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Behavior of Highway Bridge PSC Girder with Different Support Arrangements Under Dynamic Loading

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ABSTRACT

This article presents a detailed finite element analysis of a three-span PSC I-girder bridge using MIDAS Civil software. The primary objective is to investigate the structural behavior of the bridge girder under different support configurations, namely simply supported and continuous systems, combined with elastomeric Bearings and roller Supports. The analysis incorporates loading conditions as per IRC:6-2017, IRC: 112-2011, and IRC SP: 114-2018. The bridge model was subjected to IRC Class A and Class 70R vehicular loads, in addition to seismic loads, to evaluate critical performance parameters of deflections, bending moments, shear forces, torsional effects, and dynamic characteristics, such as natural periods, which were comprehensively studied. The results highlight that Continuous Girders with elastomeric bearings provide superior stiffness, reduced deflections, better control of torsion, and improved seismic performance compared to other configurations. The findings demonstrate that the selection of an efficient girder-support system plays a vital role in ensuring safety, serviceability, and resilience of medium to long-span PSC I-girder bridges.

INTRODUCTION

Prestressed concrete (PSC) I-girder bridges are widely utilized in modern highway and railway infrastructure due to their structural efficiency, durability, and capability to accommodate long spans with minimal deflection. Over the past decade, numerous studies have explored the design, analysis, and performance of steel and PSC I-girder bridges under various loading and boundary conditions. For example, Vikas Parmar (2025) demonstrated the effectiveness of CSI-Bridge software in evaluating bending, shear, and axial forces in steel I-girder bridges, highlighting the conservativeness of IRC loading. Similarly, Sedhain (2025) evaluated the structural response of steel I-girder bridges, emphasizing the accuracy of numerical simulations in predicting deflection, bending, and torsional effects under various load cases. Karim et al. (2025) reviewed optimization techniques and material considerations in PSC box girder design, emphasizing the importance of strand configurations and software-aided analysis. Research by Verma et al. (2024), Rahul Solanki (2024), and Shen et al. (2025) further illustrated the application of MIDAS Civil for PSC-I girder bridges, integrating time-dependent effects such as creep, shrinkage, prestress losses, and shear lag phenomena in long-span single-box continuous rigid bridges. Several studies have investigated the effect of support configurations on structural performance. Notably, (Barbude et al, 2022) and (Acharya et al., 2024) conducted parametric studies on I-girder bridges using STAAD Pro and the grillage method, analyzing different support configurations under IRC Class A and 70R live loads to assess structural robustness and serviceability. The studies (Vestman, 2023) and (Rishabh Singh et al., 2022) specifically highlighted the importance of lateral bracing in I-girder bridges, showing that proper bracing improves torsional stability and overall structural resilience. The study showed that continuous spans with equally spaced supports exhibited superior performance, with lower maximum bending moments, smoother prestress cable profiles, reduced shear forces, and smaller deflections compared to other configurations. Despite these insights, most existing research focuses on single-span or two-span bridges, with limited exploration of multi-span PSC I-girder bridges under combined static and dynamic loads, including dead, live, and seismic forces. Moreover, the influence of support types (elastomeric bearings vs. roller supports), structural continuity (simply supported vs. continuous), and time-dependent material effects on critical response parameters such as torsion, natural frequencies, and vibration periods remains insufficiently addressed. To fill this gap, the present study investigates a three-span PSC I-girder bridge with a deck width of 13.5 m, analyzed under four configurations: Simply Supported with Elastomeric Bearings (SSEB), Simply Supported with Roller Supports (SSRS), Continuous with Elastomeric Bearings (CGEB), and Continuous with Roller Supports (CGRS). The bridge is modeled in MIDAS Civil, considering prestressing effects, time-dependent material properties (creep and shrinkage), and seismic response through Response Spectrum Analysis. Key structural responses, including deflections, bending moments, shear forces, torsional effects, natural frequencies, and vibration periods, are examined under dead, live (IRC Class A and 70R), and seismic loads.

This research aims to identify the most structurally efficient and seismically resilient configuration by systematically comparing the influence of support conditions and girder continuity on the bridge's performance. The findings address the critical knowledge gap regarding multi-span PSC-I girder bridges under combined static and dynamic loading, providing practical insights for design optimization, enhanced safety, and cost-effective bridge construction.

