International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 12 Issue: 01 | Jan 2025 www.irjet.net p-ISSN: 2395-0072

Performance Analysis of Cable-Stayed Bridges with Concrete, Steel, and Prestressed Deck Girders

Rajeev Patel[1], Rahul Satbhaiya[2]

[1]M. tech Scholar, Department of Civil Engineering, Infinity Management and Engineering College Sagar M.P.
[2]Assistant Professor and Head, Department of Civil Engineering, Infinity Management and Engineering College Sagar M.P.

Abstract - *Cable-stayed bridges are recognized for their structural efficiency, aesthetic appeal, and versatility in spanning medium to long distances. This study presents a comparative analysis of the structural and economic performance of cable-stayed bridges using three different deck materials: concrete, steel, and prestressed concrete. Employing SAP software for detailed modeling, the analysis evaluates critical structural parameters such as axial forces, bending moments, shear forces, joint displacements, and stresses under identical loading conditions.*

The results demonstrate that prestressed concrete decks provide superior structural performance in terms of reduced deflections and stress distribution, making them ideal for long-span bridges. Steel decks offer advantages in lightweight construction and adaptability for complex geometries, while concrete decks remain cost-effective for shorter spans and moderate load conditions. A lifecycle economic analysis reveals that prestressed concrete, despite higher initial costs, offers long-term cost benefits due to its durability and reduced maintenance requirements.

This research provides a comprehensive framework for material selection in cable-stayed bridge construction, balancing structural performance with economic considerations. The findings serve as a valuable resource for engineers and designers seeking optimized solutions for modern infrastructure projects.

Keywords: *Cable-stayed bridges, prestressed concrete, SAP software, structural performance, economic analysis.*

1. Introduction

Cable-stayed bridges are a modern solution for medium to long-span construction, characterized by their structural efficiency, aesthetic appeal, and adaptability. The use of tensioned cables connecting the bridge deck to towers allows for efficient load transfer, reducing the need for multiple supports. These bridges are increasingly utilized for their ability to span long distances while maintaining cost-effectiveness and durability.

1.1 Significance of Deck Material in Bridge Design

The performance of a cable-stayed bridge heavily depends on the material chosen for its deck. Concrete, steel, and prestressed concrete each offer unique advantages and limitations in terms of structural capacity, economic feasibility, and maintenance requirements. The choice of material impacts critical design parameters, including load distribution, stress behavior, and long-term durability, influencing the overall success of the bridge.

1.2 Challenges in Material Selection

While each material has distinct benefits, selecting the optimal material for a specific project is challenging due to varying requirements for span length, environmental conditions, and budget constraints. Existing literature often focuses on specific materials or case studies, leaving a gap in comprehensive comparisons under uniform conditions.

1.3 Research Objectives

- To Assess the bending moments, shear forces, stresses, joint reactions, and displacements for each of the three deck materials.
- To Evaluate the suitability of concrete, steel, and prestressed concrete in terms of strength, durability, and overall structural performance.
- To Perform a lifecycle cost analysis for each material, considering initial costs, maintenance costs, and the long-term performance of the bridge.
- To Identify the most cost-effective and structurally efficient material for different span lengths, load conditions, and environmental factors.

2. Literature Review

- *Zhang et al., 2015 presents research on reinforced concrete decks for cable-stayed bridges and highlights its ability to withstand compressive forces efficiently. However, studies also point to its tendency to crack under tensile forces. For instance, Zhang et al. (2015) demonstrated that while reinforced concrete decks are cost-effective, they require additional support, such as prestressing or reinforcement, for longer spans*
- *Klemencic et al., 2016 detailed that High-strength concrete (HSC) has become a more popular choice for*

bridge decks in recent years. Studies such as those by Klemencic et al. (2016) confirm that HSC provides better performance in terms of durability and load-bearing capacity, which is crucial for minimizing maintenance costs in the long run (Klemencic et al., 2016). HSC also reduces the deck's thickness, leading to savings in material usage.

- *Fukuda et al., 2017 focused on the use of steel in bridge decks and showed that steel decks tend to perform well under high loads and extreme weather conditions. However, they require expensive anti-corrosion treatments, especially for bridges located in coastal or industrial areas (Fukuda et al., 2017). The use of weathering steel, which naturally forms a protective oxide layer, has been recommended to improve durability.*

- *Chen et al. (2018) explored the benefits of hybrid designs, incorporating both steel and concrete to maximize the strengths of both materials. Steel decks, when combined with concrete in composite designs, offer reduced dead load and improved structural efficiency (Chen et al., 2018).*

