils

In the research work, both steel and aluminum materials are used to analyze the structural performance of an industrial warehouse using ETABS. The study includes the design of three different types of 3D building structures under static and dynamic forces.

Common Parameters for Steel and Aluminum Structures :-

1) Dimensions : Length = 60 m, Bay Spacing = 6 m, Width = 24 m, Eave Height = 8.402 m.
2) Brickwork : 2.1 m from the ground, Remaining 6.3 m = cladding.
3) Roof Slope:- 9.91°.
4) Roofing : GI sheets for protection.
5) Purlin Spacing : 1.523 m.
6) Girt Spacing : 2.1 m.
7) Support Condition : Pinned.

Plan Layout Of Warehouse Structure

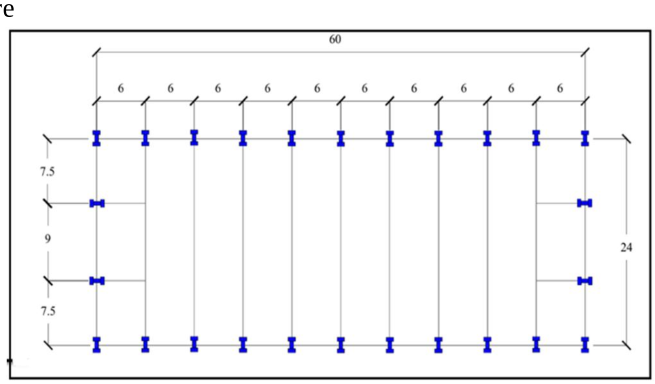

Fig.6. Plan of model

Elevation Of Warehouse Structure

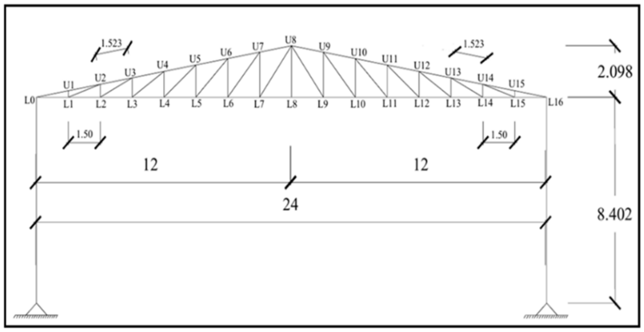

Fig.7. Elevation of model

C. Loading Calculations

The dead load and live load calculation presented for both steel and aluminum structural members in the industrial warehouse structure. Both materials follow the same load calculations based on the IS 875-1987.

Dead Load Calculation (IS 875-1987 Part-I) (pages 25 to 30):

1) Total Load on Purlin :-

- Weight of Sheet = 0.058 kN/m²
- Weight of Fixing = 0.025 kN/m²
- Weight of Services = 0.100 kN/m²
- Total weight per unit area = 0.058+0.025+0.100 = 0.183kN/m².

2) Total Weight on Purlin

- Spacing of Purlin = 1.523 m
- Total Weight on Purlin = weight (kN/m²) × spacing of Purlin.

3) Total Load Calculation

Total weight on purlin = 0.183 kN/m² × 1.523 m
= 0.278 kN/m

4) Weight of Purlin

Assumed at 0.10 kN/m for both steel and aluminum structures.

Weight of Truss :-

Weight of truss = (Span/3+5) × 10 = (24/3+5) × 10
= 0.130 kN/m2
= 0.103 × plan length = 0.103 × 1.5
= 0.154 kN/m

5) Conversion to Uniform Load

The value of 0.103 kN/m² represents the truss system's distributed dead load per unit area, derived from IS 875 guidelines.

6) Total Dead Load

Sum of all calculated loads = 0.278 + 0.1 + 0.154 = 0.532 kN/m

Dead Load (Steel & Aluminum) :- 0.532 kN/m

7) Live Load (Steel & Aluminum)

The general formula for calculating live load (LL) involves applying a correction factor based on the roof slope. For a roof slope of 9.91°, the factor seems to be, where:

- 750 is the basic live load (in kN/m²),

- 20 is the correction factor per degree of roof slope,
- (9.91 – 10) adjusts the live load based on the angle.

= 750 – 20(9.91 – 10)
= 0.751 kN/m2
= 0.751 × 1.523 = 1.143 kN/m
= 2/3 × 1.143
= 0.762 kN/m

D. Wind Load Calculation (IS 875-1987 Part-III) (page 49-50)

Basic Wind Speed :- $V_b = 39\,\mathrm{m/s}$

Design Wind Speed: $V_z = K_1 \times K_2 \times K_3 \times V_b$

Design wind pressure = $Pz = 0.6\ Vz^2$

Wind pressure on roof = $(C_{pe} - C_{pi})$

Where:-

Cpe = Coefficient of external wind pressure
Cpi = Coefficient of internal wind pressure
K1 = Risk coefficient (Based on a mean probable design life of 50 years)
K2 = Terrain height and structure size factor
K3 = Topography factor

