

Comparative Structural Performance Assessment of a Continuous RCC Bridge and a Long-Span Cable-Stayed Bridge Using STAAD.Pro

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Abstract

Selecting between a conventional reinforced-cement-concrete (RCC) bridge and a cable-stayed bridge requires an evidence-based comparison of load-transfer mechanism, force demand, and dynamic behaviour rather than a judgment based on span length alone. This study presents a finite-element-based comparative assessment of two STAAD.Pro models: a continuous RCC deck-girder bridge and a long-span cable-stayed bridge, both verified at an overall longitudinal length of 541.8 m. The RCC model comprises seven spans of 72.914 m and one span of 31.5 m, a 250 mm deck slab over three girders spaced at 3.75 m centres, M30 concrete and Fe500 reinforcement. The cable-stayed model has a 285.6 m main span and two 128.1 m side spans, a 14.20 m deck carried by two H-frame pylons and eighty semi-harp stay cables. Structural response was extracted for bending moment, shear force, support reaction, member-end forces, and modal characteristics. The RCC bridge returned a maximum bending moment of 14,890 kN·m, maximum shear of 2,180 kN, total vertical reaction of 16,860 kN, and a first-mode frequency of 1.295 Hz (period 0.772 s). The cable-stayed bridge returned a maximum bending moment of 67,356.56 kN·m, maximum shear of 5,778.45 kN, a self-weight vertical reaction of approximately 181,000 kN, and a far more flexible first-mode frequency of 0.09 Hz (period 11.16 s). Raw percentage differences of 352.36%, 165.07%, and 973.55% respectively reflect the far greater length, deck area, and concentrated pylon load path of the cable-stayed system rather than structural inefficiency. The results confirm that the RCC form remains the rational choice for medium, multi-support crossings, while the cable-stayed form is structurally justified only where an unobstructed long span is the governing requirement.

Keywords

RCC Bridge; Cable-Stayed Bridge; STAAD.Pro; Finite Element Analysis; Comparative Structural Analysis; Modal Analysis; Bending Moment and Shear Force

1. Introduction

Bridges form the connective backbone of highway, rail, and urban transport networks, and the structural system selected for a crossing directly governs its span capability, construction cost, and long-term serviceability. For medium spans in the 20-75 m range, the continuous reinforced-cement-concrete (RCC) deck-girder form remains the dominant choice in Indian highway practice because of its familiar detailing, conventional reinforcement practice, and well-understood load path: wheel loads are distributed transversely through the deck slab into longitudinal girders, and thence into piers and foundations. Beyond roughly 200 m, however, the self-weight and flexural demand of an RCC section grow disproportionately with span, making the form increasingly uneconomical.

Cable-stayed bridges address this limitation by replacing intermediate vertical supports with a system of inclined, tensioned cables that transfer deck load directly into pylons in axial compression. This load path allows a cable-stayed structure to achieve unobstructed spans of several hundred metres - as in the configuration studied here, with a 285.6 m main span - while remaining stiffer and less material-intensive than a comparable suspension bridge. The trade-off is a structurally more complex, geometrically nonlinear system whose deck, pylons, and cables must be analysed together, and whose dynamic behaviour is markedly more flexible than a short-span girder bridge.

Finite-element software such as STAAD.Pro has become the standard tool for reconciling these two structural philosophies within a single, code-compliant modelling environment, offering beam, plate, and cable element libraries alongside IRC moving-load generation and modal/time-history analysis. Because RCC and cable-stayed bridges are typically studied and reported independently in the literature, there is limited work that places verified geometry, loading, and STAAD.Pro output for both systems side by side under a common, consistent set of units and load cases.

This study addresses that gap by presenting a single integrated STAAD.Pro-based comparison of a continuous RCC bridge and a long-span cable-stayed bridge, both modelled to an equal overall length of 541.8 m, so that the structural consequences of the two load-transfer mechanisms can be examined on a common length basis. The specific objectives are given in Section 4.

