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A Finite Element Study on Structural Performance of Reinforced Concrete, Steel, and Prestressed Concrete Deck Girders in Cable-Stayed Bridges

Hari Om Dhar Badgaiyan[1], Hariram Sahu[2]
M.Tech. Scholar, Structural Engineering, Department of Civil Engineering, School of Engineering, Eklavya University, Damoh (M.P.), India[1]
Assistant Professor, Department of Civil Engineering, School of Engineering, Eklavya University, Damoh (M.P.), India[2]

Abstract — Cable-stayed bridges are widely adopted for medium- to long-span crossings owing to their structural efficiency and aesthetic appeal, and the deck girder material strongly influences their stiffness, weight and overall performance. This paper presents a comparative finite element evaluation of a representative 180 m (30 m + 120 m + 30 m) cable-stayed bridge with three deck girder alternatives — reinforced concrete (RC), structural steel, and prestressed concrete (PSC) — modelled in SAP2000 under identical geometry, cable arrangement, support conditions and IRC Class AA loading. Linear static analysis was carried out with the deck material as the sole variable across the three models. Structural response was compared in terms of joint reactions, joint displacements and rotations, internal frame forces, and area-shell stresses. Results show that the steel deck consistently produced the lowest reactions, displacements, internal forces and stresses owing to its high strength-to-weight ratio; the RC deck exhibited intermediate global response but the highest tensile stress; and the PSC deck attracted the largest internal forces and vertical reactions yet achieved the lowest tensile stress because of prestressing. An indicative life-cycle cost comparison further shows that RC offers the lowest first cost, steel the highest, and PSC the most favourable long-term economy. The findings provide practical, results-based guidance for deck-material selection in cable-stayed bridge design.

Keywords— Cable-stayed bridge; finite element analysis; SAP2000; reinforced concrete deck; structural steel deck; prestressed concrete deck; joint reaction; shell stress; IRC loading.

I. INTRODUCTION

Bridges are among the most significant achievements of civil engineering, enabling the movement of people and goods across natural and artificial obstacles. Among the various bridge typologies, cable-stayed bridges have emerged as one of the most structurally efficient forms for medium- to long-span crossings, typically spanning 200 m to 1,100 m, because the deck is directly supported by a series of inclined stay cables connected to one or more towers. This direct load-transfer mechanism increases stiffness, reduces bending demand on the deck, and permits longer spans with relatively slender members compared with conventional girder bridges.

A cable-stayed bridge system comprises four principal components — the deck, stay cables, towers (pylons) and foundations — that act together to resist applied loads. Unlike a suspension bridge, where the deck hangs from vertical hangers attached to a continuous main cable, each stay cable in a cable-stayed bridge transmits deck load directly to the tower; under external loading the cables resist tension while the towers carry the resulting compression, so bending demand on the deck is substantially reduced. Because the deck is continuously supported at closely spaced cable-anchorage points rather than at a few widely spaced piers, its structural response — and hence the influence of its material — is highly sensitive to self-weight, stiffness and stress distribution, which is the central motivation for the present comparative investigation.

Modern cable-stayed bridge construction has been made possible by parallel advances in high-strength materials, precision cable manufacture, and computer-based structural analysis. Early cable-stayed bridges of the mid-twentieth century relied on a limited number of thick cables and comparatively stiff decks; contemporary practice instead favours multi-cable, fan- or harp-type arrangements with closely spaced stays, which reduce local bending in the deck and allow slender, materially efficient girder sections. This evolution has, in turn, widened the practical choice of deck material available to designers — from conventional reinforced concrete through structural steel to prestressed concrete — making a rigorous, results-based comparison of these alternatives increasingly relevant to current practice, including the growing number of cable-stayed bridge projects in India.
The deck girder is one of the most important components of a cable-stayed bridge: its material governs the self-weight, stiffness, cable forces, tower reactions and overall serviceability of the structure. Reinforced concrete (RC),

structural steel, and prestressed concrete (PSC) are the three deck systems most commonly adopted in practice, each with distinct mechanical and construction characteristics, as summarised qualitatively in Table II. However, most existing studies examine a single deck material, a specific case-study bridge, or a comparison between only two of the three alternatives, so a consistent, results-based comparison of all three systems under identical geometry, loading and analysis procedures remains limited. This uncertainty at the preliminary design stage often leads designers to rely on regional practice or cost alone rather than a comprehensive structural evaluation.