METHODS

In the present work, there is a comparison of the PSC-I girder Bridge with four different support configurations, namely:

1. Simply Supported Girder with Elastomeric Bearings (SSEB).
2. Simply Supported Girder with Roller Supports (SSRS).
3. Continuous Girder with Elastomeric Bearings (CGEB).
4. Continuous Girder with Roller Supports (CGRS).

The present study focuses on a three-span prestressed concrete (PSC) composite I-girder bridge designed in accordance with IRC guidelines. The bridge consists of five precast girders, each spaced at 2.7 m center-to-center, supporting a 250 mm thick deck slab with an overall width of 13.5 m, accommodating two traffic lanes over a span length of 40 m. Structural analysis was performed for both simply supported and continuous configurations with elastomeric bearings and roller supports, while time-dependent material properties such as creep, shrinkage, and modulus of elasticity were incorporated. The bridge geometry, support conditions, time-dependent properties, and load combinations are summarized in Table 1. The material grades for girders, deck, diaphragms, substructure, and steel reinforcement are listed in Table 2, while the prestressing details, including tendon type, diameter, number of strands, and jacking method, are presented in Table 3. The sectional dimensions of end and internal diaphragms are provided in Table 4, ensuring adequate transverse load distribution and structural integrity.

Table 1. Properties of PSC - I Girder Bridge

Parameter	Description
Bridge Type	PSC Composite I Girder
Span Length	40 m
No. of spans	3 Nos
Deck width	13.5 m
Thickness of slab	250 mm
No. of lanes	2 Nos
No. of girders	5 precast, spaced @ 2.7m c/c
Time Dependent Material (Creep, Shrinkage, Modulus of Elasticity)	IRC 112:2011

Loads and Load Combinations	IRC 6:2017
Support Conditions	Simply Supported and Continuous Girders with Different Support Conditions (Elastomeric Bearings and Roller Supports)

Table 2. Material Properties

PSC Girder	M45
Deck	M40
Diaphragm	M40
Substructure	M40
Grade of steel	Fe540

Table 3. Tendon properties

Type of pre-stressing	Internal post-tensioned
Duct diameter	100 mm
Tendon area	12 strands of 15.2 mm
Type of Bond	Bonded
Jacking	Both ends

Table 4. Section Properties

End Diaphragm	Solid Rectangle	0.4 m X 1.8 m
Internal Diaphragm	Solid Rectangle	0.3 m X 1.8 m

The structural layout and sectional details of the PSC I-girder bridge are illustrated in Figures 1 and 2. Figure 1 presents the general arrangement of the bridge, showing the overall deck width of 13.5 m, consisting of a 250 mm thick deck slab, crash barriers, parapets, footpaths, and five PSC I-girders spaced at 2.7 m c/c, supported on bearings, pedestals, and a pier cap. The arrangement ensures adequate carriageway and footpath provisions along with effective load transfer to the substructure. Figure 2 shows the cross-sectional details of a typical PSC I-girder, with an overall depth of 2.5 m and top and bottom flange dimensions carefully proportioned to resist flexural and shear demands, thereby ensuring both structural efficiency and serviceability.