2. Literature Review

Hassan et al. [6] optimised the stay-cable cross-sections of a Quincy-Bayview-type cable-stayed bridge (285.6 m main span, 128.1 m side spans, H-shaped pylons, 80 stays) - the same reference geometry adopted for the cable-stayed model in the present study - using a finite-element/B-spline/genetic-algorithm approach, achieving roughly a 32% reduction in cable-steel weight relative to a conventional design. Their work establishes the baseline geometry used here but addresses design optimisation rather than a direct comparison against an RCC alternative.

Janbandhu [7] and Peshattiwar and Raut [17] independently used STAAD.Pro to study cable-stayed bridge behaviour, both concluding that the cable-anchored deck system substantially reduces girder depth relative to conventional construction, but neither work benchmarked the cable-stayed results against an RCC bridge of comparable overall length.

Sanjay et al. [20] compared four cable arrangements (fan, harp, radial, star) across three material properties using STAAD.Pro, evaluating shear force, bending moment, and displacement to identify the most efficient configuration; their work demonstrates that cable geometry materially changes force distribution but is confined to cable-stayed systems only.

Shukla and Singh [23] and Shaikh and Vyas [21] each used STAAD.Pro/SAP2000 to compare pylon shapes (H, A, Y, diamond, inverted-Y) under IRC and AASHTO loading. Shaikh and Vyas reported that a diamond pylon reduced base shear and displacement by approximately 22% and bending moment by 16-19% relative to a single-eyon configuration, underlining that pylon geometry is a first-order design variable - a parameter outside the scope of the present study but flagged here as a natural extension.

Kumar and Nallasivam [12] and Smirnova [24] both used detailed finite-element models (ANSYS and MIDAS Civil respectively) to extract modal frequencies for long-span cable-stayed bridges, reporting first-mode frequencies below 0.35 Hz - consistent in order of magnitude with the 0.09 Hz first mode obtained for the cable-stayed model in this study, and supporting the general finding that cable-stayed decks behave as long-period, flexible systems.

Zheng and Cui [29] compared a cable-stayed bridge against an arch and a cable-stayed-arch hybrid of equal span, finding maximum dead-load girder bending moments of 102,027 kN·m for the conventional cable-stayed form against 41,971-50,429 kN·m for the arch-based alternatives - evidence, consistent with the present findings, that a cable-stayed girder carries substantially higher force than a shorter-span, multiply-supported alternative, without that force level implying inferior performance.

Collectively, the reviewed literature demonstrates depth in cable arrangement, pylon geometry, dynamic response, and monitoring of cable-stayed bridges considered in isolation, and separately confirms mature design practice for continuous RCC girder bridges. What is comparatively rare is a single study reporting both systems' verified STAAD.Pro geometry, loading, and force/modal output under one consistent reporting framework and length basis - the gap this study addresses.

3. Research Gap

Existing STAAD.Pro-based studies on cable-stayed bridges [6], [7], [17], [20]-[24] focus on internal design variables - cable layout, pylon shape, material grade - evaluated within the cable-stayed system alone. Parallel studies on RCC deck-girder bridges are similarly self-contained. Cross-system comparative work that reports both bridge types' verified geometry, material properties, loading, and STAAD.Pro results under a common length basis and consistent units is limited, and where comparisons exist in the literature they typically hold span length fixed at a value convenient to one system rather than genuinely equal overall length.

This study is a comparative analytical investigation, not a novel analysis methodology: it does not propose a new modelling technique, optimisation algorithm, or design code provision. Its contribution is the integration of two independently verified STAAD.Pro models - an RCC bridge and a cable-stayed bridge, each 541.8 m in overall length - into one transparent comparative report, with unavailable parameters explicitly marked rather than estimated, so that raw structural differences can be correctly attributed to load-transfer mechanism rather than to inconsistent modelling assumptions.

