

Dynamic Analysis of Prestressed Girder: Comparative Finite Element Study of RCC and PSC Bridge Systems

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Abstract

This paper presents a comparative finite element study of reinforced cement concrete (RCC) and prestressed cement concrete (PSC) girder bridge systems for a representative two-span continuous bridge of 40 m + 40 m configuration. The study is motivated by the practical design problem of selecting a structurally efficient and serviceable bridge system for medium-span highway applications under Indian Roads Congress (IRC) loading conditions. A uniform bridge geometry, carriageway width, deck slab thickness and support configuration were considered for both variants so that the influence of prestressing on structural response could be clearly identified. The bridge models were analysed in STAAD-Pro using shell elements for the deck slab and beam elements for the longitudinal and cross girders. Dead load, superimposed dead load, IRC Class AA tracked loading and IRC Class A loading were applied. The comparison focuses on bending moment, shear force, support reaction, mid-span deflection and deck slab stress response. The results show that the PSC system reduces sagging moments and significantly improves serviceability by limiting deflection and bottom fibre tensile stress. Although the PSC option shows slightly higher pier reactions and a marginally higher initial construction cost, it offers superior structural efficiency, reduced cracking potential and better long-term durability. The study confirms that prestressing is particularly advantageous for medium-span continuous girder bridges where performance, durability and life-cycle economy govern system selection.

Keywords: Prestressed girder, RCC bridge, PSC bridge, STAAD-Pro, finite element analysis, IRC loading, bridge serviceability.

1. Introduction

Bridge superstructures are among the most important components of transportation infrastructure because they provide safe, uninterrupted and economical movement across rivers, roads, valleys and other physical barriers. For the span range commonly used in Indian highway practice, reinforced cement concrete (RCC) and prestressed cement concrete (PSC) remain two widely adopted systems. RCC bridge girders rely on conventional reinforcement to resist tensile stresses after concrete cracking, whereas PSC girders introduce a pre-compression through high-strength tendons so that tensile stresses under service loads are reduced or eliminated. This fundamental behavioural difference directly affects moment distribution, cracking, deflection, durability and economy.

The selection between RCC and PSC is often guided by rules of thumb, yet modern bridge engineering requires a more quantitative comparison based on actual structural response under codal loading. Prestressing is known to improve stiffness, reduce service-load cracking and increase span efficiency, but its practical advantage must be demonstrated through analysis using identical geometry and loading assumptions. The present study therefore compares both systems for the same 80 m two-span bridge using STAAD-Pro and current IRC provisions. The following conceptual diagram, provided by the user, summarises the complete analytical framework adopted in the paper.

