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Study of Different Truss Type Railway Steel Bridge

Vikas Bankar[1], Poorva Pimpalkar[2], Ganesh Upparwar[3], Shruti Bhoyar[4], Raj Kathale[5], Chinmay Kadam[6], Tejas Khodake[7]
Department of Civil Engineering[1,2,3,4,5,6,7], Assistant Professor[1], Students[2,3,4,5,6,7]

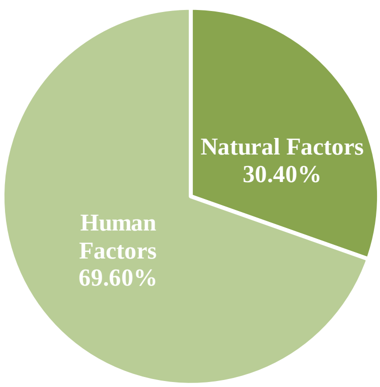
Email: ppimpalkar14@gmail.com[2], ganeshupparwar1449@gmail.com[3]

Abstract-A railway bridge serves as a vital component of infrastructure, designed to bear train loads while ensuring reliable and efficient transportation. Among the different bridge types, truss railway bridges are extensively utilized due to their exceptional strength-to-weight ratio, structural effectiveness, and capability to cover long spans. However, these bridges are prone to several failure mechanisms, including shear forces, which can cause web buckling and joint failures; axial forces, leading to buckling in compression members or fatigue-induced fractures in tension members; excessive deflection, which may result in serviceability issues and excessive steel weight, which increases dead loads. These failure risks emphasize the importance of optimizing truss design and utilizing advanced structural analysis to improve bridge durability, safety, and overall performance. This review paper explores the concept of Truss railway bridge. It also focuses on the various types of truss railway bridges, highlighting their structural configurations. Also, it reviews existing literature on truss railway bridge performance, failure mechanisms, and design optimizations.

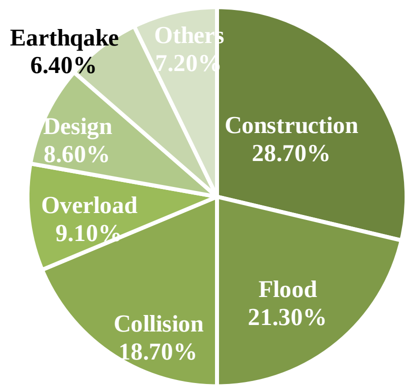
Index Terms- railway bridge; truss railway bridges; shear forces; axial forces; deflection; steel weight; optimizing truss design; structural analysis; bridge durability; structural configurations

1. Introduction

Railway bridges are crucial components of transportation infrastructure, providing seamless rail connectivity across natural and man-made obstacles such as rivers, valleys, and roads. These structures are specifically engineered to endure substantial train loads, dynamic forces, and various environmental conditions while maintaining safety, longevity, and operational efficiency. Beyond their fundamental role in transportation, railway bridges significantly impact economic development, regional integration, and supply chain efficiency. By reducing travel time, facilitating trade, and improving mobility, they are indispensable for both freight and passenger rail networks. Due to the frequent and heavy loads they bear, ensuring their structural integrity and long-term performance remains a key priority in bridge engineering.



(a) Percentage of Natural and Human Factors causing bridge failure



(b) Reasons of collapse

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Fig 1. Causes of bridge failures between 2009 and 2018. (a) Percentage of Natural and Human Factors causing bridge failure. (b) Reasons of collapse [1].