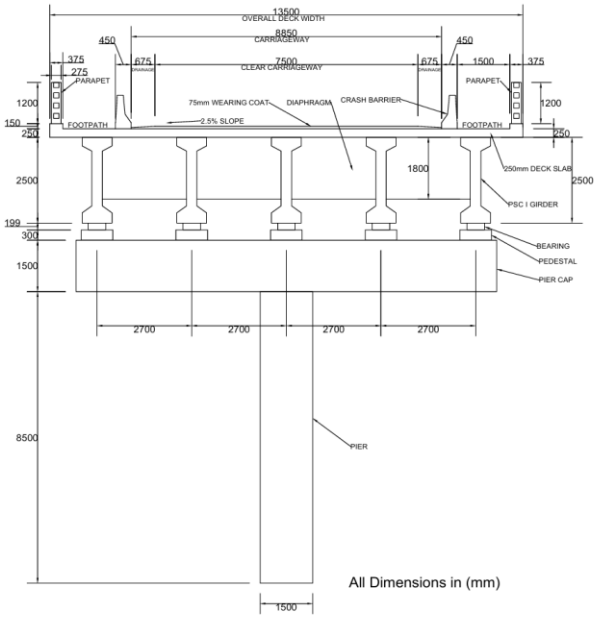

Figure 1. Structural Arrangement of PSC I-Girder Bridge

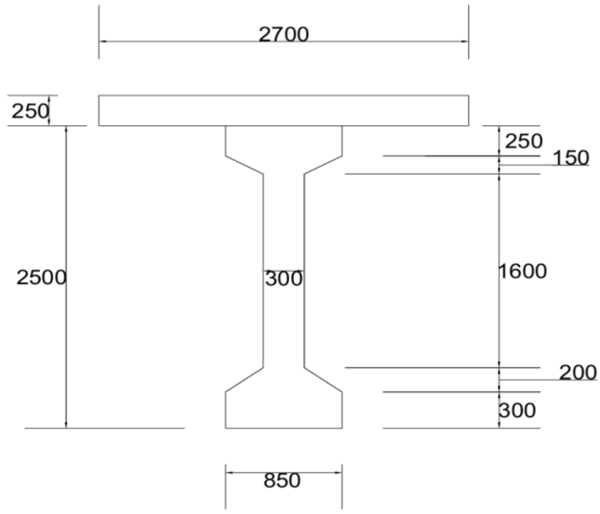

Figure 2. Dimensions of PSC Composite I-Girder

Load Calculations

1. Self-Weight & Superimposed Dead Loads

Self-weight: Automatically taken by the software

Superimposed Dead Loads (SIDL):

Wearing course (concrete)

Thickness = 0.075m

Load = 1.875 kN/m^2

Parapet = 5.4 kN/m

Crash barrier = 8 kN/m

2. Prestressing Load (From IS 1343:2012)

Duct diameter (Internal) is considered as 100mm. Clear cover protecting cable from the nearest concrete surface is kept at 75mm as per IRC: 112-2011.

$f_{pi} = 0.75*f_{pu}$

nominal area of strand = 140mm^2

Breaking Load of Strand = 260.7 kN

ultimate tensile strength, f_{pu} = 1862.142 N/mm^2

f_{pi} = 0.75 * 1862.142 = 1396.6 N/mm^2

Adopted jack pressure = 1395 N/mm^2

3. Moving Loads (From IRC 6:2017)

Footway/Pedestrian Load

$P = (P^{1} – 260 + 4800 / L) \times ((16.5 – W) / 15)$

$P = (500 – 260 + 4800 / 40) \times ((16.5 – 1.5) / 15)$

$= 356.62$ kg/m^2

$= 3.5$ kN/m^2

Vehicle load (Figure 3)

IRC Class A Loading

IRC Class 70R Loading

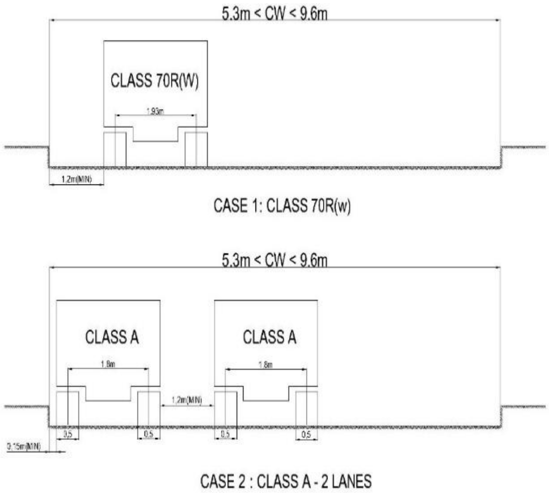

Figure 3. Carriageway Width and Loading Arrangement for Two-Lane Bridge

4. Seismic Load (From IRC SP 114:2018):

The dynamic behavior of bridges under seismic loading is assessed using the Response Spectrum Method as recommended in IRC:6-2017 and IRC SP 114:2018. The response spectrum represents the peak response of a single-degree-of-freedom system subjected to ground motion and is applied to bridge structures considering their natural frequencies and mode shapes. The adopted seismic design parameters for Zones II and V are presented in Table 5.

Table 5. Seismic Properties

Seismic Zone	II	V
Zone Factor, Z From IRC SP 114:2018 table 4.2	0.1	0.36
Response Reduction Factor, R From IRC SP 114:2018 table 4.1	3	3
Importance Factor, I From IRC SP 114:2018 table 4.3	1.2	1.2
Soil Type	II (medium)	II (medium)
Damping factor	5%	5%

RESULTS AND DISCUSSION

The investigation aims to provide a comprehensive understanding of the influence of support conditions and girder continuity on the overall behavior of the bridge deck system. It is examined by comparing the results of different configurations. The study identifies the most efficient and structurally suitable girder-support arrangement in terms of strength, serviceability, and seismic performance. The following acronyms are used while discussing the results to keep the language more precise and easier to understand.