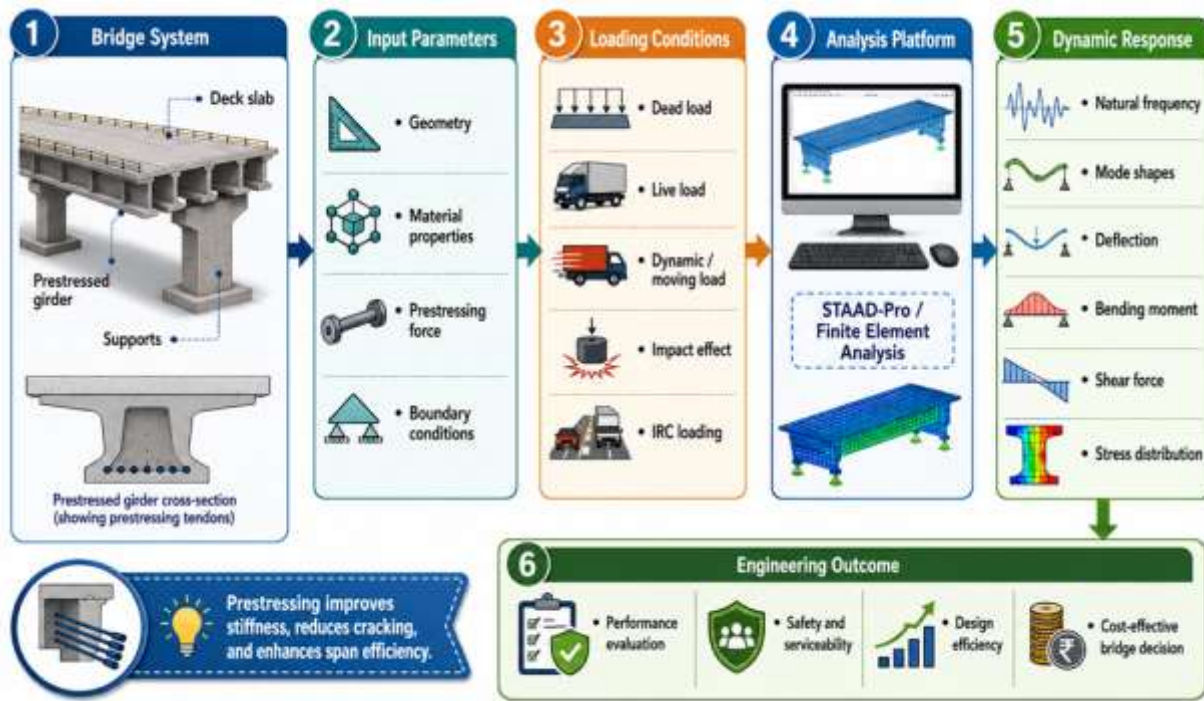


Figure 1.1. Integrated framework for prestressed girder bridge analysis showing bridge system

The study is significant because medium-span concrete girder bridges are frequently used in Indian infrastructure projects, and their long-term performance depends greatly on serviceability and maintenance requirements. By keeping the bridge geometry constant for both systems and comparing response quantities such as bending moment, shear force, support reaction, deflection and stress, the research provides a clear basis for selecting the more suitable bridge type. In addition, the paper converts dissertation-level work into a compact research-paper format that is ready for printing and academic submission.

1.1. Aim and Objectives

Aim:

To perform a comparative finite element analysis of RCC and PSC bridge girder systems using STAAD-Pro and evaluate their structural response under IRC loading.

Objective

1. To study the geometry, material properties and loading configuration of a representative 40 m + 40 m continuous bridge.
2. To model RCC and PSC bridge variants in STAAD-Pro using shell elements for deck slabs and beam elements for girders.
3. To apply self-weight, superimposed dead load, IRC Class AA tracked vehicle and IRC Class A wheeled loading.
4. To compare bending moments, shear forces, support reactions, mid-span deflections and deck slab stresses.

2. Literature Review

Hegde and Bhat (2022) highlighted that revised IRC loading provisions affect live-load and impact-factor demand on bridge girders, especially for prestressed members designed using updated limit-state methods. Ramaswamy (2021) emphasized the usefulness of STAAD-Pro for bridge superstructure modelling and showed that plate-girder idealisation can effectively capture moving-load effects in routine bridge analysis. Syed Sofiya et al. (2023) compared RCC and PSC T-beam girders for a 50 m bridge using STAAD.Pro and reported lower bending moment, shear force and deflection in the PSC girder. This supports the present study because prestressing reduces tensile stress and improves serviceability. Gong et al. (2024) studied prestressed concrete bridges with grouting defects and showed that tendon-related defects can reduce stiffness and durability. This indicates that PSC bridge performance depends not only on design but also on proper construction quality, duct grouting and anchorage protection. Elshazli et al. (2024) used numerical modelling to study prestressed girder behaviour and confirmed that advanced finite element simulation can accurately represent the

response of prestressed members. He et al. (2024) studied the influence of prestress loss in prefabricated PSC bridges and stated that loss estimation and deck deflection monitoring are important for service-life prediction. Wang et al. (2024) proposed a response-based method to identify prestress force in prestressed slab systems, showing that dynamic response can be used for condition assessment. Chen et al. (2025) developed a dynamic finite element model for prestressed box-girder bridges using impact data, confirming the importance of modal and nondestructive evaluation in bridge monitoring.