4. Aim and Objectives

Aim: To develop an integrated STAAD.Pro-based comparison of the modelling characteristics and structural performance of a continuous RCC bridge and a long-span cable-stayed bridge using only verified project data.

- To compile verified geometry, material, section, loading, support, and analysis data for both bridge systems.
- To document the finite-element models of both systems with correctly referenced STAAD.Pro outputs.
- To compare common force, reaction, deformation, and modal parameters using consistent units.
- To compute transparent raw and percentage differences without estimating unavailable results.
- To identify the structural advantages, limitations, and appropriate application range of each bridge form.

5. Methodology

The study follows a comparative analytical design. Each bridge is first modelled and verified independently, after which only genuinely common, unit-consistent parameters are compared. The sequence proceeds from bridge geometry, through material and section properties, loading and load combinations, STAAD.Pro modelling and analysis, to result extraction, comparison, engineering interpretation, and conclusions.

The RCC bridge is idealised with four-noded shell elements for the deck slab and prismatic beam elements for longitudinal girders, cross girders, and pier shafts. The cable-stayed bridge is idealised with beam elements for the deck and pylons, connected to tension-carrying cable elements. Where a dimension or result is not explicitly available in the source model, it is recorded as "Not Provided" rather than assumed - a rule applied consistently through Sections 6-10.

6. Description of Bridge Models

6.1 Conventional RCC Bridge

The RCC STAAD.Pro model has a verified overall longitudinal length of 541.8 m, composed of seven spans of 72.914 m and one span of 31.5 m. The deck cross-section carries a 250 mm slab spanning transversely across three longitudinal girders spaced at 3.75 m centres, a 10.5 m carriageway, and 600 mm kerbs on each side, giving an overall deck width of 11.7 m. Continuity over the modelled intermediate supports produces both span sagging moments and support-region hogging moments.

6.2 Cable-Stayed Bridge

The cable-stayed model follows the Quincy-Bayview reference configuration [6]: an overall length of 541.8 m comprising a 285.6 m main span and two 128.1 m side spans. The deck is 14.20 m wide (12.2 m between cable planes), carries two traffic lanes, and consists of a 230 mm precast concrete slab on two steel main girders with transverse floor beams at 9.0 m spacing. Two H-frame pylons, each formed from two concrete legs joined by upper and lower struts and a 1.22 m thick lower web wall, anchor eighty semi-harp stay cables - forty per pylon, with forty cables supporting the main span and twenty supporting each side span.

6.3 Geometrical and Structural Parameters

Parameter	RCC Bridge	Cable-Stayed Bridge
Overall length	541.8 m	541.8 m
Span arrangement	7 x 72.914 m + 1 x 31.5 m	285.6 m main + 2 x 128.1 m side
Deck width	11.7 m (10.5 m carriageway)	14.20 m
Deck slab thickness	250 mm	230 mm (precast)
Primary supports	3 longitudinal girders, piers	2 H-frame pylons, 80 stay cables
Girder/cable spacing	3.75 m c/c (girders)	9.0 m (floor beams); 12.2 m (cable planes)
Concrete grade	M30	30 MPa (fck)
Reinforcement	Fe500	Steel main girders, E = 200,000 MPa

7. Loads and Load Combinations

7.1 Dead Load

Both models include structural self-weight. The RCC bridge additionally carries a 1.76 kN/m² wearing coat.

7.2 Live Load

The RCC bridge is analysed for IRC Class AA tracked and IRC Class A wheeled moving loads, generated at a one-metre increment. The cable-stayed bridge methodology identifies IRC Class A/AA live load as an applicable case, though a corresponding numerical live-load output is not available in the source model.

7.3 Other Applicable Loads

The RCC bridge carries a kerb load of 4.03 kN/m and a parapet load of 0.48 kN/m on each side, together with a defined seismic time-history case. The cable-stayed bridge methodology identifies wind loading (IS 875, Part 3), seismic response-spectrum loading, and cable pretension as applicable, though numerical results for these cases are Not Provided in the source model.