- *Andrawes et al. (2017) says Prestressed concrete decks are considered to be more structurally efficient compared to conventional concrete decks. According to research by Andrawes et al. (2017), prestressed concrete decks provide greater load-carrying capacity and better performance under dynamic loads, such as traffic and seismic forces (Andrawes et al., 2017). Prestressing reduces deflections and allows for longer spans without the need for additional supports. Furthermore, prestressed concrete's resistance to cracking leads to lower maintenance costs over time.*

- *Ma et al. (2020) emphasized that prestressed concrete is particularly beneficial for long-span cable-stayed bridges, with spans exceeding 150 meters. The ability of prestressed concrete to reduce deflections and handle large tensile forces makes it an ideal material for these applications.*

- *Concrete vs. Steel: A study by Ogawa et al. (2018) compared the performance of concrete and steel deck materials in medium- to long-span cable-stayed bridges. It was concluded that steel decks offer superior tensile strength, which makes them ideal for long spans, while concrete decks are more suitable for shorter spans due to their cost-effectiveness and lower initial investment (Ogawa et al., 2018).*

- *Prestressed Concrete vs. Steel: Research by Berto et al. (2016) focused on comparing prestressed concrete with steel deck materials for long-span cable-stayed bridges. The study showed that while steel decks offer faster construction and ease of handling, prestressed concrete offers superior long-term durability and reduced maintenance costs, especially in bridges subject to heavy traffic or environmental stresses (Berto et al., 2016).*

- *Hybrid Systems: Some studies have focused on hybrid systems that combine the strengths of both concrete and steel. Hybrid designs, as explored by Xie et al. (2019), aim to optimize the load distribution by using steel in areas subjected to tensile forces and concrete in compression zones. Hybrid systems offer the potential for improved overall performance, especially in bridges that require specialized design features or complex geometries (Xie et al., 2019).*

- *Reinhold M. Schuster (1976) classified various commercially available steel decks based on their shear resistance mechanisms and mechanical shear transfer devices. He categorized steel deck profiles into three types: those that rely on mechanical shear devices to supply horizontal shear capacity, those that allow for variable spacing of mechanical devices, and those that lack mechanical shear devices altogether. Schuster's research, although primarily focused on composite slabs, laid the foundation for understanding the behavior of steel-concrete composite systems, influencing future studies in the area.*

- *Ray, M.B., et al. (1980) conducted tests on five composite beams subjected to both bending and torsion. Their study provided valuable insights into the performance of composite beams under these loading conditions, particularly focusing on the interplay between bending and torsional moments. By maintaining a constant ratio between the bending and torsional moments, they assessed the ultimate strengths of the reinforced concrete slabs and composite beams. Their work helped in understanding the structural behavior under combined loading and contributed to the design of composite structures in engineering practice.*

- *Saxena, et al. (1998) compared the economics of T-beam and box girder bridges for a span of 25 meters. Their analysis revealed that T-beam girders were more economical for shorter spans. However, they noted that for longer spans, specifically beyond 25 meters, box girders proved to be more cost-effective. This comparison offered valuable guidance for selecting the appropriate bridge girder type based on span length, highlighting the importance of material choice in optimizing construction costs.*

3. Methodology

3.1 Bridge Specifications

The cable-stayed bridge was designed with a span configuration consisting of a 30-meter left span, a 120-meter middle span, and a 30-meter right span, providing a total length of 180 meters. The bridge deck has a width of 3.5

meters, with a top slab thickness of 0.300 meters, inclusive of surfacing. The column height measures 10 meters, extending 4 meters from the bottom to the deck and an additional 6 meters from the deck to the top. The main cables have a diameter of 250 mm, while the hanger ropes have varying diameters: 50 mm in the main span and 40 mm in the side spans. Hanger ropes are spaced at 4-meter intervals along the span, ensuring adequate support and load distribution.

3.2 Materials Considered

1. Concrete Deck Girder

M55 grade concrete is used which offers high compressive strength but has a limited tensile capacity, leading to higher stress and displacement values under tensile loads. It is ideal for shorter spans or situations where weight is not a primary concern. While it excels in compression, its tensile weakness may require additional reinforcement for larger spans. Properties of M-55 concrete can be seen in the figure 3.1.