Table 1. Qualitative Comparison of Deck Materials for Cable-Stayed Bridges

Attribute	RC Deck	Steel Deck	PSC Deck
Self-weight	High	Low	Moderate
Tensile capacity	Low (needs reinforcement)	High	High (via tendons)
Initial material cost	Low	High	Moderate
Construction speed	Moderate	Fast (prefabricated)	Moderate
Durability / maintenance	Moderate; crack-prone	Corrosion-sensitive	High; crack-resistant
Damping characteristics	Good	Comparatively low	Good
Typical span suitability	Short-to-moderate	Long, fast erection	Medium-to-long

The rapid expansion of highway and expressway networks, together with the growing number of cable-stayed bridge projects under national infrastructure programmes, has made deck-material selection an increasingly important design decision, since the deck governs self-weight, stiffness, cable forces, tower reactions, foundation loads and vibration characteristics for the bridge system as a whole. The present study addresses the identified research gap through a controlled finite element investigation. The specific objectives are: (i) to develop three SAP2000 models of a representative cable-stayed bridge with RC, steel and PSC deck girders while keeping geometry, cable arrangement and support conditions identical; (ii) to compare joint reactions, displacements, rotations, internal member forces and shell stresses among the three deck systems under IRC Class AA loading; and (iii) to combine the structural findings with an indicative economic and life-cycle evaluation so as to provide practical, results-based guidance for deck-material selection in cable-stayed bridge design.

The significance of this comparison extends beyond the specific bridge configuration analysed. For practising engineers, a systematic, results-based comparison of RC, steel and PSC decks under common performance parameters assists in selecting suitable deck systems based on structural requirements, construction feasibility, durability and economic considerations rather than on regional convention or prior experience alone. For structural engineering research, comparative investigations involving all three deck materials under consistent modelling and loading conditions remain relatively limited in the published literature, which more commonly examines individual materials or specific case-study bridges; the present study, and the finite element framework it demonstrates, therefore also provides a useful reference for further work on bridge analysis, material selection and structural optimisation. Finally, since deck-material choice directly affects material consumption, construction duration and long-term maintenance demand, a rigorous structural-cum-economic comparison such as this one supports more sustainable and cost-effective infrastructure decisions. The remainder of this paper is organised as follows. Section II reviews prior comparative and material-specific studies on cable-stayed bridge decks. Section III describes the bridge geometry, loading and finite element modelling approach common to all three models. Section IV presents and discusses the comparative results for joint reactions, displacements, element forces and shell stresses. Section V extends the discussion to an indicative economic and life-cycle evaluation, and Section VI concludes the paper with recommendations and directions for future work.

II. LITERATURE REVIEW

Prior research on cable-stayed bridge decks broadly confirms that RC decks are economical and easy to construct but are prone to cracking and larger self-weight-induced deflection, particularly for longer spans [1], [8], while structural steel decks offer a superior strength-to-weight ratio and reduced dead load at the expense of corrosion-protection and maintenance costs [3], [9]. Prestressing has been shown to improve stiffness, control cracking and enhance long-term durability, making PSC decks attractive for medium- and long-span applications [2], [4], [5]. Finite element analysis, particularly using platforms such as SAP2000, is now the preferred tool for capturing deck–cable–tower interaction under static, construction-stage and dynamic loading [7], [13]. Economic studies further emphasise that life-cycle maintenance and durability, not merely initial cost, should govern material selection [6].

Direct comparative studies remain limited even in pairwise form. Ogawa et al. [14] compared RC and steel decks and reported that steel reduced overall dead load, cable tension and tower reactions and permitted longer unsupported cantilever segments during erection, but required more extensive corrosion protection; RC decks offered higher inherent damping and lower initial cost but produced larger internal forces in the cables and towers for very long spans. Berto et al. [3] compared PSC and steel decks and found that, while steel remained lighter and faster to erect, PSC provided superior long-term serviceability through crack control. Neither study, however, evaluated RC, steel and PSC together under one identical bridge geometry and loading scheme.