For all general building and structure, Mean probable design life = 50 years

Risk coefficient K1 = 1.0
Terrain category = 3 ……... (As height of building 10 m)
Class B ……..… (As horizontal or vertical dimension in between 20 to 50 m)
K2 = 0.99
K3 = topography factor
K3=1
= 1.0 × 0.99 × 1.0 × 39
= 38.61 m/s
Design wind pressure = Pz = 0.6 × (Vz)2

$$= 0.6 \times 38.61^2$$
$$= 894\ \mathrm{N/m^2}$$

Wind Pressure on Roof :-

$$\text{Wind pressure} = (C_{pe} - C_{pi}) \times P_z$$

The values for Cpe and Cpi depend on specific building shape, orientation, and open/closed nature of the structure.

Basic Wind Speed :- 39.00 m/s
Design Wind Speed :- 38.61 m/s
Design Wind Pressure :- 894 N/m²

E. Modelling

ETABS is widely used for the analysis and design of steel and aluminum structures, including Industrial Sheds Constructed with Steel and Aluminum Members. The software provides a powerful platform for modeling warehouses, industrial buildings, and other structural systems with precision. ETABS supports various section properties, materials, and international design codes, enabling engineers to model and optimize steel and aluminum members efficiently. Structural elements such as C-sections, I-sections, and tapered sections can be customized to enhance performance and structural efficiency. For industrial sheds utilizing aluminum members, ETABS allows the creation of lightweight yet strong structural components by defining web and flange dimensions along with varying thicknesses, ensuring optimal strength-to-weight ratio and material efficiency. Beams and columns are modeled as line elements, while slabs, walls, and shear walls function as plate elements, facilitating a comprehensive structural analysis and efficient design process.

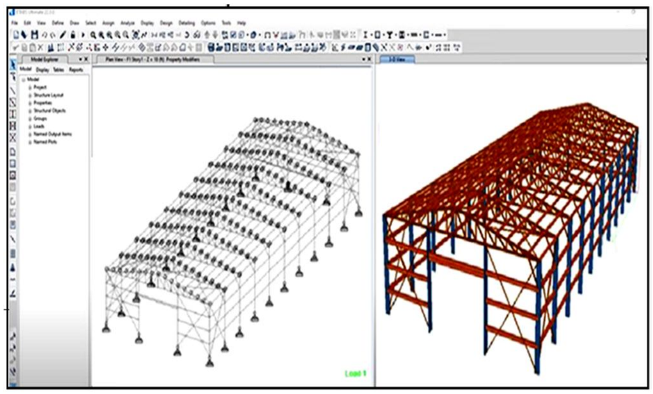

Fig.8. Modelling and Rendered View of steel Structure

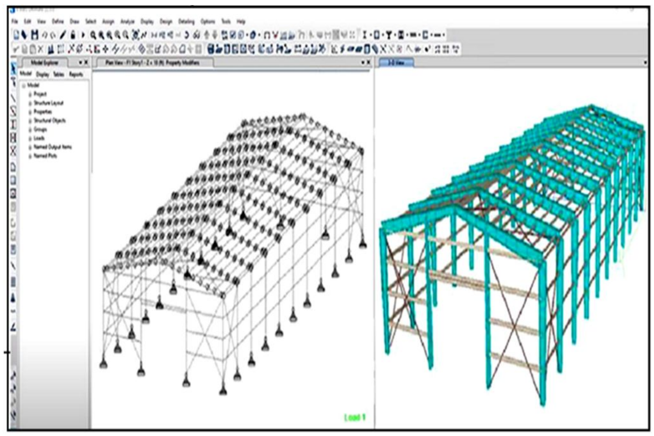

Fig.9. Modelling and 3D View of Aluminum Structure

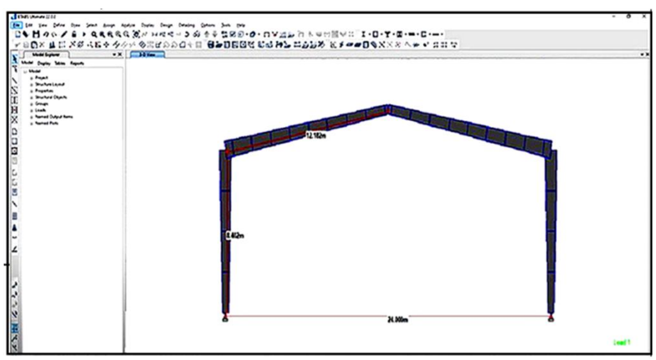

Fig.10. Assembled Tapered Section

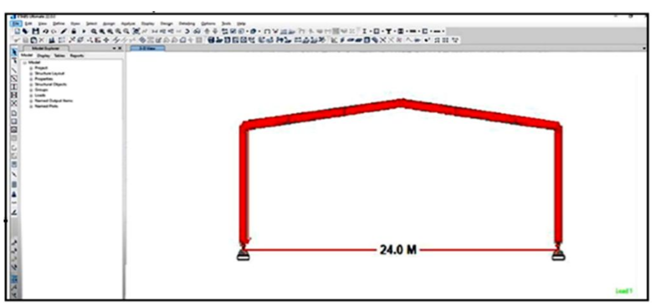

Fig.11. Assembled I-Section OF CSB Section

A Tapered section is a structural member with varying cross-sectional dimensions along its length. It is primarily used to optimize material usage by increasing strength where needed while reducing weight. It is likely used in long-span beams, portal frames, or cantilever structures to enhance efficiency and minimize material costs.