Jia et al. (2024) used deflection observations for probabilistic identification of prestressed concrete bridges and showed that model updating reduces uncertainty in stiffness and serviceability evaluation. Sun et al. (2024) studied deterioration identification and finite element model updating of bridge structures and concluded that calibrated models predict damaged bridge response better than uncalibrated design models. Wu et al. (2024) combined finite element analysis with deep learning and showed that surrogate models can predict displacement and stress fields with less computational time. Haghighi and Urgessa (2024) studied prestressed UHPC girders through finite element analysis and showed that validated FE models can represent cracking, nonlinear response and moment–deflection behaviour. AbdelMalek (2024) modelled prestressed girder bridges under lateral impact loading using LS-DYNA, extending FE applications from gravity loading to extreme events. Sarmiento et al. (2025) studied time-dependent reliability of PSC bridges using Bayesian updating, while Tiprak et al. (2025) used probabilistic finite element model updating with particle swarm optimisation. Overall, the literature shows that PSC bridges generally offer better serviceability, reduced deflection, improved crack control and better durability than RCC bridges for medium and long spans. However, PSC performance strongly depends on accurate prestress modelling, prestress losses, grouting quality, construction control and long-term monitoring. The present study is therefore relevant because it directly compares RCC and PSC variants for a 2×40 m continuous bridge using STAAD-Pro and IRC loading.

2.1. Research Gap

The reviewed literature shows that many studies separately discuss RCC bridge design, PSC girder behaviour, finite element modelling, prestress loss, durability, dynamic testing and reliability analysis. However, limited research presents a direct RCC–PSC comparison using identical geometry, identical loading and identical boundary conditions under current Indian highway loading practice. Older Indian studies mainly focus on static bending moment, shear force and deflection, while recent international studies focus on advanced PSC issues without comparing them with RCC alternatives. Therefore, a research gap exists for a compact STAAD-Pro-based study that compares RCC and PSC bridge systems for a practical 2×40 m continuous bridge. The present study addresses this gap by evaluating the effect of prestressing on bending moment, shear force, support reaction, deflection, deck stress, serviceability, durability and preliminary cost.

3. Research Methodology

3.1 Study Design

The research follows an analytical and comparative design. Two bridge superstructure models were prepared: an RCC deck slab–girder bridge and a PSC girder bridge. Both variants were analysed under identical geometry and loading so that the influence of prestressing could be isolated.

3.2 Bridge Configuration and Materials

The bridge considered in the study is a two-span continuous system of $40\text{ m} + 40\text{ m}$ with a clear carriageway width of 10.5 m . The deck slab thickness is 250 mm and the longitudinal girders are $400\text{ mm} \times 1400\text{ mm}$. M30 concrete and Fe500 reinforcement were adopted for the RCC model, while M45 concrete and Fe1860 prestressing steel were used for the PSC variant.

3.3 Loading and Codal Basis

The loading includes self-weight, wearing coat, kerb and parapet loads as well as IRC Class AA tracked vehicle and IRC Class A wheeled vehicle live loading. The analysis framework follows IRC:6-2017 for loading and load combinations, IRC:18 for prestressed concrete design considerations, IRC:21/IRC:112 provisions for concrete bridge behaviour, and standard finite element modelling practice.

3.4 STAAD-Pro Analysis Procedure

In STAAD-Pro, the deck slab was modelled using shell elements, while longitudinal and cross girders were modelled using beam elements. Supports were assigned to represent the abutments and intermediate pier. For the PSC bridge, an internal post-tensioning force was introduced through the post-stress load command. After model generation, load cases were analysed and critical output quantities were extracted through the post-processing module.