A parallel body of work has explored steel–concrete composite and hybrid decks, in which steel resists tension and concrete resists compression to improve efficiency and reduce weight. Xie and Zhou [11] reported that composite decks achieved lower dead load than RC while offering greater stiffness than conventional steel decks, with improved fatigue resistance and a more favourable distribution of internal forces between the deck and stay cables, and Chen and Liu [10] similarly found that hybrid configurations can reduce both construction time and maintenance cost while retaining excellent load-carrying capacity. These composite alternatives are, however, constrained by more complex detailing and quality-control requirements, and — as with the pairwise studies above — are typically benchmarked against only one conventional deck material rather than against RC, steel and PSC simultaneously. Within the Indian context specifically, cable-stayed bridge construction has grown steadily alongside expanding expressway and river-crossing infrastructure, yet published comparative structural studies benchmarked against IRC loading provisions remain comparatively few, with most Indian case studies again focusing on a single completed bridge and its as-built deck material rather than on a controlled, multi-material comparison. Despite the contributions summarised above, comprehensive comparisons involving RC, steel and PSC decks under identical bridge geometry, IRC loading and a common finite element framework remain scarce, and very few Indian-context studies combine structural performance with life-cycle economic evaluation. This paper responds directly to this gap by presenting a results-based, three-way comparison of deck materials for a representative cable-stayed bridge.

III. METHODOLOGY

1. Bridge Geometry and Deck Materials

A representative three-span, twin-tower cable-stayed bridge was adopted as the reference structure, comprising a 30 m left side span, a 120 m main span and a 30 m right side span (total length 180 m). The deck was 3.5 m wide with a 300 mm slab thickness including wearing surface; towers were 10 m tall (4 m below deck, 6 m above); main stay cables were 250 mm in diameter, with hanger ropes of 50 mm (main span) and 40 mm (side spans) diameter spaced at 4 m. Bridge geometry, span arrangement, tower configuration, cable layout and support conditions were held identical across all three finite element models so that any difference in structural response could be attributed solely to the deck material. The key geometric and material parameters are summarised in Table II.

Table 2. Principal Geometric Parameters and Material Properties Adopted for the Three Deck Models

Parameter	**Value / Property**
Span arrangement (side + main + side)	30 m + 120 m + 30 m (total 180 m)
Deck width / slab thickness	3.5 m / 0.300 m (incl. surfacing)
Tower height (below / above deck)	4 m / 6 m (total 10 m)
Main cable diameter	250 mm
Hanger rope diameter (main / side span)	50 mm / 40 mm; spacing 4 m
RC deck concrete grade	M55: unit wt. 24.99 kN/m³, E = 3.708×10^7 kN/m², ν = 0.20
Steel deck grade	Fe-550: unit wt. 76.97 kN/m³, E = 2.0×10^8 kN/m², fy = 550 MPa, fu = 585 MPa
PSC deck	M55 concrete + prestressing tendon: E = 1.965×10^8 kN/m², fy = 1689.9 MPa, fu = 1861.6 MPa

Table 3. Structure of the Applied Load Combination Scheme (25 Load Cases per Deck Model)

Type	Load Case No.	Description
Primary	1	Dead Load (DL)
Primary	2–7	IRC SLS Class AA Loading, Vehicle Position 1
Primary	8–13	IRC SLS Class AA Loading, Vehicle Position 2
Primary	14–19	IRC SLS Class AA Loading, Vehicle Position 3
Primary	20–25	IRC SLS Class AA Loading, Vehicle Position 4

2. Loading and Load Combinations

Identical loading was applied to all three bridge models in accordance with IRC:6–2000. The load comprised (i) dead load, computed automatically from the assigned material densities and therefore differing slightly among the three models because of differing deck self-weight; (ii) IRC Class AA vehicular live load (tracked and wheeled configurations), applied through moving-load analysis at four critical longitudinal vehicle positions; and (iii) a uniform temperature load reflecting the differing thermal-expansion coefficients of concrete and steel. As Table III, twenty-five serviceability load cases — one dead-load case and six load cases at each of the four IRC Class AA vehicle positions — were analysed for every deck model, ensuring that the comparison among materials was carried out under exactly the same loading scheme.