An I-Beam (or H-Beam) is a structural element with an "I" or "H" shaped cross-section, known for its high strength-to-weight ratio. It is ideal for primary load-bearing elements due to its high strength-to-weight ratio. It is commonly used in columns, main beams, and girders, ensuring structural stability and load distribution while resisting bending and shear forces effectively.

Both sections enhance the design by improving strength, reducing material usage, and optimizing weight distribution, making the structure more efficient and cost-effective.

IX. RESULTS AND DISCUSSION

The structural analysis and design of the considered structure were carried out using the ETABS software, which is highly efficient and user-friendly. ETABS provides a comprehensive database for modeling and analyzing steel and aluminum structures with precision.

Graphical representations of the results obtained from the software offer clear insights into the structural performance, including load distribution, deflections, stresses, and member forces. The advanced analysis tools in ETABS ensure accurate evaluation and optimization of steel and aluminum sections, enhancing overall design efficiency and structural integrity.

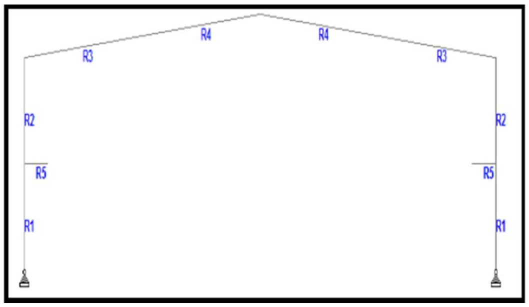

Fig. 12. Typical Section of aluminum IS 8147:1976 Frame

Table V: Sectional Details of aluminum Frame

Profile	Length (m)	Weight (t)
Tapered Member No: 1	12	5.006
Tapered Member No: 2	37.68	26.925
Tapered Member No: 3	37.68	23.763
Tapered Member No: 4	12	6.616
ST ISMB300	7.5	3.243
ISA 75X75X6	502.65	8.150604
ISA 50X50X6	501.143	22.04178
ST 200Z60X2	3680	20.16215
Total	-	**115.9015**

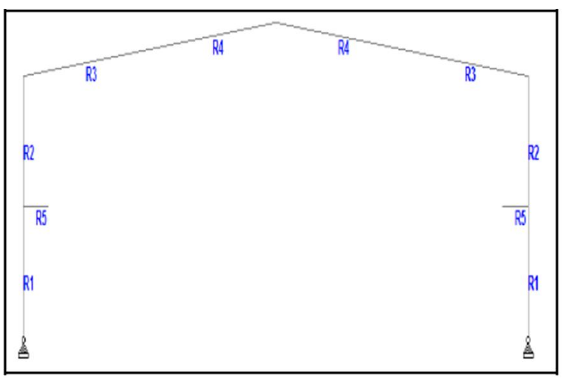

Fig. 13: Typical Section OF aluminum- AISC/LRFD Frame

Table VI: Sectional Details of aluminum IS 8147:1976 Frame

Profile	Length (m)	Weight (t)
Tapered Member No: 1	12	5.006
Tapered Member No: 2	28.68	20.49387
Tapered Member No: 3	28.68	18.08712
Tapered Member No: 4	12	6.616
ST ISMB300	7.5	3.243
ISA 75X75X6	506.851	8.218725
ISA 50X50X6	506.843	22.29248
ST 200Z60X2	3680	20.16215
Total	-	**104.3854**

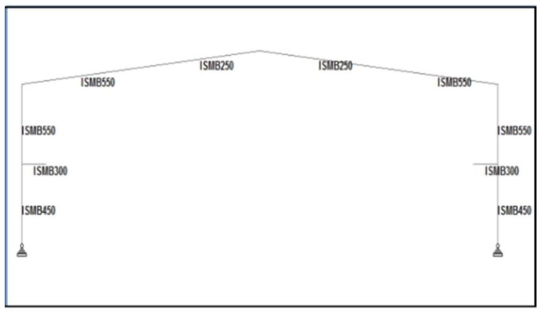

Fig. 14:: Typical Section of CSB-IS 800:2007 Frame

Table VI : Sectional Details of CSB-IS 800:2007 Frame

Profile	Length (m)	Weight (t)
ST ISMB250	48.1	17.554968
ST ISMB300	10	4.324
ST ISMB450	24	17.016
ST ISMB550	74.02	75.124717
ISA 75X75X6	583.03	38.78454
ISA 50X50X6	587.02	25.67551
ST 200Z60X2	6140	33.640115
Total	-	**212.1185**