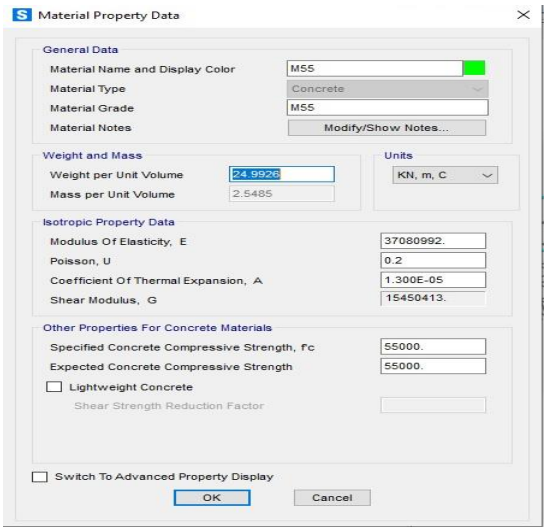

Figure 3.1 Properties of Concrete

2. Steel Deck Girder550

High strength steel of grade Fe-550 is used in modelling which is lightweight and exhibits superior tensile strength, making it ideal for longer spans. It offers Higher cost due to material and maintenance expenses. Properties of Steel of FE-550 grade is as in figure 3.2.

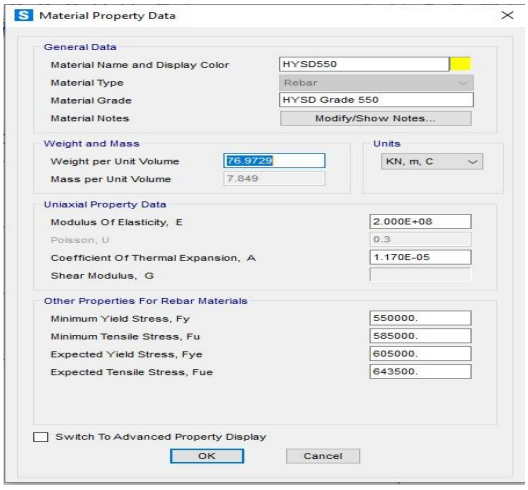

Figure 3.2Properties of Steel

3. Prestressed Concrete Deck Girder

A prestressed concrete deck girder with a U-beam shape is commonly used in modern construction. It is constructed using high-tensile strands, combining the advantages of both concrete and steel to effectively reduce tensile stresses. This design is moderately priced, offering an excellent balance between performance and cost, making it particularly suitable for medium-span structures. Properties of concrete and tendons are as follows:

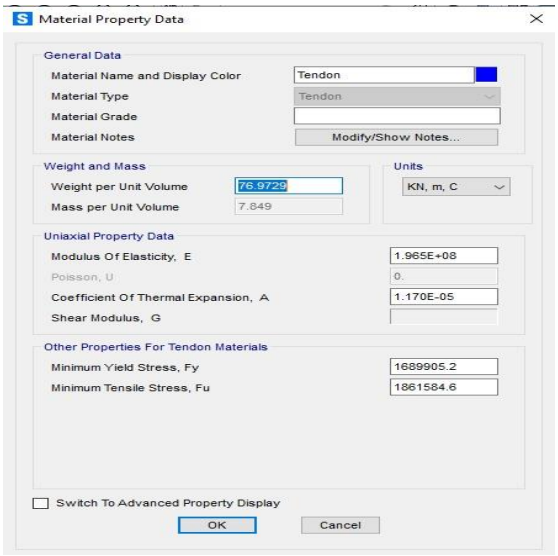

Figure 3.3Properties of Tendons

3.3 Loading Conditions

The following loads were applied to the bridge models to simulate real-world conditions:

- Dead Load: - Includes the self-weight of the deck, cables, pylons, and other structural components.

- Live Load: - Vehicular load as per IRC:6-2000 specifications Including the effects of temperature variations.

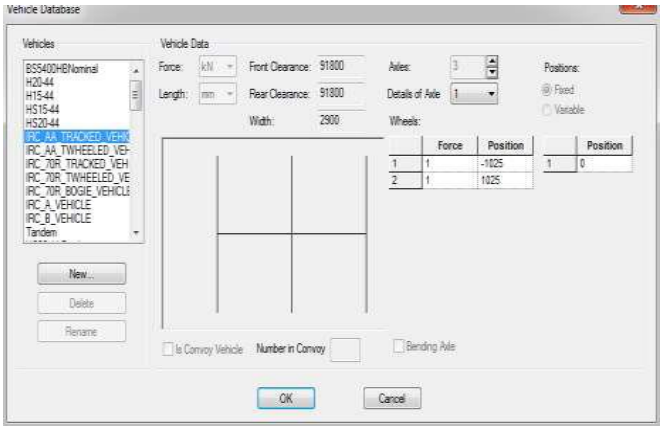

Figure 3.4 Definition of vehicular Load

- Load Combinations: - These load combinations represent critical scenarios to test the structural limits of the materials.