3.5 Evaluation Parameters

The comparison focuses on five key response parameters: bending moment, shear force, support reaction, mid-span deflection and plate stress in the deck slab. These results were interpreted in relation to serviceability, cracking control, stiffness and structural efficiency.



Figure 3.1 Methodology flowchart

4. Results and Discussion

The finite element results obtained from the dissertation file clearly show the behavioural differences between the RCC and PSC variants. Representative output diagrams from the original file are reproduced below, followed by four core comparison tables and short interpretations.

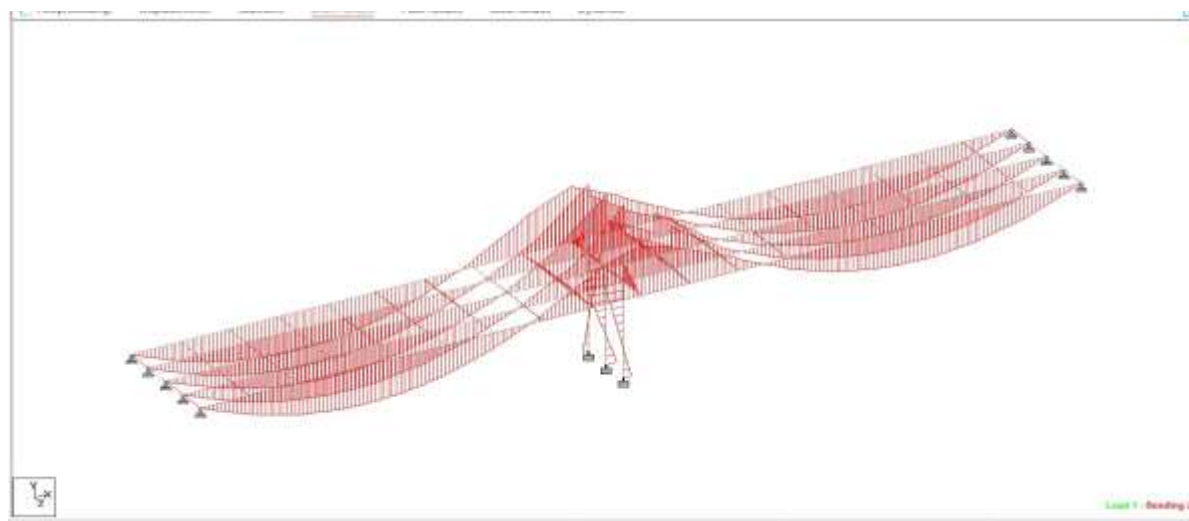


Figure 4.1. Bending moment diagram of the longitudinal girders for the RCC variant.