Table VII: Comparison Of Weight Between steel & AL Frame

Frame Type	Weight (kN)
Steel Frame (IS 800:2007)	1394.289
Aluminum Frame (IS 800:2007)	935.619
Aluminum Frame (AISC LRFD)	879.151

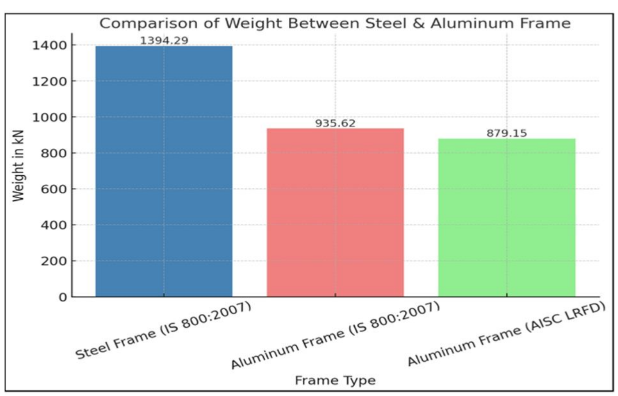

Fig. 15: Weight Correlation

Based on the design outcomes obtained in this study, it is observed that the weight of an Industrial Shed Constructed with Steel and Aluminum Members is reduced by 33% when designed as per Indian standards and by 37% when designed as per American standards compared to a conventional steel building (CSB) structure. This highlights the significant weight savings achieved by incorporating aluminum members while maintaining structural efficiency.

Table VIII: Steel Quantity For Purlin

Type of Frame	Weight (kN)
CSB FRAME (Hot Rolled Steel Section) IS 800:2007	333.796
PEB FRAME (Cold Formed Steel Section) IS 800:2007	144.19
PEB FRAME (Cold Formed Steel Section) AISC LRFD	105.09

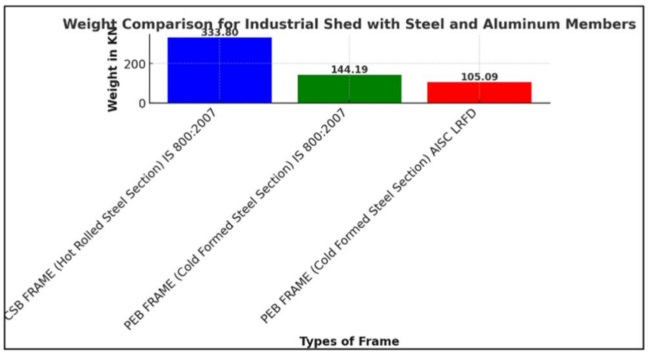

Fig. 16: Steel Quantity required for Hot Rolled Section and Cold Formed Steel section used for Purlin members

Based on the design outcomes obtained in this study, it is observed that the purlin weight of the aluminum structure, as per the Indian code, is reduced by 56.80%, and as per the American code, it is reduced by 68.51% compared to the steel structure. This highlights the efficiency of aluminum members in minimizing material usage while maintaining structural integrity in an industrial shed constructed with steel and aluminum members.

Table IX: Steel Quantity for Grit Members

Types of Frame	Weight (KN)
CSB FRAME (Hot Rolled Steel Section) IS 800:2007	352.118
PEB FRAME (Cold Formed Steel Section) IS 800:2007	56.807
PEB FRAME (Cold Formed Steel Section) AISC LRFD	39.439

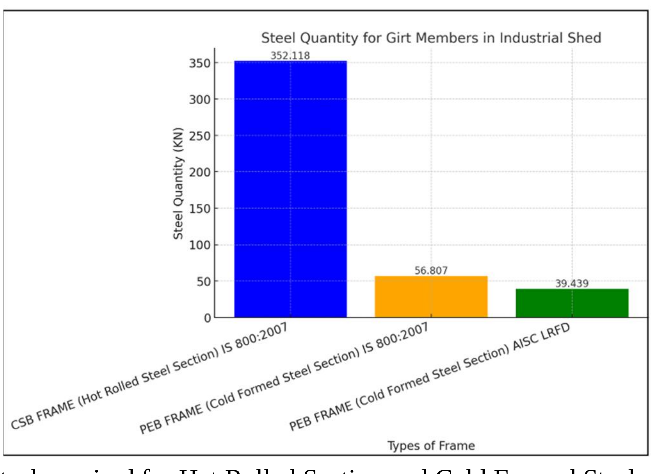

Fig. 17: Quantity of steel required for Hot Rolled Section and Cold Formed Steel used for Girt members

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue III Mar 2025- Available at www.ijraset.com

It is observed that the Girt Member weight in an aluminum structure, as per the Indian code structure (IS 800:2007), is reduced by 83.86%, and as per the American code structure (AISC LRFD), it is reduced by 88.79% compared to the Girt Member weight in a steel structure. This demonstrates the lightweight advantage of aluminum members while ensuring structural stability in an industrial shed constructed with steel and aluminum members.