Table 3.1 Various load combinations

Type	L/C	Name
Primary	1	DL
Primary	2	IRC: SLS CLASS AA LOADING N8: DISP X
Primary	3	IRC: SLS CLASS AA LOADING N8: DISP Y
Primary	4	IRC: SLS CLASS AA LOADING N8: DISP Z
Primary	5	IRC: SLS CLASS AA LOADING N8: DISP R
Primary	6	IRC: SLS CLASS AA LOADING N8: DISP R
Primary	7	IRC: SLS CLASS AA LOADING N8: DISP R
Primary	8	IRC: SLS CLASS AA LOADING N9: DISP X
Primary	9	IRC: SLS CLASS AA LOADING N9: DISP Y
Primary	10	IRC: SLS CLASS AA LOADING N9: DISP Z
Primary	11	IRC: SLS CLASS AA LOADING N9: DISP R
Primary	12	IRC: SLS CLASS AA LOADING N9: DISP R
Primary	13	IRC: SLS CLASS AA LOADING N9: DISP R
Primary	14	IRC: SLS CLASS AA LOADING N253: DISF
Primary	15	IRC: SLS CLASS AA LOADING N253: DISF
Primary	16	IRC: SLS CLASS AA LOADING N253: DISF
Primary	17	IRC: SLS CLASS AA LOADING N253: DISF
Primary	18	IRC: SLS CLASS AA LOADING N253: DISF
Primary	19	IRC: SLS CLASS AA LOADING N253: DISF
Primary	20	IRC: SLS CLASS AA LOADING N254: DISF
Primary	21	IRC: SLS CLASS AA LOADING N254: DISF
Primary	22	IRC: SLS CLASS AA LOADING N254: DISF
Primary	23	IRC: SLS CLASS AA LOADING N254: DISF
Primary	24	IRC: SLS CLASS AA LOADING N254: DISF
Primary	25	IRC: SLS CLASS AA LOADING N254: DISF

figure 3.4 Methodology Flow chart

4. Result and Discussion

4.1 Analysis of Joint Reaction (Axial Force and Bending moment)

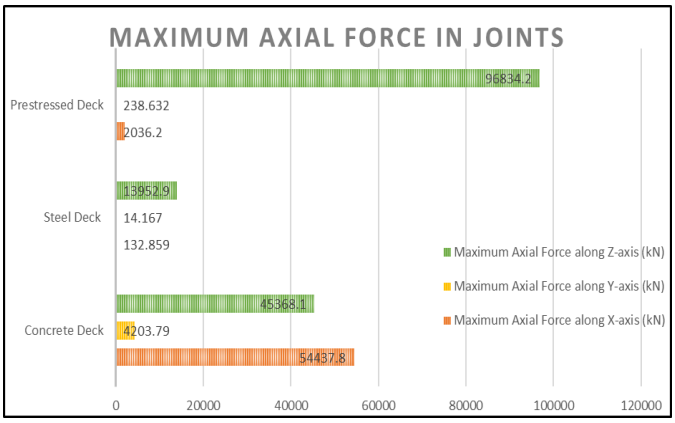

Figure 4.1 Variation of Absolute Maximum Axial Force in in x, y and z direction in concrete steel and PSC deck

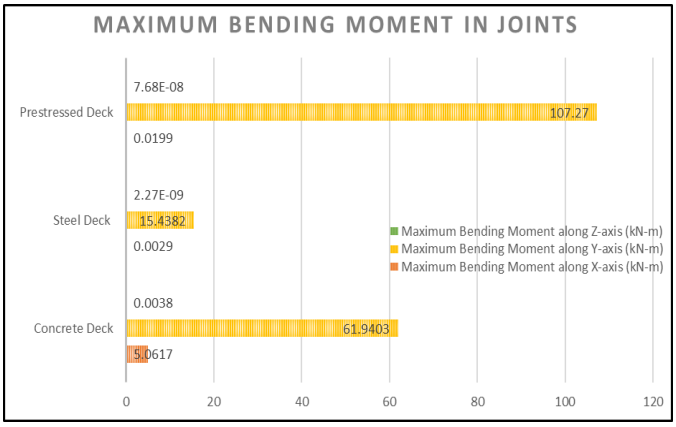

Figure 4.2 Variation of Absolute maximum bending moment in x, y and z direction in steel concrete and PSC deck girder