7.4 Load Combinations

The comparative force results in Section 9 are drawn from the self-weight load case for the cable-stayed bridge and from the reported governing static/moving-load and time-history envelope for the RCC bridge. Numerical comparison in this article is restricted strictly to load cases for which output actually exists in both models.

8. STAAD.Pro Modelling and Analysis

8.1 Modelling Approach

The RCC deck is modelled with four-noded shell elements integrated with a beam-element girder grid so that wheel loads distribute transversely before reaching the girders. The cable-stayed deck, pylons, and cables are modelled as a connected beam-and-cable-element system with fixed pylon bases.

8.2 Material Properties

Property	RCC Bridge	Cable-Stayed Bridge
Concrete grade / strength	M30	30 MPa
Long-term elastic modulus	21,720 MPa	22,360.68 MPa
Poisson's ratio (concrete)	0.17	0.20

Property	RCC Bridge	Cable-Stayed Bridge
Unit weight (concrete)	23.56 kN/m ³	25 kN/m ³
Reinforcement	Fe500	-
Structural steel modulus	-	200,000 MPa (Poisson 0.30)
Cable strength / pretension	-	Not Provided

8.3 Section Properties

The RCC deck retains a 250 mm slab on three girders at 3.75 m centres (Section 6.1). The cable-stayed deck retains a 230 mm precast slab on two steel main girders with 9.0 m floor-beam spacing (Section 6.2). Individual girder and pylon leg dimensions beyond those stated are not explicitly available and are not inferred.

8.4 Boundary Conditions

The RCC bridge is supported at modelled deck-end and intermediate pier locations, consistent with a continuous multi-span system. The cable-stayed bridge pylon bases are fixed, with the deck otherwise carried through cable tension - a fundamentally different support philosophy that concentrates reaction demand at fewer locations.

8.5 Cable Modelling

The eighty stay cables are represented as tension-carrying elements in a semi-harp arrangement. Cable pretension magnitude, cross-sectional area, and ultimate strength are not numerically available in the source model and are recorded as Not Provided; the analysis is linear-elastic, and no nonlinear cable-sag or staged-tensioning procedure is reported.

8.6 Analysis Procedure

Both models were solved for static gravity effects; the RCC model additionally includes a linear modal and time-history analysis, and the cable-stayed model includes a linear modal analysis. Results were extracted as beam-end forces/moments, support reactions, and the first six modal frequencies and periods for each model. A mesh-convergence check on the RCC deck (Section 9.7) confirmed the adequacy of the adopted shell discretisation.

9. Results and Discussion

9.1 Bending Moment Comparison

The RCC bridge developed a maximum bending moment of 14,890 kN·m at a critical intermediate support/pier region. The cable-stayed bridge developed a maximum reported member-end bending moment of 67,356.56 kN·m in a primary deck-pylon member.

9.2 Shear Force Comparison

The RCC bridge's maximum shear force was 2,180 kN at the outer girder near an intermediate support. The cable-stayed bridge's maximum reported shear was 5,778.45 kN near a principal pylon/support region.

9.3 Axial Force Comparison

Representative RCC beam-end axial forces under self-weight ranged from approximately -15.4 kN to -10.7 kN (Beams 2 and 3, Table 2). Cable-stayed axial force is concentrated in the pylon legs and cable elements, consistent with a cable-supported load path; a global maximum axial-force envelope is not separately tabulated in the source model beyond the member-end force table.

9.4 Deflection Comparison

The RCC bridge's maximum mid-span deflection was reported as 32.5 mm, within a stated 50 mm (L/800) serviceability limit. A corresponding deflection value for the cable-stayed deck is Not Provided.

9.5 Support Reaction Comparison

The RCC bridge's total vertical support reaction was 16,860 kN. The cable-stayed bridge's self-weight case produced a total vertical reaction of approximately 181,000 kN, verified as equal and opposite to the applied load, with only a negligible residual in the Mz moment component.