Table X: Maximum Shear Force In Kn

Types of Frame	Shear Force (kN)
CSB Frame (IS 800:2007)	403.064
PEB Frame (IS 800:2007)	204.744
PEB Frame (AISC LRFD)	151.018

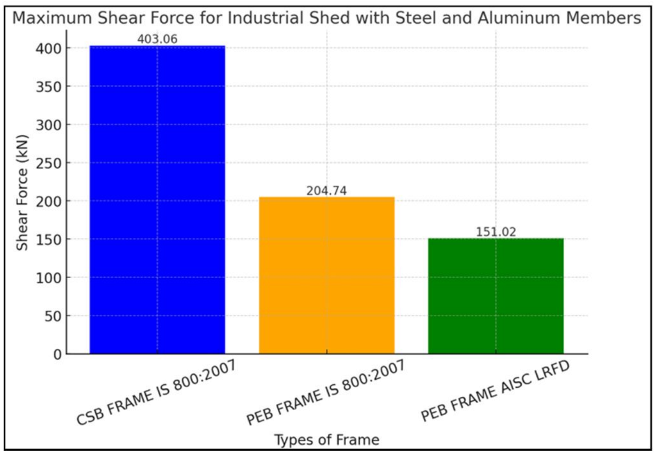

Fig. 18: Maximum Shear Force

In this study on industrial shed construction using steel and aluminum members, it is observed that the maximum shear force in PEB, as per the Indian code structure, is reduced by 49.27%, while the maximum shear force in PEB, as per the American code structure, is reduced by 62.53% compared to the CSB structure.

Table XI: Maximum Support Reaction in KN

Types of Frame	Support Reactions (KN)
CSB FRAME (IS 800:2007)	193.067
PEB FRAME (IS 800:2007)	159.603
PEB FRAME (AISC LRFD)	121.266

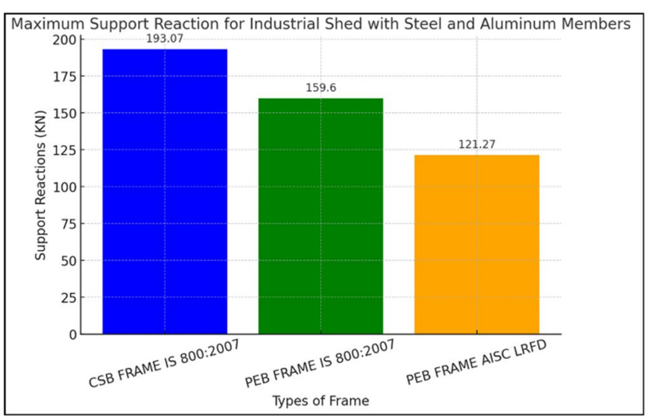

Fig. 19: Maximum Support Reaction

In this study, it is observed that the Maximum Support Reaction for an Industrial Shed constructed with Steel and Aluminum Members is reduced by 17.33% when designed as per the Indian code structure and by 37.18% when designed as per the American code structure, compared to the Maximum Support Reaction of a Conventional Steel Building (CSB) structure.

Table XII : Cost Analysis

Types of Frame	Weight of Frame (kN)	Purlin Weight (kN)	Grit Member Weight (kN)	Total Weight (kN)	Total Weight (kg)	Rate of Steel (₹/kg)	Total Cost (₹)
CSB FRAME (IS 800:2007)	1394.289	333.796	352.118	2080.2	2,12,118.30	55	1,16,66,506
PEB FRAME (IS 800:2007)	935.619	144.19	56.807	1136.62	1,15,900.73	55	63,74,540.3
PEB FRAME (AISC LRFD)	879.151	105.09	39.439	1023.68	1,04,384.65	55	57,41,155.7

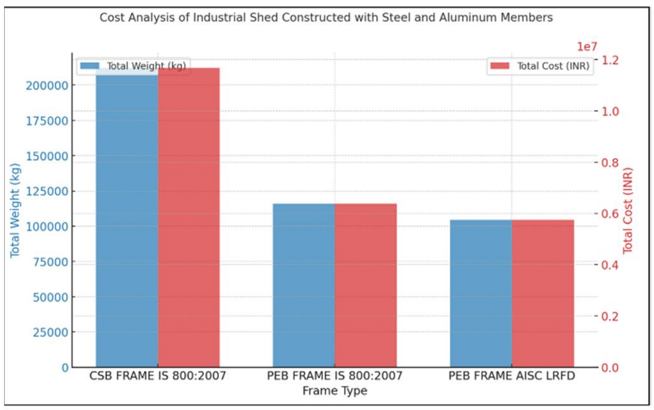

Fig. 20: Cost Analysis

In this study, it is observed that the cost of an Industrial Shed Constructed with Steel and Aluminum Members using PEB as per Indian standards is reduced by 45.36%, while the cost using PEB as per American standards is reduced by 50.78%, compared to the cost of the CSB structure.