To withstand demanding operational conditions, railway bridges must be designed to resist high axial loads, shear forces and deflection. Unlike road bridges, which distribute loads across various vehicle types, railway bridges support concentrated axle loads, requiring a more robust structural design and material selection. Therefore, selecting the appropriate bridge type is essential to achieving optimal stability, efficiency, and cost-effectiveness. Figure 1 (a) shows that human related factors (69.6%) are the leading cause of failures, while natural factors (30.4%) contribute less. Figure 1 (b) categorizes the specific reasons behind bridge failures and their respective percentages. It shows that Construction Issues is the most significant cause with 28.70%, likely due to design flaws, material deficiencies, or workmanship problems. Then there is Flood/Scour with 21.30% which may be water related issues, such as riverbed erosion removing support from the bridge. Then comes Collision with 18.70% which may be due to impact from vehicles, ships etc. Other reasons include overload, design flaws and earthquake. From this, it is clear that human-related issues are responsible for almost 70% of bridge failures, emphasizing the importance of better engineering, construction standards, and maintenance. Flooding and scour are the most significant natural cause, highlighting the need for better flood-resistant infrastructure and collisions and overloading are also major contributors, suggesting improvements in traffic regulation and bridge load monitoring. Figure 1 (b) clearly shows that construction issues are the leading cause of bridge failures, accounting for 28.7% of all collapses between 2009 and 2018. This means that nearly one-third of all bridge failures stem from problems during construction, such as poor workmanship, material defects, or engineering errors.

1.1. Truss Bridges

Truss bridges have long been a preferred choice for railway applications due to their exceptional strength-to-weight ratio, capacity for long spans, and efficient load distribution. These bridges are composed of interconnected triangular components, which help transfer forces through axial loads rather than bending moments. This design allows truss bridges to support heavy railway traffic while optimizing material usage and reducing construction costs.

The advantages of truss bridges in railway infrastructure are significant. Their high load-bearing capacity ensures they can handle the intense weight and forces exerted by trains, while their efficient use of materials provides structural stability with minimal resource consumption. Additionally, truss bridges are particularly well-suited for long spans, making them ideal for crossing large bodies of water or deep valleys where other bridge types may be less effective. Another key benefit is their modular design, which simplifies maintenance and repairs, allowing for individual components to be inspected and replaced without disrupting the entire structure.

Truss railway bridges have been in use for over a century and have continuously evolved with advancements in materials, construction techniques, and structural analysis. Modern designs incorporate high-strength steel, finite element analysis (FEA), and optimized cross-sections, enhancing both durability and performance.

However, despite their many benefits, truss railway bridges face certain structural challenges, including fatigue cracking, buckling in compression members, excessive deflection, and connection failures caused by dynamic railway loading. These potential failure mechanisms highlight the importance of ongoing research and innovation in bridge design, material development, and structural optimization to ensure long-term safety and reliability.

1.1.1. *Load Distribution and Components of Truss Bridges*

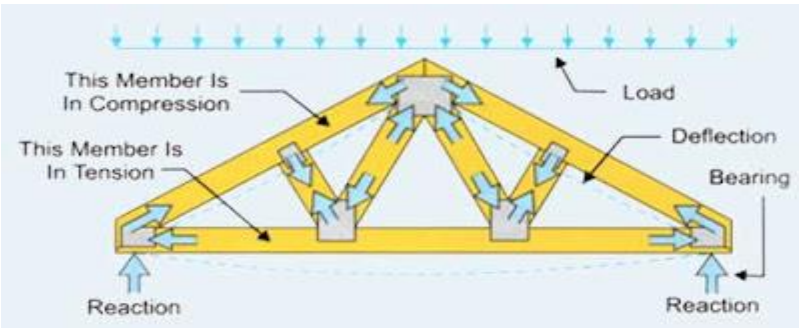

Fig 2. Load Distribution in a Truss [2]

In a truss bridge, load distribution occurs through a system of interconnected members that transfer forces efficiently. The applied load, such as the weight of trains or vehicles, is distributed across the truss structure, where different members experience either compression or tension. Compressed members act like columns, resisting inward forces, while tensioned members counteract pulling forces to maintain structural integrity. This force transmission allows the bridge to handle heavy loads while minimizing material stress. The load is ultimately transferred to the supports (bearings) at both ends, where reaction forces balance the applied load and ensure stability. While some deflection may occur due to the weight and forces acting on the bridge, the triangular truss design minimizes bending moments, allowing for efficient force distribution. This structural efficiency makes truss bridges highly reliable for railway and heavy-load applications.