9.6 Member Force Comparison

Table 1. Representative RCC beam-end forces and moments (self-weight case)

Member / Node	Fx	Fy	Fz	Mx	My	Mz
Beam 2 - Node 2	-10.669	-488.885	-1.503	41.964	1.869	-666.923
Beam 2 - opp. end	-	513.625	-	-	-	-
Beam 3 - Node 2	-15.433	658.349	-	-	-	4,201.867
Beam 3 - Node 192	+15.433	-605.004	-	-	-	-1,648.000

Units: forces in kN, moments in kN·m.

These values are local member-end results for the self-weight case and are distinct from the global critical-force envelope reported in Sections 9.1-9.2.

9.7 Other Relevant Parameters - Modal Characteristics and Mesh Convergence

Table 2. Modal frequency and period comparison (first six modes)

Parameter	RCC Bridge	Cable-Stayed Bridge
First-mode frequency	1.295 Hz	0.09 Hz
First-mode period	0.772 s	11.16 s
Frequency range (Modes 1-6)	1.295-2.115 Hz	0.09-0.242 Hz
Period range (Modes 1-6)	0.772-0.473 s	11.16-4.136 s
Dominant Y-participation mode	Mode 1 (5.273%)	Mode 4 (14.355%)

Mesh-convergence testing on the RCC deck showed the maximum bending moment stabilising from a 1.40% change at 200 shell elements to a 0.29% change at 800 elements, confirming that the adopted mesh density adequately captures global flexural response.

10. Comparative Analysis

Table 3. Comparative structural response (RCC Bridge as reference)

Parameter	RCC	Cable-Stayed	Abs. Diff.	% Diff	Governing
Overall length	541.8 m	541.8 m	0	0%	Equal (by design)
Max bending moment	14,890 kN·m	67,356.56 kN·m	52,466.56 kN·m	352.36%	RCC lower demand
Max shear force	2,180 kN	5,778.45 kN	3,598.45 kN	165.07%	RCC lower demand
Total vertical reaction	16,860 kN	~181,000 kN	164,140 kN	973.55%	RCC lower demand
First-mode frequency	1.295 Hz	0.09 Hz	1.205 Hz	93.05%	RCC stiffer
First-mode period	0.772 s	11.16 s	10.388 s	1,345.85 %	RCC shorter period

Percentage Difference = | Cable-Stayed value - RCC value | / RCC value x 100.

On every raw force metric the RCC bridge shows the lower absolute demand - but this does not indicate that the RCC form is structurally superior. The two models differ fundamentally in span arrangement: the RCC bridge distributes 541.8 m of length across eight spans and multiple intermediate supports, whereas the cable-stayed bridge carries the same overall length as a single 285.6 m unsupported main span flanked by two 128.1 m side spans. The cable-stayed system must therefore collect and transfer a far larger tributary deck area through a small number of pylon and anchorage locations, which mechanically produces higher local force and reaction magnitudes. The governing engineering conclusion is not "RCC outperforms cable-stayed" but that raw force comparison must be read alongside span arrangement: the RCC bridge is the more force-efficient solution for a multiply-supported medium-span crossing, while the cable-stayed bridge is the only one of the two forms capable of achieving a 285.6 m clear span at all.

11. Structural Behaviour Discussion

The RCC bridge resists load through slab-and-girder flexure and shear, with tensile stress carried by Fe500 reinforcement after the concrete cracks in the tension zone. Its high first-mode frequency (1.295 Hz) and short period (0.772 s) reflect a stiff, short-span, multiply-restrained system. The cable-stayed bridge instead resolves deck load into cable tension, which is transferred to the pylons predominantly as axial compression; the pylon legs and lower web wall in turn carry this compression, together with bending induced by unbalanced cable pull, into the fixed foundations. This load path explains why the cable-stayed model's maximum bending moment and reaction are concentrated in primary deck-pylon members rather than distributed across many piers as in the RCC model.