A. Strengths and Weaknesses of Steel and Aluminum

Strength and capacity are two of the main attributes essential in steel to make it daggedly bone for an industrial shed. The acceptance of steel for making industrial buildings is predicated not only on its ability to withstand extreme conditions but also by the lower initial cost of the material. All of these become some cost-effective solutions for most industrial applications. Still, it is one of the metals subjected to corrosion, especially in high humidity or chemicals, and it demands frequent maintenance and protective coatings [38].

Aluminum excels in this area with its natural oxide layer that prevents corrosion, making it an ideal material for coastal or high-humidity exposure. This would make installation easier because it is lighter, but the cost of aluminum is quite higher due to the higher material costs and energy-intensive manufacturing processes. Structures built out of aluminum will need to have sections larger than those of steel to achieve similar strength. This will affect overall design considerations.

B. Insights into Selection Criteria

The decision regarding steel or aluminum should be made based on project requirements like ambient conditions, load-bearing requirement, and budgetary considerations. Steel is appropriate for large, hefty structures, while aluminum is more frequently used in environments needing corrosion resistance and reduction in weight [39].

TABLE XIII. COMPARISON OF STEEL AND ALUMINUM FOR INDUSTRIAL SHEDS

Property	Steel	Aluminum
Strength	High	Moderate
Corrosion Resistance	Low (requires protection)	High (naturally resistant)
Weight	Heavy	Light
Cost	Lower material cost	Higher material cost
Maintenance	Requires periodic maintenance	Low maintenance

Comparatively filming the steel and aluminum sheds under the different loading conditions as in Fig. 6 shows that while steel is superior in the case of design for very heavy loads, aluminum demonstrates better performance with respect to environmental damage [40].

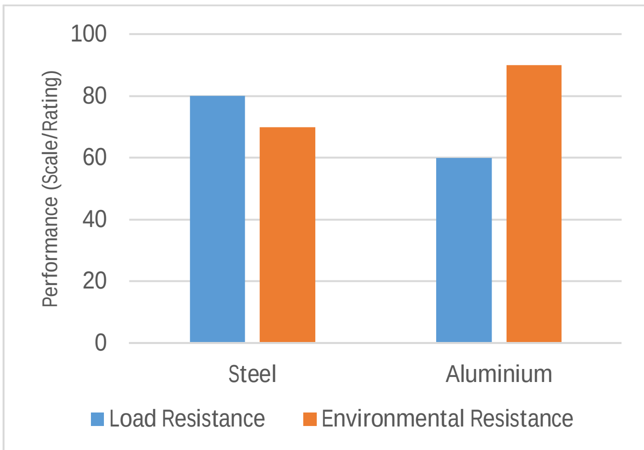

Fig. 21. Comparative Performance of Steel and Aluminum Sheds Under Different Loading Conditions

X. CONCLUSION

Steel is a versatile material that plays a crucial role in our daily lives, either directly or indirectly. In Industrial Shed Construction, the use of Aluminum Members offers significant advantages such as cost-effectiveness, strength, durability, design flexibility, adaptability, and recyclability. Aluminum, like steel, is a highly sustainable material due to its infinite recyclability and availability from regional sources.

Based on analytical and design results comparing conventional steel structures and aluminum-integrated structures, the following conclusions are drawn:

Structural Weight Reduction: The weight of Industrial Sheds with Aluminum Members as per Indian standards is reduced by 33%, and as per American standards, it is reduced by 37%, compared to conventional steel structures.

Purlin Weight Reduction: The purlin weight in an Aluminum-integrated Industrial Shed as per Indian standards is reduced by 56.80%, and as per American standards, it is reduced by 68.51%, compared to conventional steel structures.

Girt Member Weight Reduction: The Girt Member weight in an Aluminum-integrated Industrial Shed as per Indian standards is reduced by 83.86%, and as per American standards, it is reduced by 88.79%, compared to conventional steel structures.

Shear Force Reduction: The maximum shear force in an Industrial Shed with Aluminum Members as per Indian standards is 49.27% lower, and as per American standards, it is 62.53% lower, compared to conventional steel structures.

Support Reaction Reduction: The maximum support reaction in an Aluminum-integrated Industrial Shed as per Indian standards is 17.33% lower, and as per American standards, it is 37.18% lower, compared to conventional steel structures.

Cost Reduction: The cost analysis of Industrial Sheds with Aluminum Members as per Indian standards shows a 45.36% reduction, and as per American standards, a 50.78% reduction, compared to conventional steel structures.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue III Mar 2025- Available at www.ijraset.com

The use of Aluminum Members in Industrial Shed Construction significantly enhances structural efficiency, reduces material weight, lowers construction costs, and improves sustainability, making it a viable alternative to traditional steel structures.

Future studies could focus on improving the cost-effectiveness of aluminum through innovative manufacturing techniques or exploring hybrid designs that combine the strengths of both materials. Modernized coatings and surface treatments for steel will also be critical in improving corrosion resistance, so steel can be more widely used. More importantly, this research will contribute to sustainability practices and recycling options for both materials as aligned with environmental standards.