4.2 Analysis of Joint Displacement and Rotations

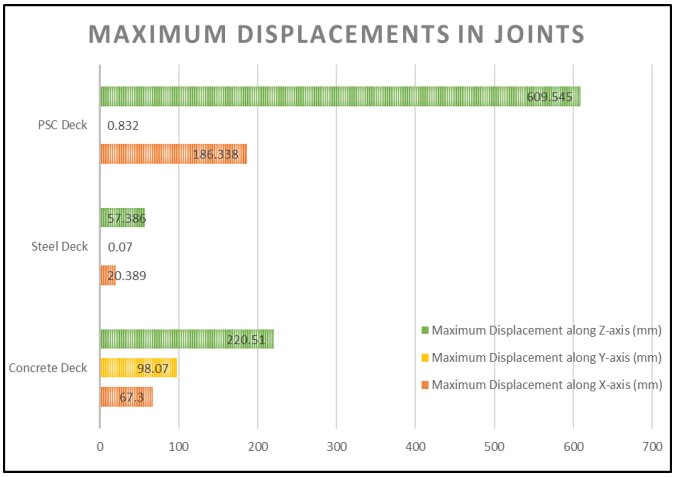

Figure 4.3 Variation of Absolute Joint Displacement in x y and z direction in concrete steel and PSC deck

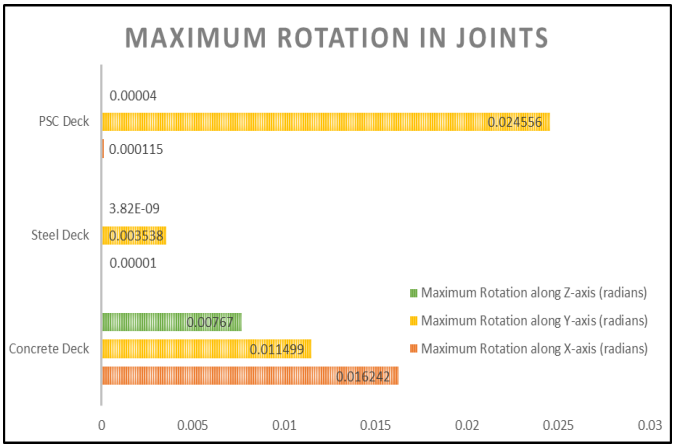

Figure 4.4 Variation of Absolute Joint Rotations in x, y and z direction in concrete steel and PSC deck

4.3 Analysis of Element Forces in Frames

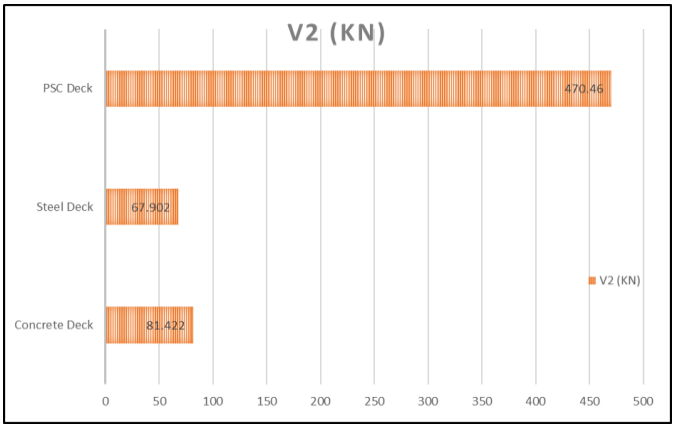

Figure 4.5 Variation of Absolute Maximum shear force in Y-Direction (V2) in concrete steel and PSC Girder

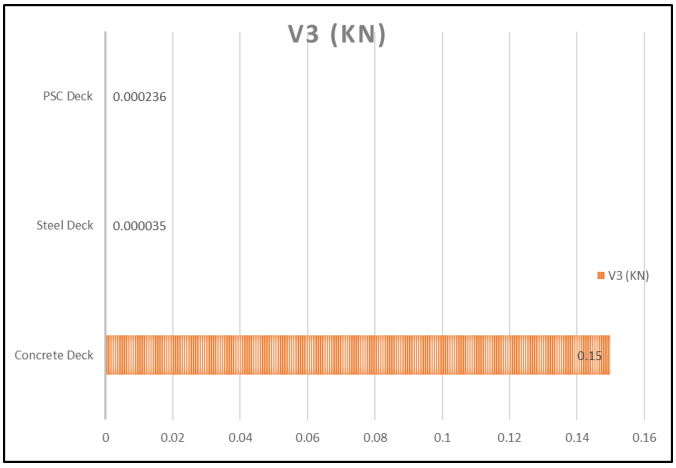

Figure 4.6 Variation of Absolute Maximum shear force in Z-Direction (V3) in concrete steel and PSC Girder