The order-of-magnitude difference in first-mode period (0.772 s versus 11.16 s) is the clearest structural signature of the two load paths: a cable-supported deck behaves as a long-period, low-stiffness system because its lateral and vertical restraint depends on cable axial stiffness rather than rigid pier support, consistent with the flexible long-span behaviour reported for comparable cable-stayed configurations in the literature [12], [24]. The absence of a numerically reported deflection value for the cable-stayed deck means deflection-based serviceability cannot yet be compared directly, and is flagged as a priority item for the extended dataset recommended in Section 14.

12. Advantages and Limitations

Criterion	RCC Bridge	Cable-Stayed Bridge
Structural efficiency	Lower absolute force per span analysed	Higher force, but spans 285.6 m unsupported
Long-span capability	Limited (span-by-span, multiply supported)	High (single 285.6 m main span)

Criterion	RCC Bridge	Cable-Stayed Bridge
Construction complexity	Conventional, well-understood	High - cable tensioning, staged erection
Material requirement	Concrete- and reinforcement-intensive per span	Steel cables + concrete/steel hybrid deck
Deflection control	32.5 mm reported, within 50 mm limit	Not Provided - requires verification
Dynamic behaviour	Stiff, short-period (0.772 s)	Flexible, long-period (11.16 s)
Maintenance	Conventional; corrosion risk from deck cracking	Cable inspection/re-tensioning required
Cost	Not available in source data	Not available in source data
Aesthetics / clearance	Limited by multiple piers	High - unobstructed long span

Cost comparison is intentionally omitted because no cost data exists in the source project; it is listed in Section 14 as a recommended future addition.

13. Conclusions

- Both STAAD.Pro models were verified at an equal overall length of 541.8 m, allowing structural differences to be attributed to load-transfer mechanism rather than length mismatch.
- The RCC bridge, arranged as seven 72.914 m spans plus one 31.5 m span, produced a maximum bending moment of 14,890 kN·m, maximum shear of 2,180 kN, and total vertical reaction of 16,860 kN.
- The cable-stayed bridge, with a 285.6 m main span and two 128.1 m side spans, produced a maximum bending moment of 67,356.56 kN·m, maximum shear of 5,778.45 kN, and a self-weight vertical reaction of approximately 181,000 kN.
- Raw percentage differences of 352.36% (bending moment), 165.07% (shear), and 973.55% (reaction) are consequences of the cable-stayed bridge's much larger tributary deck area concentrated at fewer support points, not evidence of structural inefficiency.
- Modal results show the RCC bridge is a stiff, short-period system (first mode 1.295 Hz, 0.772 s) while the cable-stayed bridge is a flexible, long-period system (first mode 0.09 Hz, 11.16 s), consistent with the general dynamic character of cable-supported long-span structures reported in the literature.
- The RCC bridge's reported mid-span deflection of 32.5 mm remains within its stated 50 mm serviceability limit; an equivalent cable-stayed deflection value could not be obtained from the source data.
- Global load-reaction equilibrium was independently verified for the cable-stayed self-weight case, confirming model stability for that load case.
- The RCC bridge is the structurally and economically rational choice for a medium-span, multiply-supported crossing of this type, while the cable-stayed configuration is justified specifically where a single, unobstructed 285-290 m span is a governing requirement (navigation clearance, obstacle-free crossing).
- No single "optimum" system emerges from raw force comparison alone; bridge-type selection must weigh span requirement, foundation conditions, construction capability, and life-cycle maintenance alongside the force magnitudes reported here.
- From a sustainability and material-use standpoint, the cable-stayed system achieves a substantially longer unsupported span per unit of foundation footprint, which is significant where minimising in-water or in-ground disturbance is a design priority, although a formal material-quantity or embodied-carbon comparison was outside the scope of the available data.

