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Comparative Design of Different Trusses by using Different Material, Cross-section, and Truss type for Footbridge Applications

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Abstract

This study presents the analysis and design of various truss systems for medium-span footbridges, focusing on identifying the most cost-effective configuration. The analysis considers different truss types, material types, and cross-sections to determine their economic and structural performance. The truss type analyzed include the Warren and N-types, utilizing Tata and channel sections. Among these, the model requiring the least steel after design that model was further designed using different cross-sections to identify the most efficient option. The comparison was conducted based on maximum deflection, yield strength, and steel usage across various truss types and cross-sections. Subsequently, a cost analysis was performed to evaluate the economic viability of different configuration. The results indicate that the Warren truss with Tata circular sections reduces costs and steel usage by 2.49 and 1.71 times respectively for footbridge, although it exhibits averagely 22.35 % higher deflection than all other trusses. This study highlights the significance of selecting appropriate truss systems, materials, and cross-sections to achieve cost-effective and structurally efficient footbridge designs.

INTRODUCTION

The truss as structure made of slender members connected at their ends, which primarily experience axial forces. Trusses are used in bridges, roofs, and towers due to their efficiency in load distribution [1]. Trusses as lightweight structures formed by straight or curved bars connected at joints [2]. The trusses are designed as pinned joint and carried axial force either tension or compression. The trusses d constructed in various types, such as Warren truss, N-type truss, K-truss, and Howe truss, each exhibiting different behaviors under load.

The selection of truss type influences not only steel consumption but also structural performance aspects such as deflection [4].

Warren trusses, characterized by an efficient design that uses diagonal members arranged in equilateral triangles, are commonly used in bridge where material efficiency and lightweight design are crucial. Their straightforward construction makes structure cost-effective and suitable for projects requiring high strength-to-weight ratios [5]. Conversely, the N-type truss, which includes diagonal and vertical members, offers greater load redundancy and enhanced stability [6]. This design is particularly recognized for its ability to distribute loads more efficiently and provide resistance to dynamic forces [7].

Different cross-section choices also significantly affect structural behavior, material efficiency, and cost. While solid cross-sections provide greater strength but increased weight and costs [15]. In contrast, hollow or tubular cross-sections reduced weight, making structure more effective for longer spans where efficiency is a priority. These shapes not only determine the minimized steel usage but also economy of project up to 36 % [25].

Material selection further impacts cost and steel consumption. The use of high-strength Tata steel minimizes material usage due to its superior load-bearing capacity, despite its higher initial cost. In contrast, standard steel is more affordable but requires additional material, increasing overall weight and expenses. Tata and channel both materials have different strengths and structural performance so considered here for analysis.

This study presents a comprehensive analysis and design of a footbridge with a 20-meter span, focusing on optimizing the structural performance, while minimizing steel usage and costs. The investigation considers various truss types, material types, and cross-sectional shapes, with the objective of achieving an efficient and cost-effective design. The truss height is considered only one meter with considering transportation and implementation issues due to more height of truss. A constant yield strength of 240 MPa is applied to all trusses, ensuring consistency in the comparison of structural performance.

Two distinct truss configurations are analyzed: the Warren truss and the N-type truss, each constructed using two different materials: Tata steel (cold-formed) and channel sections (hot-rolled formed). The selection of material influences the overall steel consumption and structural performance. This study aims to identify which truss design that minimizes steel usage while satisfying strength and stability requirements by considering different material, section type, truss type with one-meter height.

To assess the comparative effectiveness of each design, key performance parameters such as maximum deflection, yield strength, steel usage, and economy efficiency are evaluated. Upon determining the truss configuration that consumes the least steel, further this model is analysis and design by considering different cross-sectional shapes, including rectangular, circular, and square, to enhance structural performance and economic feasibility. The findings provide valuable insights into selecting the most efficient and economically viable truss design for footbridge with a medium span.

METHOD0LOGY

1. Modeling

Six models were developed for analyzing and designing a footbridge. Four of these models were prepared for Warren and N-type truss using Tata rectangular and channel sections. The Figure 1 and Figure 2 represent the front-elevation of Warren and N-type truss. Among four model which required least steel that model was selected for further design with different cross- section. Additionally, two more models were created with circular and square cross-section (for rectangular model already prepared) to identify the most efficient cross-section in terms of material usage. In a truss model of twenty meters length with a one-meter height were placed at one-meter intervals transversely. The truss is connected by the connections of cross- like structures which gives stability to the truss.