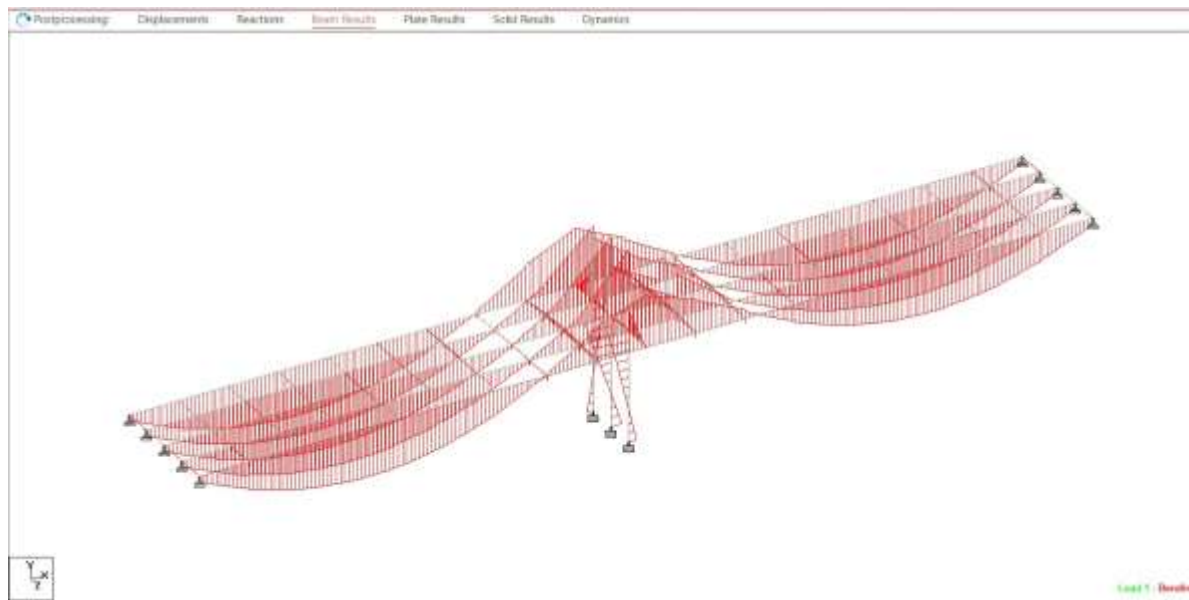


Figure 4.2. Bending moment diagram of the longitudinal girders for the PSC variant.

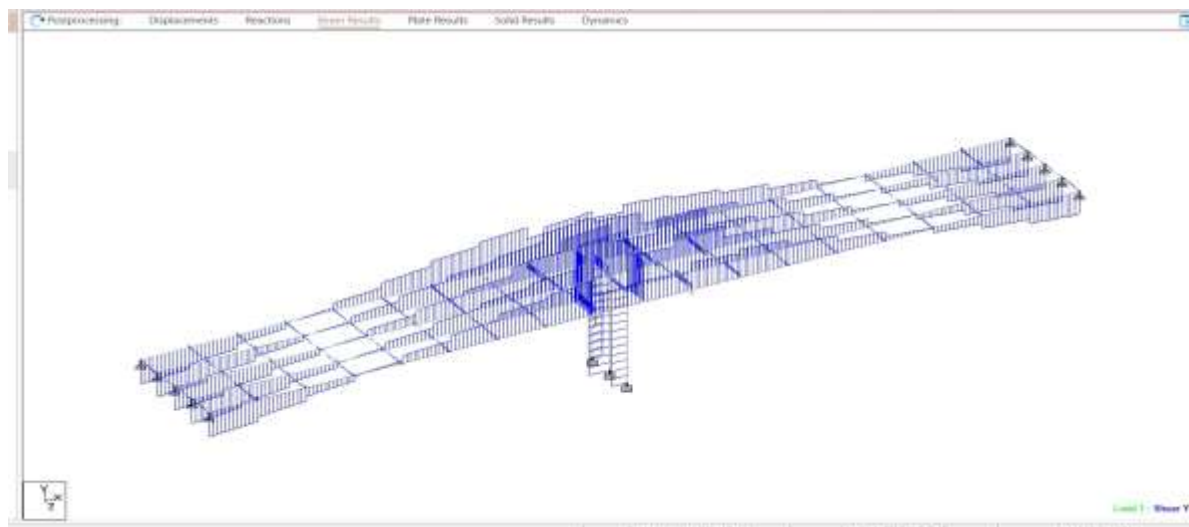


Figure 4.3. Shear force diagram of the longitudinal girders for the PSC variant.