1. SSEB: Simply Supported Girder with Elastomeric Bearings.
2. SSRS: Simply Supported Girder with Roller Supports.
3. CGEB: Continuous Girder with Elastomeric Bearings.
4. CGRS: Continuous Girder with Roller Supports.

Deflection Results

The deflection analysis of the PSC I-girder bridge was carried out separately for dead load and live load conditions. The dead load deflection corresponds to the deformation induced by the self-weight of girders, deck slab, diaphragms, and other superstructure components, which represents the long-term sustained displacement of the bridge system. The live load deflection, on the other hand, was obtained by applying moving vehicle loads in accordance with IRC:6-2017 to capture the transient response of the girders under traffic loading. The results were evaluated for both simply supported and continuous spans with elastomeric bearings and roller supports, and the computed deflections were verified against the permissible serviceability limits specified in IRC codes to ensure safe and efficient structural performance.

The deflection results under dead load (Table 6 and Figure 4) show that the Simply Supported Elastic Bearing (SSEB) and Simply Supported Roller Support (SSRS) systems undergo higher negative deflections of 66.8 mm, while the Continuous Girder with Elastic Bearings (CGEB) and Continuous Girder with Roller Supports (CGRS) display significantly reduced deflections of 36.3 mm. The absence of notable positive deflections confirms that dead load primarily induces downward displacement. These findings highlight that continuous systems provide greater stiffness and improved serviceability compared to simply supported systems, as also indicated in earlier research outcomes emphasizing the benefits of continuity in PSC I-girder bridge behavior.

The comparison of deflections under live load (Table 7, Figure 5, Figure 6) indicates that simply supported systems (SSEB and SSRS) experience higher deflections, with SSRS showing the maximum values of 22.54 mm (positive) and 33.61 mm (negative). In contrast, the continuous girder with elastic bearings (CGEB) demonstrates the lowest deflections of 13 mm (positive) and 15.75 mm (negative), highlighting the superior stiffness provided by continuity. The continuous girder with roller supports (CGRS) shows intermediate behavior, with positive deflection of 25.7 mm and negative deflection of 28.9 mm. Overall, the results confirm that continuous systems effectively reduce deflections and enhance serviceability under moving load conditions, consistent with the general understanding from previous research on PSC I-girders.

Table 6. Comparison of Deflections under Dead Load

Girder System	Negative Deflection (mm)	Positive Deflection (mm)
SSEB	66.8	0
SSRS	66.8	0
CGEB	36.3	0
CGRS	36.3	0

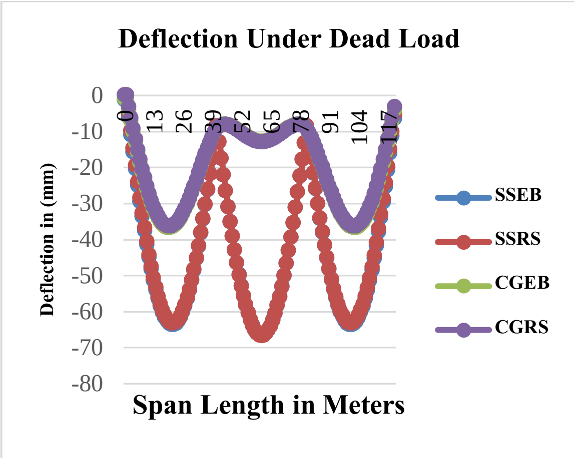

Figure 4. Deflection under Dead Load

Table 7 Comparison of Deflections under Live Load

Girder System	Positive Deflection (mm)	Negative Deflection (mm)	Load case
SSEB	16	26.32	Single lane class 70R with footway
SSRS	22.54	33.61	Single lane class 70R with footway
CGEB	13	15.75	Single lane class 70R with footway
CGRS	25.7	28.9	Single lane class 70R with footway