14. Future Scope

- Extraction of a matching cable-stayed deflection value and complete wind/seismic numerical output to enable full serviceability comparison with the RCC model.
- Nonlinear cable analysis incorporating cable sag, pretension loss, and staged-construction equilibrium.
- Parametric study of cable-stayed main-span length and pylon shape to establish sensitivity of force and modal results to geometry.
- Response-spectrum and time-history seismic analysis of both bridges under identical input motion and damping assumptions.
- Normalisation of comparative results by deck area, structural mass, and applied load to derive genuine efficiency indices rather than raw percentage differences.
- Life-cycle cost, construction duration, and embodied-carbon comparison to complete the sustainability assessment.

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16. References

- [1] Abdelaziz, M. M., El-Ghazaly, H. A., & Gomaa, M. S. (2024). Numerical modeling for collapse analysis of cable-stayed bridges using the improved applied element method. *Iranian Journal of Science and Technology, Transactions of Civil Engineering*, 48, 2891-2904.
- [2] Fan, Q., Yang, Z., Yang, Z., Ma, C., Wang, J., & Liu, J. (2025). Optimization of cable forces of completed asymmetric hybrid-girder cable-stayed bridge with fish-shuttle-shaped single tower based on MIDAS Civil. *Atlantis Highlights in Engineering*, 37, 213-227.
- [3] Fawzy, A. M., El-Kashif, K. F., & Abdalla, H. A. (2022). Seismic performance of cable-stayed bridges with different geometric conditions. *Journal of Engineering and Applied Science*, 69, Article 82.
- [4] Galar, N., & Pahwa, S. (2025). Review - Seismic analysis of cable-stayed bridge under moving loads using IRC and AASHTO methods with different shapes of pylons. *International Journal of Advanced Scientific Research and Engineering Trends*, 9(7), 38-42.
- [5] Gao, L., Liu, Z., Dai, F., & Chen, J. (2024). Response analysis of a long-span cable-stayed bridge with ultra-high piles subjected to near-fault ground motions. *Advances in Bridge Engineering*, 5, Article 34.

- [6] Hassan, M. M., Annan, C. D., & Norlander, G. W. (2012). Optimal design of stay cables in cable-stayed bridges. *Proceedings of the 3rd International Structural Specialty Conference*, 2140-2149.
- [7] Janbandhu, N. K., & Gaikwad, S. (2018). Study and analysis of cable stayed bridges using STAAD.Pro. *Journal of Emerging Technologies and Innovative Research*, 5(9), 260-264.
- [8] Kallingal, S. S., & Singh, P. (2021). Dynamic analysis of cable-stayed bridge with various patterns of pylon. *E3S Web of Conferences*, 304, Article 02005.
- [9] Khan, A., & Akhtar, S. (2023). Structural analysis of cable-stayed bridge with different shape of pylon using STAAD.Pro. *International Journal of Science, Engineering and Technology*, 11(4), 1-9.
- [10] Klusáček, L., Nečas, R., Koláček, J., Bezručová, K., & Vašinová, M. (2026). Cable-stayed bridges, diagnostic survey of stays. *Civil and Environmental Engineering*, 22(1), 332-345.
- [11] Krishna, M. V., Reddy, Y. A., & Kishore, I. S. (2017). Analysis of segments across cable-stay bridge through simulation using STAAD.Pro model study. *International Journal of Civil Engineering and Technology*, 8(4), 1452-1461.
- [12] Kumar, S., & Nallasivam, K. (2024). Modal analysis of natural dynamic frequency for a double-deck cable-stayed steel bridge by using finite element method. *Discover Civil Engineering*, 1, Article 115.
- [13] Liu, Y., Wang, B., & Liu, X. (2023). Comprehensive assessment of cable-stayed bridge based on PageRank algorithm. *Advances in Bridge Engineering*, 4, Article 32.
- [14] Lu, N., Liu, Y., Cui, J., Xiao, X., Luo, Y., & Noori, M. (2024). A time-frequency-based data-driven approach for structural damage identification and its application to a cable-stayed bridge specimen. *Sensors*, 24(24), Article 8007.
- [15] Luo, C., Xin, J., Yang, J., Jiang, Y., Huang, L., & Zhou, J. (2025). Shear properties of jointed dual-pylon of the cable-stayed bridge with separated unequal-width decks under asymmetric load. *Advances in Bridge Engineering*, 6, Article 3.
- [16] Nie, Y., Zhang, Z., & Zeng, J. (2025). Wind-resistant performance comparison between a long-span CFRP and a steel cable-stayed bridge. *Advances in Bridge Engineering*, 6, Article 32.
- [17] Peshattiwar, A. R., & Raut, S. (2019). Comparison and study of cable-stayed bridges using STAAD.Pro. *International Journal of Research in Engineering, Science and Management*, 2(7), 41-45.
- [18] Radhika, & Choudhari, P. (2023). Design and dynamic analysis of cable-stayed bridge in STAAD.Pro. *International Journal of Innovations in Engineering and Science*, 8(9), 30-37.
- [19] Reddy, G. M. K., Akash, C. L., Dhtari, D., Rahul, G., & Kaveri, G. (2025). Analysis, design and modelling of cable stayed bridge using BIM and integrating with AR. *International Journal of Research Publication and Reviews*, 6(4), 4298-4305.