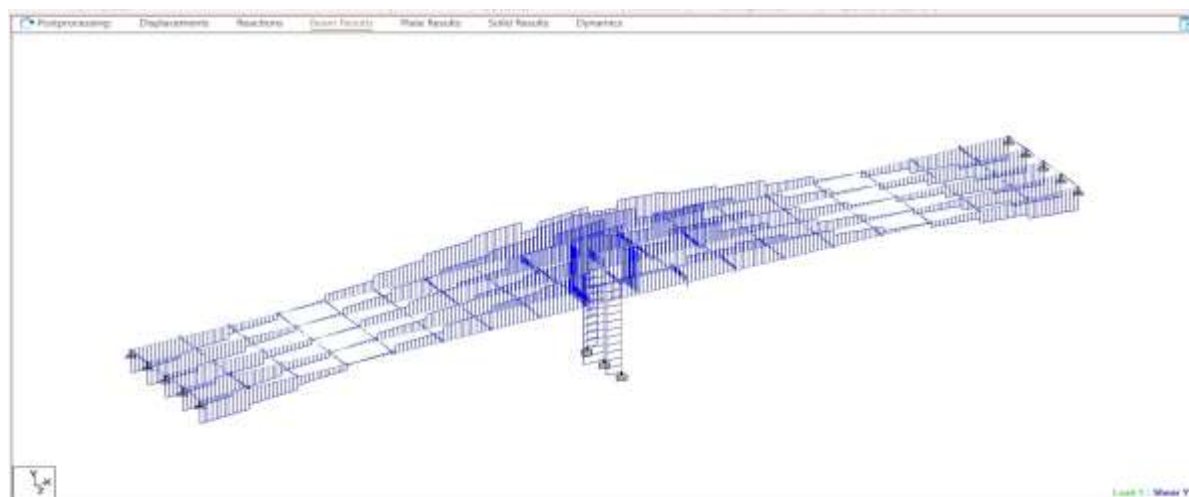


Figure 4.4. Shear force diagram of the longitudinal girders for the RCC variant.

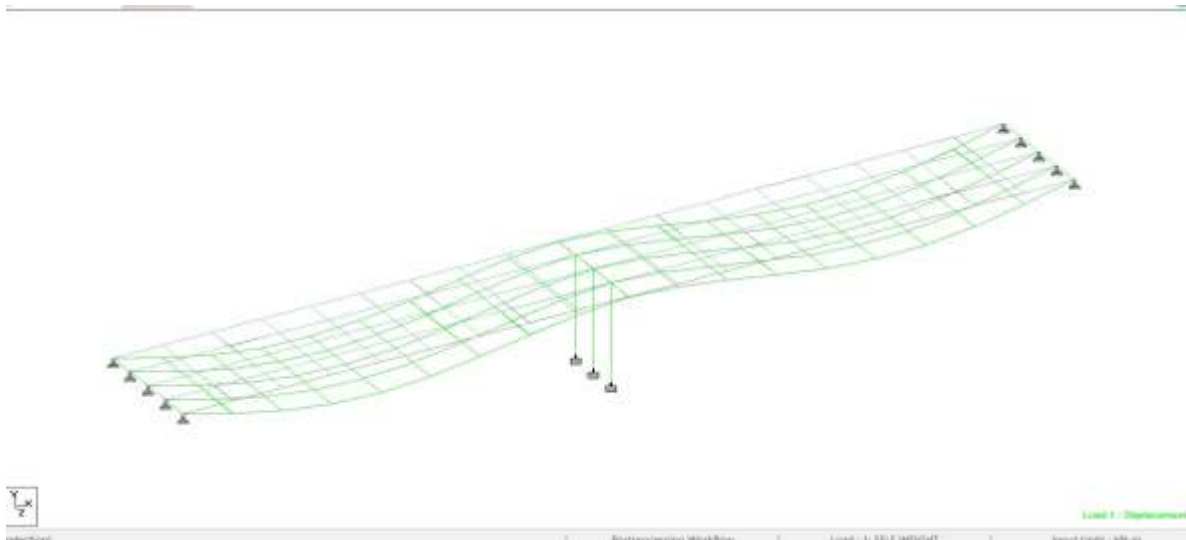


Figure 4.5. Deflected shape of the PSC bridge under the critical load case, showing upward camber due to prestress.