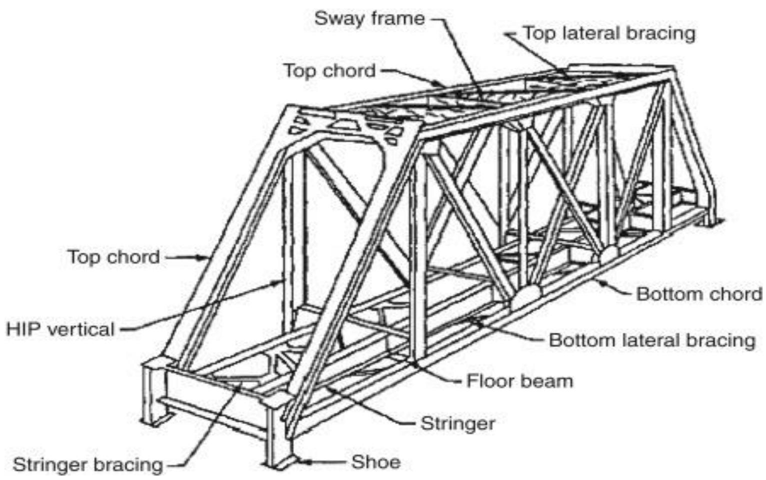

Fig 3. Truss Bridge Components [3]

Figure 3 depicts the structural components of a truss bridge that contribute to its strength and stability. The top chord and bottom chord form the primary load-bearing members, with the top chord typically in compression and the bottom chord in tension. HIP vertical members provide additional support by transferring loads efficiently. The sway frame and top lateral bracing enhance lateral stability, preventing excessive movement from wind or external forces. Bottom lateral bracing reinforces the lower structure, while floor beams and stringers distribute the load from the deck to the truss framework. The stringer bracing further stabilizes the stringers, ensuring structural integrity. The shoe serves as a support point where the truss bridge rests on its foundation. These interconnected components work together to create a strong, durable, and load-efficient structure, making truss bridges ideal for railway and heavy-load applications.

1.2. Types of Truss Bridge Configurations

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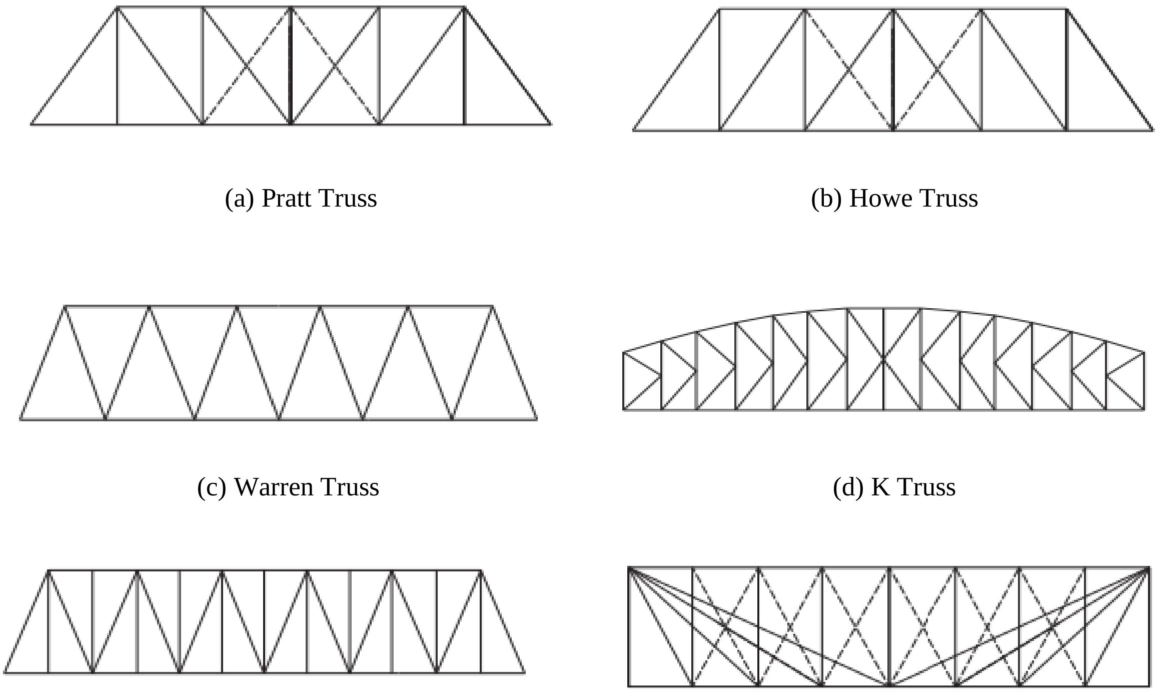