REFERENCES

[1] Singh, K. D., Yi, X., Shagolsem, L. S., & Toijam, J. (2024). Assessing Green Features of "Phumdi" as a Sustainable Material: A Comparative Analysis with Bamboo, Wood, Metal, and Plastic. Sustainability, 16(2), 637.

[2] Jyothirmayee, S., Reddy, B. D. K., Rakesh, M., Pooja, S., Neha, T., & Naik, G. K. (2024, June). A Comparative Study on Design of Commercial Building using Etabs and Staad Pro. In Journal of Physics: Conference Series (Vol. 2779, No. 1, p. 012035). IOP Publishing.

[3] Hassan, H. Z., & Saeed, N. M. (2024). Advancements and applications of lightweight structures: a comprehensive review. Discover Civil Engineering, 1(1), 47.

[4] Ascione, F., Maselli, G., & Nesticò, A. (2024). Sustainable materials selection in industrial construction: A life-cycle based approach to compare the economic and structural performances of glass fibre reinforced polymer (GFRP) and steel. Journal of Cleaner Production, 475, 143641.

[5] Jiang, Y. Q., Ma, H. H., Zhou, G. T., & Fan, F. (2021). Parametric and comparison study of a new and traditional aluminum alloy joint systems. Advanced Steel Construction, 17(1), 50-58.

[6] Dani, A. A., Roy, K., Masood, R., Fang, Z., & Lim, J. B. (2022). A comparative study on the life cycle assessment of New Zealand residential buildings. Buildings, 12(1), 50.

[7] Ostapska, K., Rüther, P., Loli, A., & Gradeci, K. (2024). Design for Disassembly: A systematic scoping review and analysis of built structures Designed for Disassembly. Sustainable Production and Consumption, 48, 377-395.

[8] Paul, B., Roy, K., Ji, Y., Fang, Z., Sivaji, V., & Lim, J. B. (2024). Moment capacity of perforated cold-formed aluminium channels–Tests, analysis, and design. Thin-walled Structures, 204, 112261.

[9] Cucuzza, R., Aloisio, A., Rad, M. M., & Domaneschi, M. (2024). Constructability-based design approach for steel structures: From truss beams to real-world inspired industrial buildings. Automation in Construction, 166, 105630.

[10] Cherian, P., Palaniappan, S., Menon, D., & Anumolu, M. P. (2020). Comparative study of embodied energy of affordable houses made using GFRG and conventional building technologies in India. Energy and Buildings, 223, 110138.

[11] Ahmed, S., & Arocho, I. (2021). Analysis of cost comparison and effects of change orders during construction: Study of a mass timber and a concrete building project. Journal of building engineering, 33, 101856.

[12] Agor, C. D., Mbadike, E. M., & Alaneme, G. U. (2023). Evaluation of sisal fiber and aluminum waste concrete blend for sustainable construction using adaptive neuro-fuzzy inference system. Scientific Reports, 13(1), 2814.

[13] Ullah, H., Zhang, H., Huang, B., & Gong, Y. (2024). BIM-based digital construction strategies to evaluate carbon emissions in green prefabricated buildings. Buildings, 14(6), 1689.

[14] Naqash, M. T., Alluqmani, A. E., & Farooq, Q. U. (2024). A comparative analysis of design and analysis methods for steel connections: contrasting American and European perspectives. Journal of Umm Al-Qura University for Engineering and Architecture, 15(1), 14-30.

[15] Georgantzia, E., & Kashani, M. M. (2024, May). On the use of aluminium alloys in sustainable design, construction and rehabilitation of bridges. In Proceedings of the Institution of Civil Engineers-Bridge Engineering (pp. 1-13). Emerald Publishing Limited.

[16] Kitayama, S., Iuorio, O., Josa, I., Borrion, A., & Black, L. (2024). Determining the carbon footprint reduction of reusing lightweight exterior infill walls: A case study of a school building in the United Kingdom. Journal of Cleaner Production, 469, 143061.

[17] Al-Sammar, R., & Aleisa, E. (2024). Evaluating energy efficiency and environmental sustainability in fiberglass prefabricated modular structures. Energy, 310, 133234.

[18] Naqash, M. T., Khoso, S., & Noroozinejad Farsangi, E. (2024). Wind-induced structural response of skylights: A Eurocode-based assessment. Practice Periodical on Structural Design and Construction, 29(1), 04023062.

[19] Di Giorgio, P., D'Eusanio, M., Serreli, M., & Petti, L. (2024). Social risks assessment of the supply chain of an aluminium semi-finished profile for window. The International Journal of Life Cycle Assessment, 1-20.

[20] Ubayi, S. S., Dr, B. S., Dr, E. A., Shashivendra, D., Umar, S. I., Ibrahim, A. I., & Mustapha, N. G. (2024). Shift From Traditional to Modern Building Concepts and Designs in Ringim Town: A Comparative Stusy of Aesthetics, Values, Functions and Durability. International Journal of Innovative Science and Research Technology, 9(06).