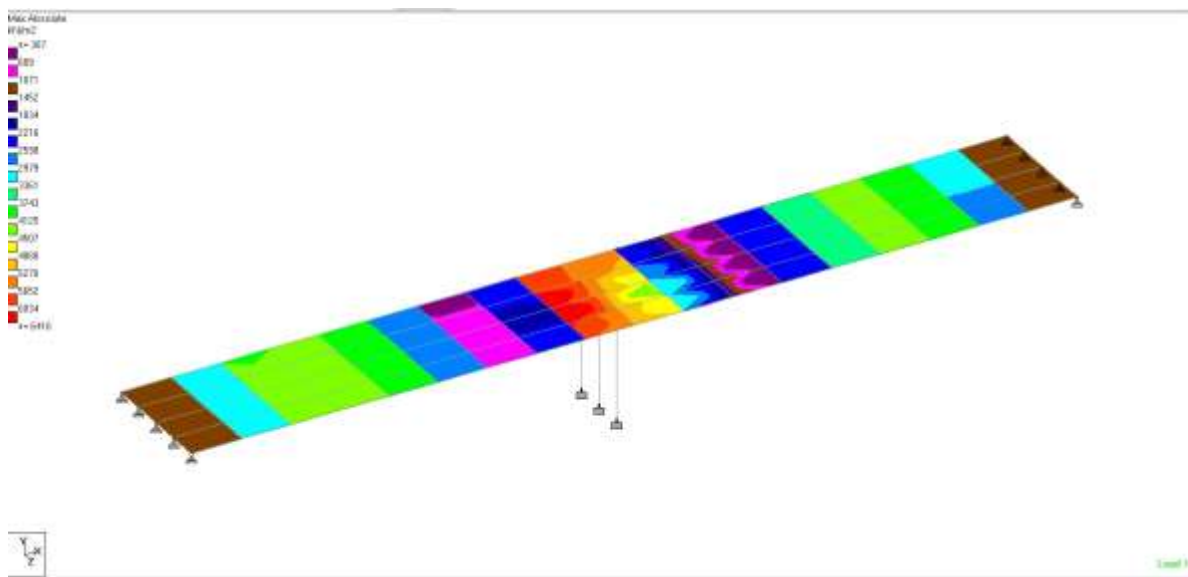


Figure 4.6. Maximum absolute plate stress contour of the deck slab.

Table 4.1. Comparison of bending moments in RCC and PSC variants

Location & Component	RCC (kN·m)	PSC (kN·m)	Change (%)
Max sagging Mz, Span 1, outer girder	8,520	6,250	−26.6
Max sagging Mz, Span 1, inner girder	6,820	4,940	−27.6
Max sagging Mz, Span 2, outer girder	8,480	6,130	−27.7
Max hogging Mz at pier, outer girder	14,890	17,210	+15.6

Prestressing reduces sagging moments by nearly 26–28%, demonstrating that the eccentric prestressing force effectively counteracts gravity loading. The increase in hogging moment over the pier is expected because the equivalent upward prestress load redistributes moments toward the support region.

Table 4.2. Comparison of shear forces in RCC and PSC variants

Location	RCC (kN)	PSC (kN)	Change (%)
Max Fy at abutment, outer girder	1,420	1,375	−3.2
Max Fy at pier (Span 1 side), outer girder	2,180	2,310	+6.0
Max Fy at pier (Span 2 side), outer girder	2,175	2,305	+6.0

The shear force pattern shows only moderate variation between the two bridge types. Abutment shears are slightly reduced in the PSC bridge, whereas pier shears are marginally higher because prestressing transfers a greater proportion of load toward the central support.

Table 4.3. Comparison of support reactions in RCC and PSC variants

Support Location	RCC (kN)	PSC (kN)	Change (%)
Abutment 1, outer bearing	1,420	1,375	−3.2
Abutment 1, inner bearing	1,130	1,090	−3.5
Pier, outer bearing	2,180	2,310	+6.0
Pier, inner bearing	1,970	2,080	+5.6

Support reactions confirm the same trend identified in the shear force comparison. The PSC alternative develops slightly higher pier reactions, implying a somewhat higher demand on the substructure and bearings at the intermediate support, though this is small relative to the serviceability gains.