3. Finite Element Modelling Approach

Three-dimensional models were developed in SAP2000. The RC and PSC decks were modelled using shell (area) elements to capture slab stress distribution, while the steel deck combined shell and frame elements, with mesh density chosen to balance accuracy of stress and deflection prediction against computational effort. Stay cables were modelled with cable elements incorporating sag-dependent nonlinear stiffness and initial pretension assigned to establish the equilibrium configuration before external loads were applied; towers were modelled as three-dimensional frame elements with cable-anchorage points at the designated locations. Cable arrangement, spacing, inclination, tower geometry and material properties were kept identical in all three models so that the deck material remained the only variable influencing the comparative structural response. Tower bases were fixed against all translations and rotations, while deck-end supports permitted longitudinal movement due to temperature while restraining vertical and transverse displacement.

Each deck model was additionally analysed in two construction conditions: a fully supported condition, representing the completed structure with the entire stay-cable system installed and engaged, and an unsupported, free-cantilever condition representing an intermediate erection stage in which only a portion of the deck and its corresponding stay cables are active. The free-cantilever check relies primarily on the flexural stiffness of the partially completed deck rather than the full cable system and therefore subjects the deck to a different, generally more severe, internal-force pattern than the service condition; confirming stable, code-consistent behaviour at this stage, in addition to the fully supported service condition analysed below, provided further confidence that the modelling approach captured realistic staged behaviour for all three deck materials.

4. Model Validation

Before the comparative analysis was carried out, the reliability of each finite element model was verified. The self-weight computed automatically by SAP2000 was checked against hand calculations based on the assigned material densities and sectional properties, and the resulting support reactions were found to be in close agreement with the calculated dead load. The distribution of axial forces, shear forces, bending moments and deck deflections was consistent with the expected behaviour of a continuous cable-stayed system, in which the stay cables reduce deck bending moment and transfer load efficiently to the towers; cable tensions increased appropriately with tributary load and cable inclination, and the deformed shape of the bridge under dead and live load remained smooth and free of numerical instability. This agreement with expected code-based behaviour confirmed that the three models provided a reliable basis for the comparative evaluation presented in Section IV.

IV. RESULTS AND DISCUSSION

1. Joint Reactions

Joint reactions transferred from the superstructure to the towers and abutments were extracted for all three deck models; the absolute maximum values are summarised in Table IV and Fig. 1.

Table 4. Variation of Absolute Maximum Joint Reactions Across the Three Deck Materials

Material	Max Axial X (kN)	Max Axial Y (kN)	Max Axial Z (kN)	Max BM-Y (kN-m)
Concrete	51443.7	3972.58	42872.9	58.53
Steel	141.5	15.09	14859.8	16.44
PSC	1985.3 (C)	232.67	94413.3	104.59

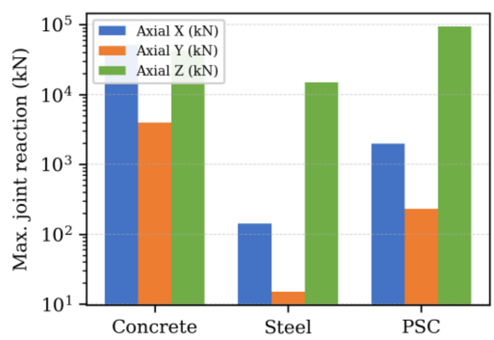

Fig. 1. Comparison of maximum joint axial reaction (X, Y, Z) by deck material (log scale).