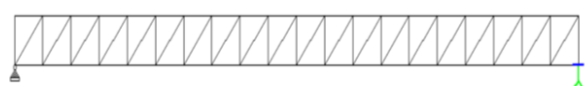

Fig.1 Front-elevation of Warren truss

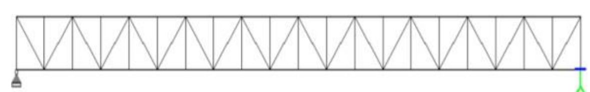

Fig.2 Front-elevation of N-type truss

2. Assigning material properties and cross-sections

Material properties were applied to all trusses with tubular cross-sections. The Tata material was assigned to the cold- formed material, while the channel sections were designated as hot-rolled formed material. For the cross-section analysis, rectangular, circular, and square cross-section were assigned and which is shown in Figure 3.

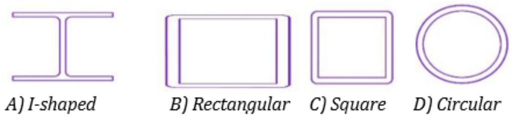

Fig.3 Cross-section used analysis and design

3. Applications of support

A total of 14 supports were apply to the bridge, with 7 supports on the left side and the remaining 7 on the right side. The bridge is designed as simply supported, with the X-direction forces released on the right-side supports to allow movements of the bridge under load.

4. Application of Loads and load combinations

The dead load, live load, wind load, seismic load, and their combinations were applied to all models, using IRC 6-2017. The wind load and seismic load was applied in the X and Z directions, while the dead load and live load in the Y direction only. The loads were applied at the node point of truss and node intensity is divided by the number of nodes applied to the truss. Figure 4 shows that load application on truss system and Figure 5 shows that load application on girder system.

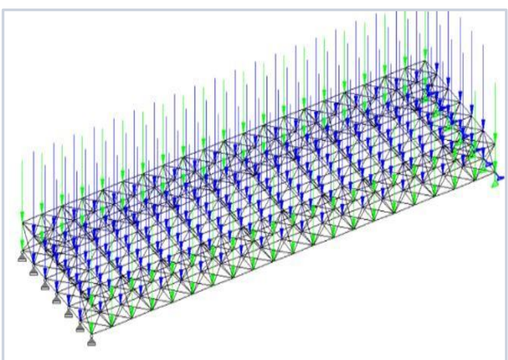

Fig.4 Load Application of Truss system

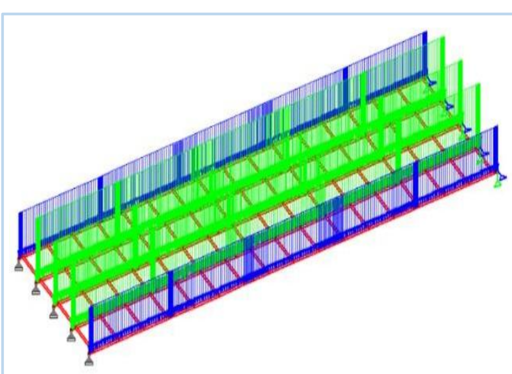

Fig.5 Load Application of Girder System

5. Analysis and Interpreted Result

The analysis was performed using the post-analysis option in STAAD-Pro. Once completed analysis by software, it generates values related to beams and nodes, including stresses, forces, deflections, and reactions. Additionally, graphical representations are provided for shear force, bending moment, and deflection. After finalizing the analysis, the results are interpreted to evaluate deflection, reactions, forces, and other structural parameters.

6. Design

The structural evaluation ensures compliances with design codes and member specifications to determine the required steel usage while verifying safety through code-based assessments.

RESULTS AND DISCUSSIONS

1. A Comparative Evaluation of Various Truss Designs:

Comparison based on deflection (mm)

This analysis compares Warren and N-type trusses constructed using Tata and channel sections for footbridge. The evaluation focuses on maximum deflection and yield strength across different truss configurations. The Figure 6 illustrates the comparison of different truss based on deflection.