Table 4.4. Comparison of mid-span deflections in RCC and PSC variants

Location	RCC (mm)	PSC (mm)	Change (%)
Mid-span deflection, Span 1	32.5	18.7	−42.5
Mid-span deflection, Span 2	32.4	18.6	−42.6
Serviceability interpretation	Within limit	Much lower than RCC	Improved

The deflection response is the strongest argument in favour of PSC. The mid-span deflection is reduced by about 42%, reflecting both the higher stiffness of M45 concrete and the upward camber introduced by prestressing. This improved serviceability directly reduces sagging, improves riding comfort and decreases the likelihood of long-term cracking.

Additional results from the dissertation indicate that the bottom fibre tensile stress in the deck slab decreases from +5.6 MPa in the RCC case to +2.1 MPa in the PSC case, while the total concrete quantity remains the same for the present geometric comparison. Thus, the superior behaviour of the PSC bridge is obtained primarily from prestressing action rather than from a larger section.

5. Conclusion

The comparative study demonstrates that prestressing significantly improves the structural performance of the selected continuous girder bridge system. Relative to the RCC bridge, the PSC variant shows lower sagging moments, lower mid-span deflection and substantially reduced tensile stress in the deck slab, indicating better serviceability and greater resistance to cracking. Although the PSC bridge develops somewhat higher hogging moments and support reactions near the intermediate pier, these effects are manageable through appropriate detailing. From an engineering viewpoint, the PSC alternative provides a better balance of stiffness, durability and span efficiency for the 40 m + 40 m bridge configuration studied. Hence, for medium-span bridge applications where long-term performance is important, the PSC girder system is preferable to the conventional RCC alternative.

6. Future Scope

The present study can be further extended by considering different bridge span lengths such as 30 m, 35 m, 45 m, 50 m and above. In this study, RCC and PSC bridge models were compared using identical geometry to clearly understand the effect of prestressing. However, in actual design practice, PSC girders are generally made more slender than RCC girders because prestressing allows better control of tensile stress and deflection. Therefore, future research can optimise the PSC girder depth, flange width, web thickness and tendon profile for different spans. This will help to identify the most economical span range where PSC becomes more beneficial than RCC in terms of material saving, structural efficiency and serviceability.

Future work may also include nonlinear behaviour of concrete and steel instead of only linear elastic analysis. In the present study, the response is mainly based on bending moment, shear force, reaction, deflection and stress values obtained from STAAD-Pro. However, actual bridge behaviour is affected by cracking, stiffness degradation, creep, shrinkage, relaxation of prestressing steel and prestress losses. Therefore, long-term analysis considering time-dependent

effects should be carried out to predict realistic deflection, stress redistribution and service-life performance of PSC girders.

The study can also be extended to seismic and dynamic analysis. Response spectrum analysis and time-history analysis may be performed to study the behaviour of RCC and PSC bridge systems under earthquake loading. Such analysis will help in understanding natural frequency, mode shapes, displacement demand, base shear, bearing forces and dynamic amplification. This is especially important for bridges located in higher seismic zones or on important highway corridors.

Further research may also consider skew bridges, curved bridges and variable-depth girder bridges. These bridge configurations are commonly used where site geometry, road alignment or river crossing conditions are complex. Skew and curved bridges develop additional torsion and uneven load distribution; therefore, their behaviour cannot be fully understood using simple straight bridge models.

Finally, detailed life-cycle cost, maintenance and sustainability analysis should be included in future studies. Although PSC bridges may have higher initial cost, they generally provide reduced cracking, lower maintenance and longer service life. Hence, future research should compare RCC and PSC bridges based on initial cost, repair cost, inspection requirement, carbon footprint, material consumption and long-term durability to support practical decision-making.

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