Table 5. Representative Joint Reactions at Selected Support and Mid-Span Locations

Material	Joint	Axial X (kN)	Axial Y (kN)	Axial Z (kN)	BM-Y (kN-m)
Concrete	1	51443.71	3972.58	42871.53	0
Concrete	145	33.63	2.02	35539.76	58.53
Steel	1	141.50	15.09	14859.88	0
Steel	145	10.08	−0.0018	12323.91	16.44
PSC	1	−187.34	−40.94	94411.85	0
PSC	145	63.98	−0.012	78300.35	104.34

The RC deck developed the highest horizontal axial reactions (51,443.7 kN in X and 3,972.58 kN in Y), a direct consequence of its greater self-weight. The steel deck recorded the lowest reactions in every direction, reflecting the advantage of its high strength-to-weight ratio in minimising the load transmitted to the substructure. The PSC deck showed a different pattern: although its horizontal reaction in X was comparatively small and compressive (−1,985.3 kN, characteristic of prestressing action), its maximum vertical reaction of 94,413.3 kN was about 2.2 times that of the RC deck and 6.4 times that of the steel deck, and it also developed the largest support bending moment (104.59 kN-m). Table V confirms this trend at the individual joint level: joint 145, located near mid-span, shows the PSC model carrying roughly 2.2 times the vertical load of the RC model and 6.3 times that of the steel model at the same location, indicating that the higher stiffness of the PSC deck enables more efficient transfer of vertical load through the stay-cable system rather than signalling an adverse response.

2. Joint Displacements and Rotations

Global deformation behaviour was assessed through the maximum joint displacements and rotations recorded for each deck model, summarised in Table VI and Fig. 2.

Table 6. Variation of Absolute Maximum Joint Displacement and Rotation Across the Three Deck Materials

Material	Max Disp. X (mm)	Max Disp. Z (mm)	Max Rot. Y (rad)
Concrete	63.6	208.38	0.010867
Steel	21.71	61.12	0.003768
PSC	181.68	594.31	0.023942

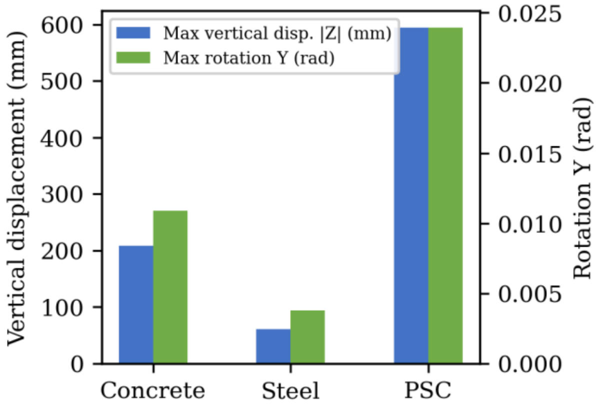

Fig. 2. Comparison of maximum vertical displacement and rotation-Y by deck material.

Table 7. Representative Joint Displacements and Rotations at Selected Deck Locations

Material	Joint	Disp. X (mm)	Disp. Z (mm)	Rot. Y (rad)
Concrete	16	39.68	−142.52	0.009957
Concrete	20	61.69	−176.25	0.008207
Steel	16	14.09	−49.42	0.003398
Steel	20	21.71	−61.12	0.002809
PSC	24	181.68	−445.80	0.020449
PSC	32	117.99	−594.31	0.018232

The steel deck exhibited the smallest deformation response, with a maximum vertical displacement of only 61.1 mm and negligible rotation, confirming its superior stiffness-to-weight efficiency. The RC deck showed intermediate deformation (208.4 mm), while the PSC deck recorded the largest vertical displacement (594.3 mm) and rotation (0.0239 rad). Table VII shows that this trend holds consistently along the span: at every sampled joint the PSC model records the largest vertical displacement and the steel model the smallest, confirming that the pattern is not confined to a single critical location. This apparently unfavourable displacement is explained by the higher overall stiffness and greater load participation of the PSC deck section, which draws a larger share of the applied load through the cable-deck system rather than indicating structural inadequacy; it is consistent with the correspondingly higher reactions noted in Table IV.

3. Element Forces in Deck Framing

Internal forces within the deck framing — shear (V2), torsion (T) and bending moment (M3) — were extracted for all three models; the absolute maxima are summarised in Table VIII and Fig. 3.