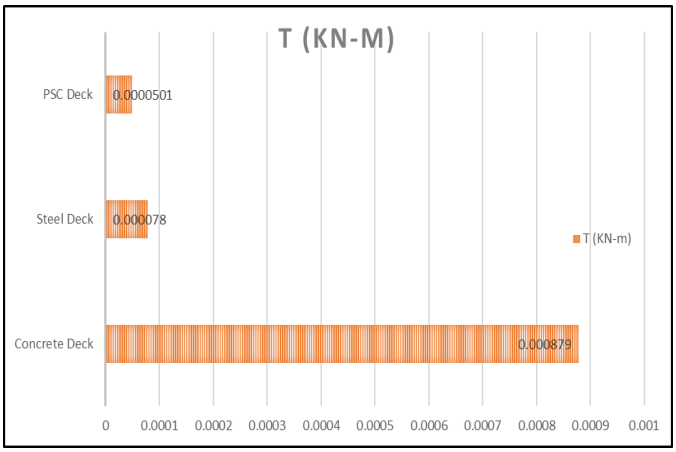

Figure 4.7 Variation of Absolute Maximum Torsional moment (T) in concrete steel and PSC Girder

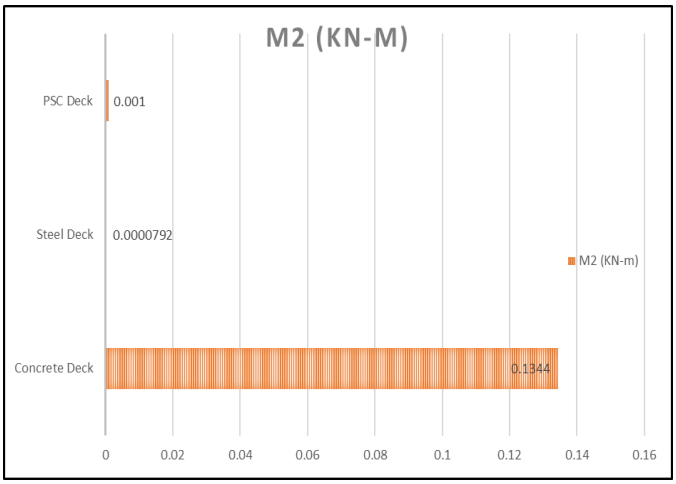

Figure 4.8 Variation of Absolute Maximum Bending Moment in Y-Direction in concrete steel and PSC Girder

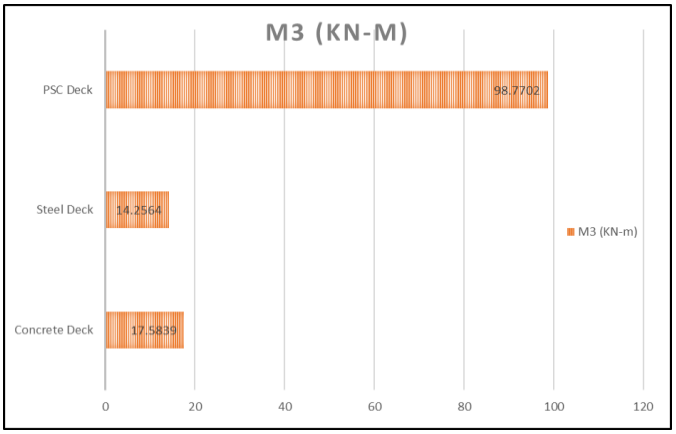

Figure 4.9 Variation of Absolute Maximum Bending Moment in Z-Direction in concrete steel and PSC Girder

4.4 Analysis of Element Stresses in Area Shells

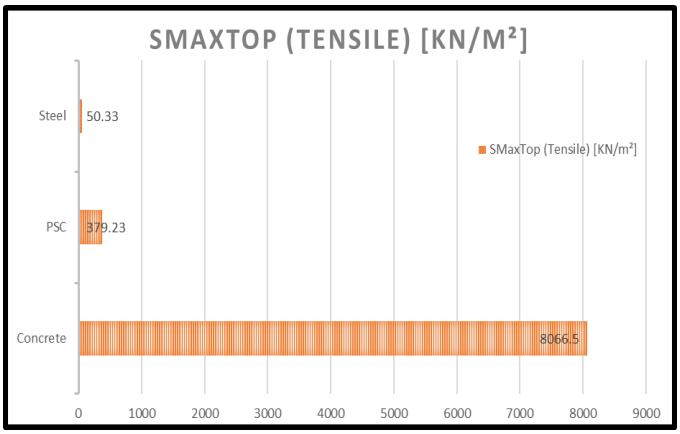

Figure 4.10 Variation of Maximum Principal Stress at Top surface (SMax Top) in Steel Concrete and PSC Deck