(a) Pratt Truss (b) Howe Truss

(c) Warren Truss (d) K Truss

(e) Modified Warren Truss (f) Fink Truss

Fig 4. Truss Bridge Configurations. (a) Pratt Truss. (b) Howe Truss. (c) Warren Truss. (d) K Truss. (e) Modified Warren Truss. (f) Fink Truss [4]

Pratt trusses have diagonals sloping downward toward the center and parallel chords, as shown in figure 4 (a). In this configuration, diagonal members handle tension, while vertical members withstand compression, making it highly efficient for supporting substantial loads. It is commonly utilized in railway and highway bridges, as well as in industrial structures, due to its strength and material efficiency. Figure 4 (b) shows Howe truss, with its diagonal members slanting outward from the center of the span toward the middle. Here, diagonal members are in compression, while vertical members experience tension, making it particularly effective for wooden bridges and extended spans. This truss is frequently seen in railway bridges, timber structures, and long-span bridges, thanks to its ability to distribute forces effectively.

Warren trusses have parallel chords and alternating diagonals, as shown in figure 4 (c). The triangular pattern ensures uniform load distribution, enhancing material efficiency and reducing overall weight. Due to its simplicity and strength, it is widely used in railway and pedestrian bridges, as well as in aircraft hangars and roofing systems. Warren trusses with verticals to reduce panel size are named as modified Warren truss, as shown in figure 4 (e). These extra vertical supports boost the load-carrying capacity, making it an excellent choice for railway bridges with heavy loads and large spans. This truss type is extensively employed in railway bridges, highway overpasses, and industrial structures where additional strength is necessary.

Figure 4 (d) shows K truss, which features a more intricate design, where diagonal members divide into smaller segments, forming K-shaped patterns within each section. This design shortens the length of compression members, mitigating the risk of buckling and improving overall stability. It is particularly suitable for long-span bridges and structures requiring superior load distribution and durability. Figure 4 (f) depicts Fink truss, which is characterized by a series of V-shaped patterns, commonly found in roof trusses and lightweight bridge designs. The use of multiple smaller triangles allows for efficient load transfer, reducing material requirements while maintaining stability. It is frequently used in roofing systems, pedestrian bridges, and short-span highway bridges, offering cost efficiency and structural strength.

1.3. Steel as a Truss Material

Steel is extensively utilized worldwide for constructing bridges of various sizes. As a highly adaptable and efficient material, it offers practical and sustainable solutions. For a long time, steel has been regarded as a cost-effective choice for different types of bridges. It dominates the market for long-span bridges, railway bridges, pedestrian bridges, and medium-span highway bridges. Additionally, it is increasingly being used for shorter-span highway structures.

Steel is a highly adaptable material, allowing it to be effortlessly shaped and formed into a wide range of geometries. However, steel tends to corrode easily [5]. Steel trusses are more resistant to heat compared to wooden trusses, which are highly susceptible to combustion [6]. Steel trusses can withstand significantly higher temperatures before their structural integrity is affected, making them a safer option compared to wooden trusses, which are more vulnerable to fire [7]. Additionally, steel's high strength-to-weight ratio makes it an excellent choice for large buildings that require trusses [8].
The advantages of steel bridge construction provide numerous benefits to society. Steel truss bridges offer numerous advantages, making them a preferred choice for modern infrastructure. They can support heavy loads across long spans with minimal dead weight, reducing foundation requirements. Prefabricated components enable rapid construction, minimizing disruptions, especially in congested urban areas. Steel bridges also outperform concrete in resisting seismic forces and blast impacts while offering a longer lifespan. Their slender design enhances aesthetic appeal and lowers embankment costs. Additionally, concerns about corrosion are mitigated with advanced protective coatings and specialized steel materials. These bridges are cost-effective due to their low life-cycle costs and economical construction. They are also easy to assemble, require minimal maintenance, and provide flexibility in design while efficiently handling dynamic loads. Overall, steel truss bridges combine durability, efficiency, and sustainability, making them a reliable choice for various transportation needs [9].