[21] Almasri, A., Dabous, S. A., Al-Sadoon, Z. A., & Hosny, F. (2023). Evaluating the efficiency of using lightweight steel in villa construction in the United Arab Emirates: A case study. Journal of Building Engineering, 72, 106524.

[22] Singh, K. D., Yi, X., Shagolsem, L. S., & Toijam, J. (2024). Assessing Green Features of "Phumdi" as a Sustainable Material: A Comparative Analysis with Bamboo, Wood, Metal, and Plastic. Sustainability, 16(2), 637.

[23] Jyothirmayee, S., Reddy, B. D. K., Rakesh, M., Pooja, S., Neha, T., & Naik, G. K. (2024, June). A Comparative Study on Design of Commercial Building using Etabs and Staad Pro. In Journal of Physics: Conference Series (Vol. 2779, No. 1, p. 012035). IOP Publishing.

[24] Rane, N. L., Anand, A., & Deepak, K. (2023). Evaluating the selection criteria of formwork system (FS) for RCC building construction. International Journal of Engineering Trends and Technology, 71(3), 197-205.

[25] Devi, K., & Yadav, T. (2023). Cost comparison of different types of formworks. Journal of Building Material Science, 5(1), 32-38.

[26] Mohammed, M., & Mohammed, A. H. (2023). ANALYSIS AND DESIGN OF PRE-ENGINEERED STEEL BUILDING FOR AIRBUS A-380 HANGAR USING IS CODES. Proceedings on Engineering, 5(S1), 1-10.

[27] Mechaala, A., Stefaniuk, D., & Belarbi, A. (2024). Comparative performance analysis of straight and harped prestressing seven-wire strands: High-strength stainless steel vs. conventional carbon steel. Construction and Building Materials, 439, 137421.
[28] Krishna, P. V. V. S. S. R., Raju, J., Reshikesh Reddy, K., Kalyan, P. S. V. A., & Govardhan, G. (2023, September). Analysis and design of energy efficient building. In AIP Conference Proceedings (Vol. 2754, No. 1). AIP Publishing.
[29] Ma, H. H., Zhao, C. Y., Jiang, Y. Q., Zhou, G. T., & Wang, Y. J. (2023). Rotational resistance test of a new aluminum alloy penetrating (AAP) joint system. Advanced Steel Construction, 19(2), 121-129.
[30] Zhong, C. J., Feng, R. Q., Huang, Y. Q., & Li, H. Y. (2023, September). 6A13-T6 high-strength aluminium alloy columns under axial compression: Experiments, finite element analysis and design recommendations. In Structures (Vol. 55, pp. 71-84). Elsevier.
[31] Naqash, M. T., Khoso, S., & Noroozinejad Farsangi, E. (2024). Wind-induced structural response of skylights: A Eurocode-based assessment. Practice Periodical on Structural Design and Construction, 29(1), 04023062.
[32] Huang, B., Xing, K., & Rameezdeen, R. (2023). Exploring Embodied Carbon Comparison in Lightweight Building Structure Frames: A Case Study. Sustainability, 15(20), 15167.
[33] Georgantzia, E., & Kashani, M. M. (2024, May). On the use of aluminium alloys in sustainable design, construction and rehabilitation of bridges. In Proceedings of the Institution of Civil Engineers-Bridge Engineering (pp. 1-13). Emerald Publishing Limited.
[34] Kitayama, S., Iuorio, O., Josa, I., Borrion, A., & Black, L. (2024). Determining the carbon footprint reduction of reusing lightweight exterior infill walls: A case study of a school building in the United Kingdom. Journal of Cleaner Production, 469, 143061.
[35] Aydogdu, I., Kilic, V., & Akin, A. (2023, September). Optimum design of pin-jointed aluminum structures to AA-ASD using three Meta-heuristic algorithms. In Structures (Vol. 55, pp. 1406-1422). Elsevier.
[36] Kitayama, S., & Iuorio, O. (2023). Disassembly and reuse of structural members in steel-framed buildings: state-of-the-art review of connection systems and future research trends. Journal of Architectural Engineering, 29(4), 03123006.
[37] Meng, Q., Hu, L., Li, M., & Qi, X. (2023). Assessing the environmental impact of building life cycle: A carbon reduction strategy through innovative design, intelligent construction, and secondary utilization. Developments in the Built Environment, 16, 100230.
[38] Khan, K., Chen, Z., Liu, J., & Javed, K. (2023). State-of-the-art on technological developments and adaptability of prefabricated industrial steel buildings. Applied Sciences, 13(2), 685.
[39] Zhong, C. J., Feng, R. Q., & Huang, S. (2024, May). Engineering application study of high-performance aluminum alloy 6A13-T6. In Structures (Vol. 63, p. 106343). Elsevier.
[40] Bock, M., Bawazeer, J., Robinson, J., Theofanous, M., & Skalomenos, K. (2023). Structural performance of additive manufactured aluminum tubular stub columns. ce/papers, 6(3-4), 751-756.