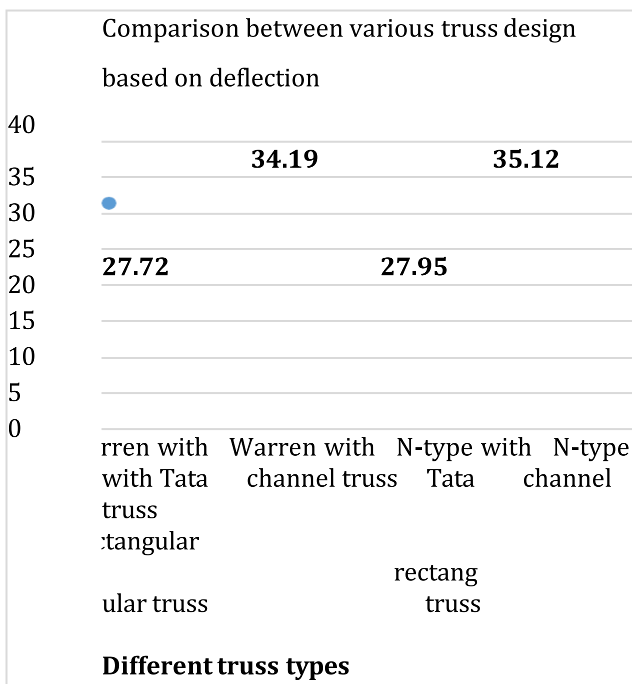

Fig.6 Comparison of Different Trusses based on deflection

The maximum deflection values of the four truss configurations reveal notable differences in structural behavior under load. Among all, the Warren truss with a rectangular section exhibits the lowest deflection at 27.72 mm, indicating superior stiffness. The N-type truss with a rectangular section follows closely with a deflection of 27.95 mm, showing only a 0.83 % increase compared to the Warren truss with a rectangular section. In contrast, the Warren truss with a channel section deflects 34.19 mm, which is 23.3 % more than Warren with Tata rectangular truss and 22.3 % higher than the N-type with Tata rectangular truss. The highest deflection, 35.12 mm, is observed in the N- type truss with a channel section, surpassing the Warren with Tata rectangular section by 26.8 % and the N-type with Tata rectangular section by 25.6 %.

When comparing the two truss types, the N-type truss with both rectangular and channel sections consistently demonstrates slightly higher deflection than the Warren with Tata truss, indicating a marginally lower stiffness under similar conditions. Warren trusses deflects less than N-type trusses may be due to their simpler load path and uniform stress distribution.

The lower deflection in Tata sections arises from their higher stiffness and moment of inertia compared to the channel sections. Channel sections show higher deflection may be due to reduced bending stiffness and susceptibility to local buckling. Theses variations reflect the impact of geometry and sectional properties on structural performance.

All the trusses, regardless of their type or section, exhibit a uniform yield strength of 240 MPa, indicating consistent material properties. While, the yield strength remains constant, the truss performance varies significantly in terms of maximum deflection. This highlights that the yield strength alone does not determine overall performance; factors such as truss geometry and section shape play crucial roles.

Comparison based on steel usage (Kg)

This analysis compares Warren and N-type trusses constructed using Tata and channel sections for footbridge. The evaluation focuses steel usage, and yield strength across different truss configurations. The Figure 7 illustrates the comparison of different truss based on steel usage.

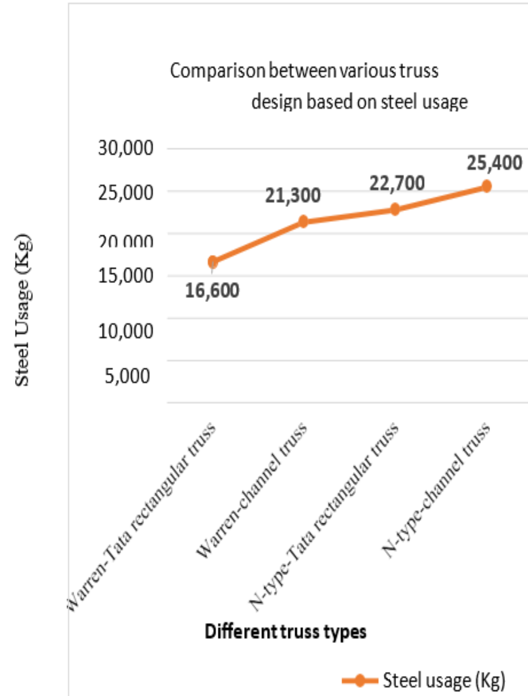

Fig.7 Comparison of Different Trusses based on steel usage.

The comparison of steel usage across the four truss configurations reveals significant differences due to variations in truss geometry and section type. The Warren truss with Tata rectangular sections uses the least steel at 16,600 Kg, indicating it is efficiency in material utilization due to its simple design and optimized load distribution. The Warren truss with channel sections requires 21,300 Kg, a 28.3 % increase, primarily may be due to channel sections, being less structurally efficient, and demand more material to achieve the required strength.