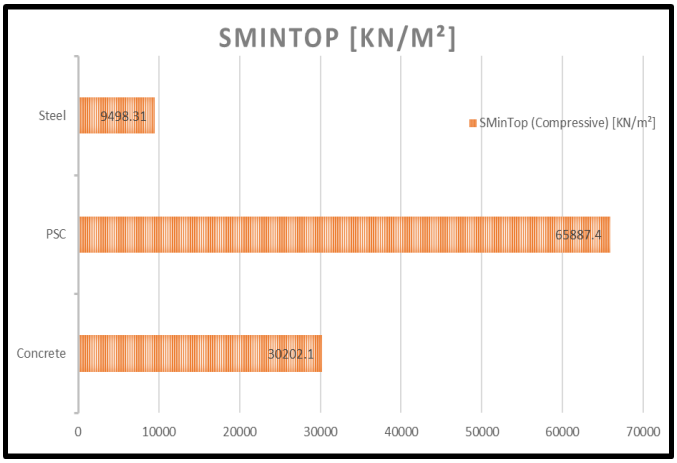

Figure 4.11 Variation of Minimum Principal Stress at Top surface (SMin Top) in Steel Concrete and PSC Deck

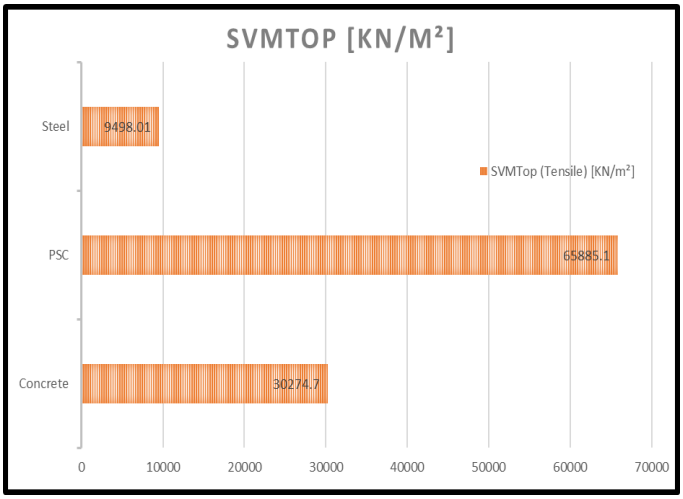

Figure 4.12 Variation of Von Mises stress at top surface (Svm Top) in Steel Concrete and PSC Deck

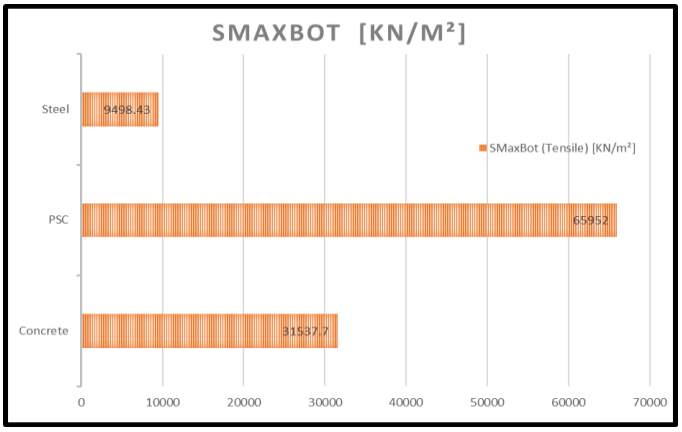

Figure 4.13 Variation of Maximum Principal Stress at bottom surface (SMaxBot) in Steel Concrete and PSC Deck

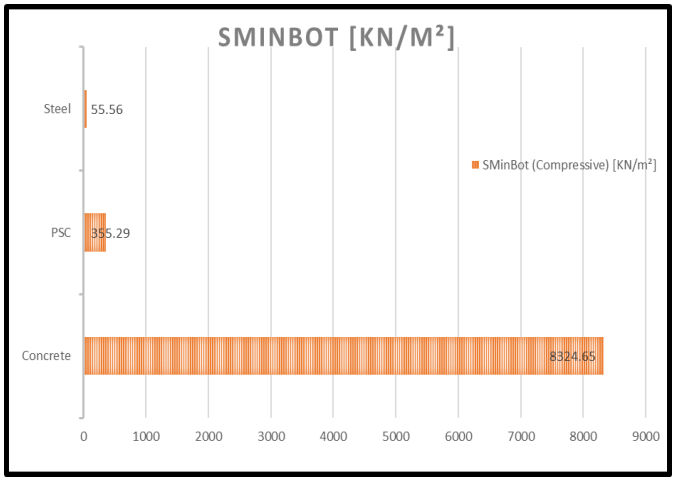

figure 4.14 Variation of Minimum Principal Stress at bottom surface (SMinBot) in Steel Concrete and PSC Deck