2. Literature Review

Watile and Kalmegh (2023) [10] explored the behavior of steel bridges during their service life, emphasizing potential distortions caused by dynamic vehicle loads. Their primary objective was to minimize the total deformation of structural members by optimizing cross-sections and material properties. They analyzed truss bridge structures under IRS loading, considering both simple and complex designs. They analyzed and designed steel truss railway bridge, evaluating different truss sections under the same broad gauge (BG) railway loadings to identify the most stable configuration.

Shende and Sinha (2022) [11] conducted a comparative study of Pratt and Warren truss bridge designs using finite element analysis. They analyzed these truss bridges using Autodesk Structural Analysis software to evaluate various structural parameters, including stress, force, moment, and material quantity under different factored load cases. The study aimed to assess the economic viability and structural performance of both truss types. The design followed AISC and AASHTO LRFD 2000 standards, considering dead loads, wind loads, and moving loads. The findings provide insights into the differences in structural behavior and cost-effectiveness between Pratt and Warren truss bridges.

Chavan and Patil (2022) [12] focused on the analysis and design of various trusses for a steel bridge in Pune, India, using STAAD Pro software. The bridge was intended to span a length of 366 meters and a width of 7.6 meters, with 30 bays of 12.2 meters each, and designed for two tracks of broad-gauge railway. The study considered seismic analysis based on seismic zone III and followed the IS 1893 (Part III) 2016 standards, while wind analysis was conducted according to IS 875 (Part III). The author compared three types of trusses- Warren, Pratt, and Howe in both static and dynamic conditions. The goal was to create a cost-effective steel bridge structure suitable for crossing the Bhima River, considering the likely increase in train traffic and the development of short-distance routes in the future.

Jain and Vimal (2021) [13] analyzed truss bridge structures using the ANSYS tool and developed an optimized truss bridge design. They focused on minimizing total deformation and stress while ensuring an efficient and cost-effective design. They evaluated four different truss bridge designs using the ANSYS Workbench, and compared their results to determine the most effective design.

Chaurasia and Singh (2019) [14] conducted a study to analyze and compare four different steel truss bridge designs which were Howe, Pratt, Warren, and K-type, each with a 50-meter span. They explored advanced methods for bridge analysis and design, including AASHTO, the Finite Element Method, the Grillage Method, and the Finite Strip Method. The primary goal was to evaluate the bridges under critical load conditions and compare their performance in terms of forces, weight, and cost. By analyzing these factors, the study aimed to determine the most economical truss bridge design.

Suman and Patel (2018) [15] focused on the design and analysis of various bridge structures for railway applications, using steel trusses for comparison. Four truss designs such as rectangular, X-type, V-type, and K-type were examined. The analysis, conducted using Staad Pro software, evaluated parameters such as support reactions, displacement, shear force, and torsion. The maximum and minimum values for each case were compared, along with a cost analysis, to determine the most efficient design.

Sharma and Pahwa (2018) [16] focused on designing and optimizing bridge structures, emphasizing the reduction of total deformation in structural members through optimized cross-sections, material properties, and weight. In this review, they examined truss bridge structures. Their findings from provided valuable insights into the analysis and design of steel bridges using locally available steel profiles. The research demonstrated that constructing steel bridges with locally sourced materials is a viable option. For many short-span temporary bridges used in road construction projects, locally assembled steel truss bridges presented a practical solution. Their suitability for remote and inaccessible areas, along with their quick assembly time, made them an efficient and cost-effective choice as their finding.

Jain and Vyas (2016) [17] conducted a modal analysis of a bridge using ANSYS, modeling it with four different materials to study its natural frequencies and mode shapes. They used an eight-node solid element for meshing and selected material properties from the literature database. The study aimed to prevent resonance by ensuring the bridge does not operate at its natural frequencies, which could lead to structural failure. The results confirmed that the bridge should not be used under loads that match its natural frequencies to avoid resonance and potential damage.