In contrast, the N-type truss with Tata sections uses 22,700 Kg of steel, 37.0 % more than the Warren with Tata sections, as its geometry responsible to increase material usage. The N-type truss with channel sections shows the highest steel consumptions at 25,400 Kg, a 14.6 % rise compared to the N- type with Tata section and a 53.0 % increase over the Warren with Tata sections. This significant difference arises from the combination of channel sections reduced efficiency and the N- type truss is more complex geometry, which requires additional steel to maintain structural integrity under load.

All the trusses, regardless of their type or section, exhibit a uniform yield strength of 240 MPa, indicating consistent material properties. While, the yield strength remains constant, the truss performance varies significantly in terms steel usage. This highlights that the yield strength alone does not determine overall performance; factors such as truss geometry and section shape play crucial roles.

2. **A Comparative Evaluation of Various Cross-sections Designs:**

Based on maximum deflection

This analysis compares Warren trusses constructed using different sections for rectangular, circular, and square of footbridge. The evaluation focuses on maximum deflection, and yield strength across different truss configurations. The Figure 8 illustrates the comparison of different cross-section

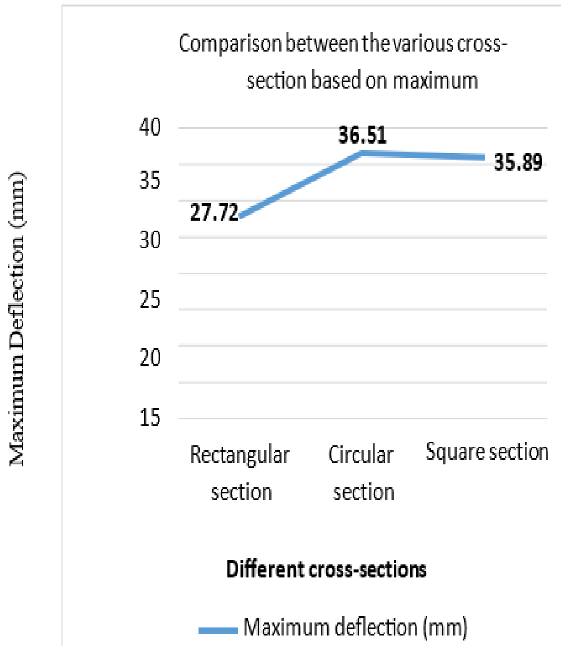

Fig.8 Comparison between the various cross-sections based on maximum deflection.

The maximum deflection values differ significantly between the rectangular, circular, and square cross-sections. The rectangular cross-section exhibits the lowest deflection at 27.72 mm. This is may be due to its higher moment of inertia, which allows it to resist bending more effectively. In contrast, the circular cross-section has the highest deflection at 36.31 mm, as it is uniform geometry distributes material evenly but does not optimize resistance against vertical loads. The square cross- section, with a deflection of 35.89 mm, falls between the rectangular and circular section. It is symmetrical geometry provides better stiffness compared to the circular cross-section but does not match the bending resistance of the rectangular section. These results highlight the superior structural performance of the rectangular cross-section in minimizing deflection.

When comparing the efficiency of the three cross-sections, several factors come into play. The rectangular cross-section proves to be the most efficient in minimizing deflection, being 22.6 % more efficient than the square and 24.1 % more efficient than the circular design. This results from it is higher moment of inertia, which provides better resistance to bending.

All the trusses, regardless of their type or section, exhibit a uniform yield strength of 240 MPa, indicating consistent material properties. While, the yield strength remains constant, the truss performance varies significantly in terms of maximum deflection. This highlights that the yield strength alone does not determine overall performance; factors such as truss geometry and section shape play crucial roles.

Based on steel usage

This analysis compares Warren trusses constructed using different sections for rectangular, circular, and square of footbridge. The evaluation focuses on steel usage across different truss configurations. The Figure 9 illustrates the comparison of different cross-sections.

In terms of steel usage, the rectangular cross-section consumes the most material at 16,600 Kg. This is may be due to it is design, which prioritizes stiffness and reduced deflection, requiring more steel. The circular cross-section uses the least material, at 10,200 Kg, as it is uniform shape minimizes steel requirements despite its lower bending resistance. The square cross-section, with a steel usage of 10,500 Kg, offers a balance, using slightly more steel than the circular design but significantly less than the rectangular design. These comparisons indicate that while the rectangular cross-section is the most effective in terms of reducing deflection, it does so at a higher material cost, whereas the circular and square designs prioritize material efficiency. The rectangular cross-section requires 38.6 % more steel than the circular cross-section and 36.7 % more than the square cross-section.