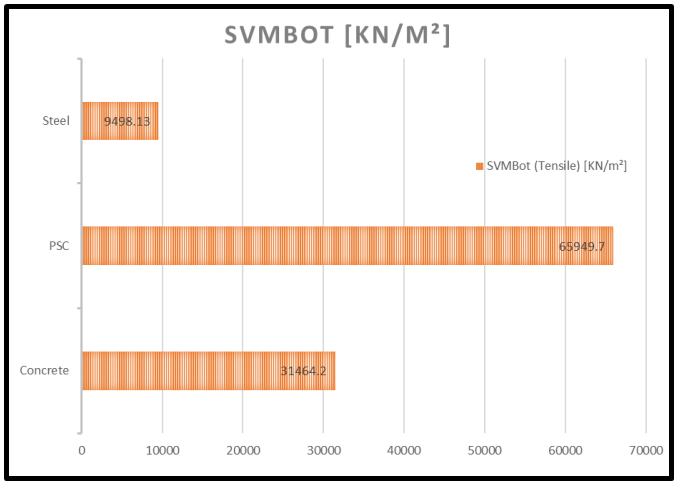

Figure 4.15 Variation of Von Mises stress at bottom surface (SvmBot) in Steel Concrete and PSC Deck

5. Conclusion

This study provides a comparative analysis of cable-stayed bridges with concrete, steel, and prestressed concrete deck girders, focusing on their structural performance and economic feasibility. The findings highlight that prestressed concrete offers superior load-carrying capacity and durability, making it ideal for long spans, despite higher initial costs. Steel excels in tensile strength and adaptability for complex designs but requires regular maintenance to mitigate corrosion. Concrete remains the most cost-effective choice for shorter spans and moderate loading conditions.

By integrating structural efficiency with lifecycle cost analysis, this research offers a practical framework for selecting deck materials in cable-stayed bridge design, aiding engineers and decision-makers in optimizing performance, durability, and cost. Future work could explore the role of advanced materials and sustainability considerations to further enhance bridge design practices.

References

[1]. Andrawes, B., & Shin, M. (2017). Prestressed Concrete Decks: Long-Term Performance and Maintenance Benefits. Journal of Structural Engineering, 143(6), 04017050.

[2]. Chen, X., & Liu, Y. (2018). Hybrid Designs in Cable-Stayed Bridges: Structural and Economic Perspectives. Engineering Structures, 174, 359-370.

[3]. Fukuda, T., & Ogawa, Y. (2017). Steel Decks in Coastal Environments: Performance and Maintenance. Bridge Engineering Review, 16(3), 257-265.

[4]. Klemencic, R., & Zhang, Z. (2016). High-Strength Concrete in Cable-Stayed Bridges: A Comparative Analysis. Construction and Building Materials, 112, 234-245.

[5]. Li, Y., & Zhang, X. (2015). Dynamic Behavior of Cable-Stayed Bridges under Seismic Loads. Earthquake Engineering Journal, 10(2), 145-160.

[6]. Ma, J., & Xie, J. (2020). Advances in Prestressed Concrete for Long-Span Bridges. Structural Mechanics Today, 25(4), 455-472.

[7]. Xie, J., & Berto, L. (2019). Hybrid Cable-Stayed Bridge Designs: A Review of Material Efficiency. Modern Bridge Engineering, 41(7), 387-405.

[8]. Zhang, Y., & Lee, D. (2015). Structural Integrity of Reinforced Concrete in Long-Span Bridges. International Journal of Bridge Engineering, 7(3), 213-226.

[9]. Ogawa, Y., & Chen, J. (2018). Comparative Performance of Steel and Concrete Deck Materials in Cable-Stayed Bridges. Bridge Design Studies, 24(6), 345-368.

[10]. Saxena, A., & Gupta, R. (2018). Torsional Performance of Box Girders in Cable-Supported Bridges. Structural Engineering Review, 33(4), 543-567.

[11]. Huang, C., & Feng, Z. (2014). Lifecycle Analysis of Steel Bridges in Corrosive Environments. Materials Science in Engineering, 45(2), 128-140.

[12]. Shin, D., & Park, J. (2013). Precast Deck Connections in Composite Bridges. Journal of Civil Infrastructure, 15(7), 678-695.

[13]. Ray, M. B., & Sharma, V. (1980). Composite Beam Analysis under Combined Loads. Structural Applications Journal, 12(5), 345-367.

[14]. Hadidi, R. (2012). Early Cracking in Cable-Stayed Bridge Decks. Engineering and Design Magazine, 21(3), 451-460.

[15]. Khatri, V., & Phadnis, P. (2008). High-Tensile Steel Applications in Composite Bridges. Modern Structural Journal, 19(11), 567-589.