Table 8. Variation of Absolute Maximum Element Forces in Deck Framing Across the Three Deck Materials

Material	Max V2 (kN)	Max T (kN-m)	Max M3 (kN-m)
Concrete	76.94	0.000831	16.62
Steel	72.32	0.000083	15.18
PSC	458.70	0.0000488	96.30

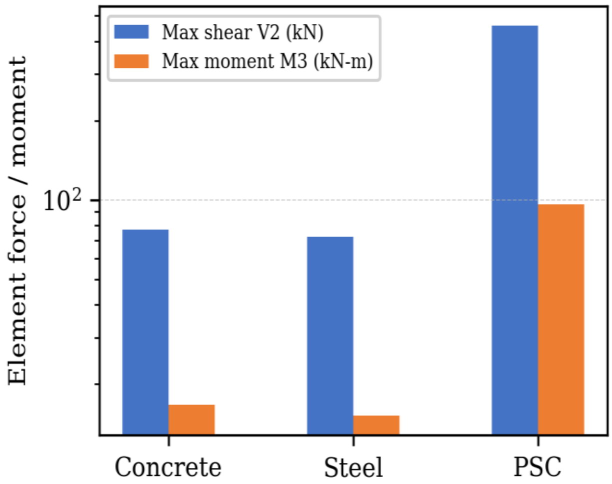

Fig. 3. Comparison of maximum shear force (V2) and bending moment (M3) by deck material (log scale).

The PSC deck attracted the highest internal force demand, with a maximum shear V2 of 458.70 kN and bending moment M3 of 96.30 kN-m — roughly six times the values recorded for the RC and steel decks. The RC deck showed intermediate values (V2 = 76.94 kN, M3 = 16.62 kN-m), only slightly higher than the steel deck (V2 = 72.32 kN, M3 = 15.18 kN-m), which recorded the lowest internal force demand in most components. Torsional moments were negligible for all three materials (≤ 0.00083 kN-m), confirming that the symmetric bridge configuration is governed by major-axis bending rather than torsion.

4. Area-Shell Stresses

Top- and bottom-surface principal and Von Mises stresses in the deck shell elements were compared across the three materials; the maxima are summarised in Table IX and Fig. 4.

Table 9. Variation of Absolute Maximum Area-Shell Stresses Across the Three Deck Materials

Material	Max SMaxTop (kN/m²)	Max SMinTop (kN/m²)	Max SVMBot (kN/m²)
Concrete	7622.8	28541.0	29733.7
Steel	53.60	10115.7	10115.5
PSC	369.75	64240.2	64301.0

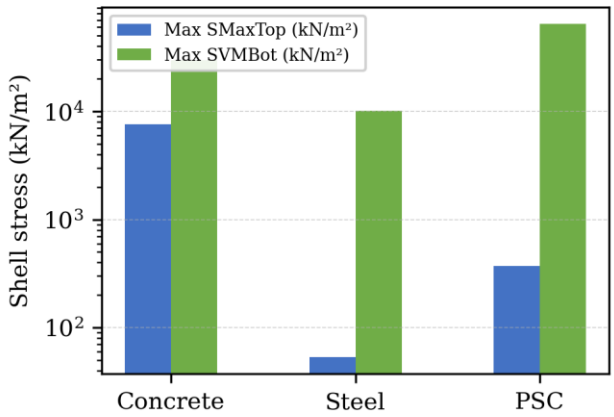

Fig. 4. Comparison of maximum top-surface principal tensile stress (SMaxTop) and bottom-surface Von Mises stress (SVMBot) by deck material (log scale).

Table 10. Representative Area-Shell Stresses at Selected Deck Elements

Material	Area	SMaxTop (kN/m²)	SMinTop (kN/m²)	SVMBot (kN/m²)
Concrete	7	180.69	−20204.29	21867.96
Concrete	9	−138.08	−26072.55	24656.75
Steel	6	9.02	−5698.51	5703.84
Steel	9	−0.65	−10115.70	10115.51
PSC	6	57.69	−36164.21	36281.60
PSC	9	−3.77	−64238.75	64300.96

The RC deck developed the highest top-surface tensile stress (SMaxTop = 7,622.8 kN/m²), consistent with a greater susceptibility to flexural cracking under service loading [8], [12]. The PSC and steel decks recorded substantially lower tensile stress (369.75 and 53.60 kN/m², respectively); for the PSC deck this reduction reflects the compressive stress field introduced by prestressing, which counteracts tensile stresses developed under external load. The PSC deck, in turn, showed the highest compressive and Von Mises stress (SVMBot ≈ 64,301 kN/m²), which is the intended structural behaviour of a prestressed section rather than a sign of distress, whereas the steel deck maintained the lowest stress levels overall (SVMBot ≈ 10,116 kN/m²), well below the yield strength of Fe-550 steel. Table X confirms that this ranking is consistent across individual deck elements and not limited to the single governing location reported in Table IX.