- [20] Sanjay, D., Ashwini, L. K., Alur, S. L., Sanjay, N., & Sunil, M. (2020). Analysis of different types of cable arrangement in cable stayed bridge with different material properties using STAAD.Pro. *International Journal of Engineering Research & Technology*, 9(5), 1215-1218.
- [21] Shaikh, S., & Vyas, J. N. (2024). Seismic analysis of cable stayed bridge under moving loads using IRC and AASHTO methods with different shapes of pylons. *International Journal for Scientific Research & Development*, 12(9), 111-120.
- [22] Shen, K., Jiang, Z., Zhao, J., Zhou, Z., Wu, Q., Qiang, Q., & Wang, H. (2025). Fire-resistance design and experimental research for the stay cables of super-long span cable-stayed bridge. *Advances in Bridge Engineering*, 6, Article 4.
- [23] Shukla, D., & Singh, H. P. (2023). Seismic analysis of cable stayed bridge with different design of tower using STAAD.Pro. *International Journal of Scientific Research & Engineering Trends*, 9(4), 1255-1260.
- [24] Smirnova, I. (2025). Dynamic analysis of cable-stayed bridges using MIDAS Civil software. *International Journal of Surveying and Structural Engineering*, 6(1), 37-42.
- [25] Teichgraeber, M. (2025). Reliability and durability assessment of bridge stay cables. *Archives of Civil and Mechanical Engineering*, 25, Article 29.
- [26] Wang, W., Song, X., Yu, Y., Chang, H., Yu, W., & Xiong, W. (2024). Extraction and evaluation of cable forces of a cable-stayed bridge based on amplitude and phase estimation method. *Advances in Bridge Engineering*, 5, Article 15.
- [27] Xia, Z., Shu, J., Ding, W., Gao, Y., Duan, Y., Debono, C. J., Prakash, V., Seychell, D., & Borg, R. P. (2025). Complete-coverage path planning for surface inspection of cable-stayed bridge tower based on building information models and climbing robots. *Computer-Aided Civil and Infrastructure Engineering*, 40(25), 4149-4171.
- [28] Yi, J., & Yu, D. (2021). Longitudinal damage of cable-stayed bridges subjected to near-fault ground motion pulses. *Advances in Bridge Engineering*, 2, Article 12.
- [29] Zheng, X., & Cui, Y. (2022). Analysis of static performance of cable-stayed arch cooperative bridge without back cable. *Archives of Civil Engineering*, 68(2), 531-548.
- [30] Zhu, B., Zhang, C., Zhang, Z., Luo, L., & Bai, X. (2023). Dynamic analysis of suspension-type monorail long-span cable-stayed bridge in a wind-vehicle-bridge system. *Urban Rail Transit*, 9(1), 19-30.