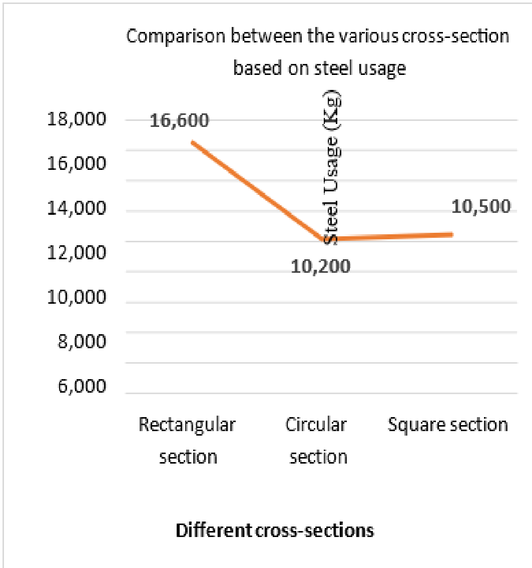

Fig.9 Comparison between the various cross-sections based on steel usage.

All the trusses, regardless of their type or section, exhibit a uniform yield strength of 240 MPa, indicating consistent material properties. While, the yield strength remains constant, the truss performance varies significantly in terms steel usage. This highlights that the yield strength alone does not determine overall performance; factors such as truss geometry and section shape play crucial roles.

3. **A Comparative Evaluations Based on Cost for Different Truss Type:**

This is a comparison of different truss type based on cost for footbridge shown in Figure 10. The cost analysis considers the highest and lowest cost required to footbridge to evaluate the impact of cost on the truss type and cross-section type. The cost considered here is for the material purpose for the footbridge. The average cost of steel is taken from market is 60 Rupees per kilogram.

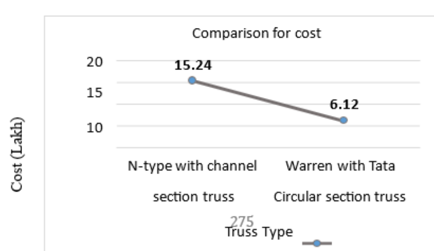

Fig.10 Comparison of different truss type based on cost.

The material cost for the N-type truss with channel section and the Warren truss with Tata circular section amounts to Rupees 15.24 lakh and 6.12 lakh, respectively. The cost difference between the N-type with channel section truss and Warren with Tata circular section truss is 9.12 lakh. In percentage terms, this represents a 59.84 % reduction in cost when opting for the Warren truss with Tata circular sections compared to the N-type with channel section. The cost of the N-type with channel section truss is approximately 2.49 times higher than the Warren with Tata circular sections.

Upon observation, it is evident that the Warren type is always superior to the N-type. Similarly, Tata materials are consistently superior to channel sections, and circular tubular shapes are always better than channel tubular shapes. All these parameters contribute significantly to minimizing the overall cost.

The observed cost difference can be explained by the inherent advantages of the Warren type, Tata materials, and circular tubular shapes. The Warren truss design efficiently distributes loads across its members, reducing material requirements and enhancing structural efficiency compared to the N-type. Tata materials are known for their higher strength and quality, which allow for better performance and reduced steel usage compared to channel section. Circular tubular shapes provide superior strength-to-weight ratios and resistance to buckling, making structure more effective than channel tubular section. These combined factors lead to significant cost savings while maintaining or improving the structural integrity of the footbridge.

CONCLUSION

This is an analysis and design of Warren and N-type trusses using Tata and channel section for a footbridge, considering various truss types, cross-sections, and materials. After identifying the model with the least steel usage, its analysis and design were further explored by considering different cross- sections to determine the most efficient cross-section. The comparison evaluates various truss types and cross-sections based on maximum deflection, steel usage, and economic efficiency.

The following are conclusions of this study,

Comparison of Different Trusses

- The Warren with Tata truss is 16.25 % more efficient than the N-type truss with a channel section in terms of deflection.
- In terms of steel usage, the Warren with Tata truss saves 8,800 Kg of steel compared

to the N-type truss with a channel section.

Comparison of Different Cross-Sections

- The rectangular cross-section truss is up to 25 % more efficient than the square cross-section truss in terms of deflection.
- In terms of steel usage, the circular and square cross- sections save up to 6,400 Kg of steel.
- The circular and square cross-sections show similar values in terms of deflection and steel usage.

Comparison based on cost

The cost of the N-type with channel section truss is approximately 2.49 times higher than the Warren with Tata circular sections.

Comparison based on material, cross-section, and type of truss

In terms of steel usage, the Warren type is better than the N- type, cold-formed is better than hot-rolled formed material, and the Tata section is better than the channel section.

This study highlights cost-effective and efficient design strategies for optimizing steel usage in structural applications.

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