5. Synthesis of Results

Table XI ranks the three deck materials (1 = most favourable, 3 = least favourable) across the principal response categories evaluated in this study.

Table 11. Comparative Ranking of the Three Deck Materials Across the Principal Response Categories (1 = Most Favourable)

Response Category	Concrete	Steel	PSC
Joint axial reaction	2	1	3
Joint displacement	2	1	3
Element shear / moment	2	1	3
Top-surface tensile stress	3	1	2
Equivalent (Von Mises) stress	2	1	3

Table 12. Indicative Comparative Cost and Life-Cycle Profile of the Three Deck Materials

Cost Dimension	RC Deck	Steel Deck	PSC Deck
Initial material cost	Lowest	Highest	Intermediate
Construction / erection speed	Moderate	Fastest	Moderate
Corrosion / cracking maintenance	Moderate–High	High	Low
Indicative life-cycle cost	Competitive (short span)	Highest	Lowest

The steel deck consistently ranks first (lowest demand) for reactions, displacement and internal forces owing to its low self-weight and high stiffness-to-weight ratio; the PSC deck ranks least favourable on these global-response measures yet ranks best on tensile-stress control because of prestressing; and the RC deck occupies an intermediate position overall but ranks worst for tensile stress, indicating comparatively higher crack susceptibility. These patterns are corroborated by [1] and [3] for RC/steel behaviour and by [2], [4] for PSC tensile-stress control.

These trends follow directly from the relative axial and flexural stiffness of the three deck sections. In a cable-stayed system, a stiffer deck attracts a larger share of the applied load through the cable-tower load path before that load can redistribute as deck bending, which is why the comparatively stiff PSC section consistently records the highest reactions, displacements and internal forces even though it is not the heaviest of the three; the lighter, more flexible steel deck instead allows a larger share of load to be carried directly by the cables with minimal deck engagement, producing the lowest response in almost every category. Tower geometry and cable layout, held identical in all three models, further govern how efficiently this load is transferred to the substructure, consistent with the role of tower configuration reported by Rodriguez and Li [13]; because these parameters were not varied here, the observed differences in Tables IV–X can be attributed to deck material alone, which is precisely the controlled comparison this study set out to provide.

V. ECONOMIC AND LIFE-CYCLE EVALUATION

Table XII presents an indicative cost profile derived from representative material costs and the life-cycle observations reported in the literature [6], combined with the structural results obtained above. The RC deck offers the lowest initial material cost, aided by the low cost and wide availability of concrete and conventional reinforcement, but its higher tensile stress (Table IX) implies a greater probability of service cracking, accelerated reinforcement corrosion and consequent maintenance. The steel deck, while structurally most efficient, carries the highest initial cost owing to the unit cost of high-strength steel, fabrication, and corrosion-protection systems; this is partly offset by faster prefabricated erection, but regular inspection and coating maintenance remain significant contributors to its life-cycle cost, particularly in aggressive environments [9]. The PSC deck occupies an intermediate initial-cost position — reflecting the additional cost of prestressing tendons, anchorages and stressing operations — but its markedly lower tensile stress translates into reduced crack-related maintenance and the most favourable indicative life-cycle cost among the three alternatives [2].

This trend is consistent with wider life-cycle cost research on bridge girders. Huang et al. [6] compared painted steel, galvanized steel and prestressed concrete highway bridges over their full service life and found that, although steel bridges were often competitive on initial cost, recurring costs for painting, corrosion protection, inspection and rehabilitation made their total life-cycle expenditure the highest of the alternatives considered, whereas prestressed concrete — by minimising cracking and reinforcement corrosion — produced the lowest total ownership cost. Saxena and Gupta [15] similarly demonstrated, for T-beam and box-girder bridges, that the most economical structural system depends on span length and configuration rather than on initial material cost alone — a principle that is directly reflected in the present findings, where the ranking of the three deck materials by first cost (Table XII) is the reverse of their ranking by indicative life-cycle cost. This confirms that the lowest first cost does not necessarily correspond to the most economical solution over the complete service life of a cable-stayed bridge, and that a combined structural-economic assessment, rather than initial expenditure alone, is essential to deck-material selection.