T. Pramod Kumar and G. Phani Ram (2015) [18] conducted the analysis and design of a road-cum-railway bridge across the Krishna River near Vijayawada, located downstream of an existing bridge. The proposed structure was a through-type steel truss bridge, with two railway tracks on the lower level and a three-lane roadway on the upper level. Analysis of structural components was performed using STAAD Pro. Design of structural members was conducted based on the Indian Railway Standard Code and the Indian Roads Congress Code. They found that a single bridge for both railway and road traffic reduce construction costs compared to building separate bridges.

Miyachi et al. (2012) [19] conducted a progressive collapse analysis of deteriorated steel truss bridges to understand the effects of live load intensity and distribution on their ultimate strength and ductility. Using large deformation and elastic-plastic analysis, they examined two continuous steel truss bridge models- Bridge Model

A (span ratio 1:2:1) and Bridge Model B (span ratio 1:1.3:1) each with a total length of 230 meters. The truss members were designed within allowable stress limits for dead and live loads, and live loads were increased until collapse occurred. Their findings indicate that in all cases, bridge collapse was caused by buckling of compression members. When the live load was fully applied to the center span, the span ratio had no significant effect on ultimate strength, which remained sufficiently high. However, when the live load was applied to the side span, bridges with longer side spans exhibited higher ultimate strength. Similarly, when the live load was applied near an intermediate support, bridges with longer center spans had greater ultimate strength. Regarding ductility, Bridge Model B was found to be generally more ductile than Bridge Model A, suggesting that the commonly used span ratio in truss bridges is structurally rational. The study clarifies the collapse mechanism, buckling behaviour, and the influence of live load distribution and span ratio on steel truss bridge stability.

Tong et al. (2011) [20] conducted an analysis of the stability of a truss bridge using both linear buckling analysis and nonlinear stability analysis with ANSYS. They considered the effects of geometric nonlinearity, material nonlinearity, and initial geometric defects in their study. Additionally, they examined the influence of Lead Rubber Bearings (LRB) on the structural stability of the bridge. They found that overall instability occurs before local instability, primarily due to the distortion of the middle pillar and linkage, leading to instability in the truss beams. Also, the critical buckling load obtained from nonlinear analysis is lower than that from linear buckling analysis, with a deviation of around 10% after considering various nonlinear effects. They also found that the presence of LRB reduces the stability of the truss bridge. Overall, they highlighted the significance of considering nonlinear factors and support conditions in truss bridge stability analysis, particularly when LRBs are introduced.

Yamaguchi et al. (2011) [21] studied the post-member-failure behavior of a steel truss bridge, focusing on bridge redundancy, the ability of a bridge to withstand partial failures without collapsing. They compared static and dynamic analysis methods and found that static analysis alone provides different results from dynamic analysis, which is crucial for assessing redundancy accurately. To address this, they proposed a post-member-failure analysis method that delivers reliable results with computational efficiency comparable to static analysis. Their method was validated through an example problem, confirming its effectiveness in evaluating bridge redundancy.

3. Conclusion

The reviewed literature provides insights into various aspects of steel truss bridge analysis and design, emphasizing structural efficiency, stability, cost-effectiveness, and resilience under different loading conditions. Several studies concentrated on optimizing truss configurations using software tools such as STAAD Pro, ANSYS, and Autodesk Structural Analysis, assessing factors like deformation, stress, and buckling behavior. Comparative analyses examined different truss types such as Pratt, Warren, Howe, K type, and X type to identify the most economical and structurally efficient designs. Additionally, studies on redundancy and post-member-failure behavior emphasized the need for robust designs capable of withstanding partial failures without leading to total collapse. The feasibility of using locally available materials for cost-effective and practical construction was also explored, particularly in remote regions. Moreover, integrated road-cum-railway bridge designs were found to offer economic benefits compared to constructing separate structures. Overall, the literature highlights ongoing advancements in truss bridge engineering, focusing on optimizing structural performance while maintaining economic viability and safety.

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