VI. CONCLUSION

A comparative finite element evaluation of RC, structural steel and PSC deck girders was carried out for a representative 180 m cable-stayed bridge under identical geometry, cable arrangement, support conditions and IRC Class AA loading. The principal, results-based conclusions are:

- The steel deck consistently produced the lowest joint reactions, displacements, internal element forces and shell stresses among the three alternatives, confirming the structural efficiency of its high strength-to-weight ratio, but it carries the highest initial cost and requires sustained corrosion-protection measures.
- The RC deck showed intermediate global response but developed the highest tensile stress of the three materials, indicating comparatively greater susceptibility to service cracking despite offering the lowest initial construction cost.
- The PSC deck attracted the largest vertical reactions, displacements and internal forces — a consequence of its higher stiffness and greater load participation rather than structural inadequacy — while achieving the lowest tensile stress and the most favourable indicative life-cycle cost through prestressing.
- Deck material selection should therefore be treated as a span- and loading-dependent decision: steel suits applications where reduced dead load and rapid, prefabricated construction govern; RC remains attractive for shorter spans and moderate loading where initial cost dominates; and PSC provides the most balanced combination of structural performance, tensile-stress control and long-term economy for medium- to long-span cable-stayed bridges such as the 120 m main-span configuration investigated here.

The comparative framework developed in this study offers practical, results-based guidance for bridge engineers during the preliminary selection of cable-stayed bridge deck systems. Because the three models share identical geometry, cable arrangement, boundary conditions and loading, the differences reported in Tables IV–X can be attributed to deck material with reasonable confidence, giving designers a controlled basis for comparison that is often unavailable when drawing conclusions from separate case-study bridges reported in the literature.

Recommendations

- For medium- to long-span cable-stayed bridges (approximately 100–120 m and above) under heavy vehicular loading comparable to IRC Class AA, PSC decks should be considered a preferred alternative because of their favourable combination of tensile-stress control, durability and long-term economy.
- Where rapid construction, reduced dead load and minimised substructure demand are the primary requirements, structural steel decks are efficient, provided that a comprehensive corrosion-protection and inspection strategy is incorporated from the planning stage.
- RC decks remain suitable for shorter-span cable-stayed and pedestrian bridges, and for projects where initial cost is the dominant consideration, provided adequate reinforcement detailing and crack-width control are implemented.
- Deck-material selection should be treated as a span- and loading-dependent decision informed by a multi-criteria evaluation — structural performance, construction feasibility, durability and life-cycle cost — rather than by initial cost alone; hybrid steel–concrete decks, dynamic/seismic response, and detailed region-specific life-cycle cost modelling are recommended directions for future research [10], [11].

Scope and Limitations

The findings and recommendations above should be interpreted within the scope of the present investigation. The study is limited to a single representative bridge configuration (180 m, twin-tower, three-span), so the results apply most directly to bridges of similar arrangement and span range; different geometries, cable layouts or support conditions may alter the comparative response. Only three deck materials — RC, structural steel and PSC — were considered; composite steel–concrete, lightweight and fibre-reinforced concrete decks were outside the scope of this work. The analysis was restricted to linear-static behaviour under dead, IRC Class AA live and uniform temperature loads; dynamic and extreme-event effects such as seismic, wind, blast and impact loading, as well as time-dependent effects including creep, shrinkage, fatigue and corrosion, were not investigated. These limitations define natural directions for future research rather than detracting from the validity of the comparative trends reported here. In particular, extending the present controlled-comparison framework to seismic and wind loading, to fatigue and time-dependent effects, and to alternative span and cable arrangements would allow the conclusions drawn here to be tested more broadly and would further strengthen their applicability to practical bridge design.

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