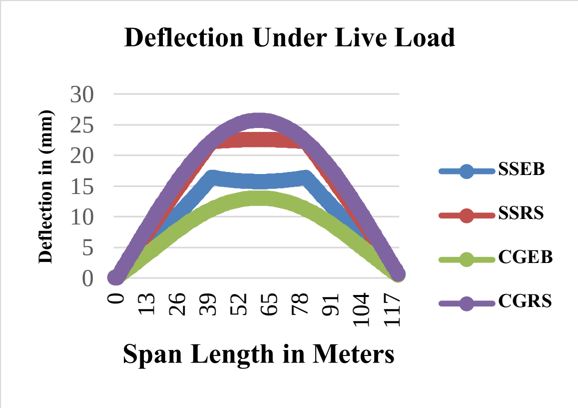

Figure 5. Positive Deflection under Live Load

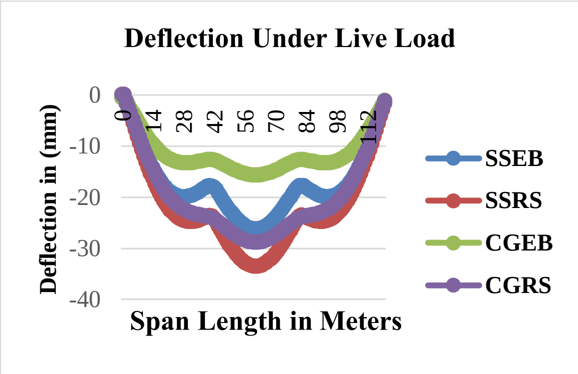

Figure 6. Negative Deflection under Live Load

Bending Moment Results (kN-m)

The bending moment distribution in the PSC I-girder bridge was evaluated independently for dead load and live load conditions to establish the critical demand on the structural system. Dead load bending moments arise from the permanent self-weight of girders, deck slab, and diaphragms, producing sustained flexural effects that dominate the long-term behavior of the bridge. Live load bending moments were obtained by simulating moving vehicle loads as per IRC:6-2017, capturing the transient and position-dependent flexural response of the girders under traffic loading. Analysis was carried out for both simply supported and continuous span systems with elastomeric bearings and roller supports, enabling assessment of the redistribution of bending moments due to continuity effects. The resulting bending moment envelopes were compared with the ultimate flexural resistance of the section to verify adequacy against strength limit states, while ensuring compliance with serviceability requirements specified in IRC:112-2011. Advanced structural analysis software, such as MIDAS Civil, was employed to perform these evaluations, providing accurate modeling of bridge geometry, support conditions, and material properties, as well as a detailed assessment of bending moment response under varying loads (Sudeep et al, 2023).

The bending moment results under dead load (Table 8 and Figure 7) clearly demonstrate the contrasting behavior of simply supported and continuous systems. In SSEB and SSRS, the girders experience very high positive bending moments (9970 kN-m) with only negligible negative moments, which reflects the typical single-span action where the maximum demand is concentrated at mid-span. On the other hand, the continuous systems (CGEB and CGRS) show a more balanced moment distribution, with reduced positive bending moments (6400 kN-m) and significant negative moments at supports (–8370 to –8390 kN-m). This redistribution is beneficial because it lowers the peak mid-span bending stresses, enhances crack control, and improves long-term serviceability. Earlier analytical and experimental research has consistently shown that continuity in PSC I-girders not only reduces mid-span deflections but also improves structural economy by optimizing prestressing requirements. The development of large negative moments at supports, while requiring careful detailing of reinforcement and prestressing tendons, increases redundancy and ductility, thus contributing to greater safety margins against sudden failure. Moreover, continuous systems are better suited to handle differential settlements and temperature gradients, conditions under which simply supported systems are more vulnerable. Therefore, the observed bending moment distribution in this study aligns with established knowledge that continuous PSC systems provide improved structural performance, durability, and resilience compared to their simply supported counterparts.

The bending moment results under live load (Table 9 and Figure 8) indicate that simply supported systems (SSEB and SSRS) are governed by higher positive moments of about 3934 to 3980 kN-m, with relatively small negative moments (–215 to –415 kN-m). This reflects the expected mid-span dominance of bending in single-span systems, where uplift or negative action is minimal. By contrast, the continuous systems (CGEB and CGRS) show considerably reduced positive moments (2996 to 3663 kN-m) but develop significantly larger negative moments (–1922 to –2312 kN-m) at the supports.

This trend highlights the moment redistribution phenomenon, where continuity transfers part of the live load effect to the supports, reducing span demand but increasing restraint forces at intermediate supports. Similar findings were reported by Zhou & Larry (2024), who observed that skewed steel I-girders exhibit moment redistribution patterns influenced by geometry, confirming the impact of girder configuration on bending behavior. From a structural performance perspective, this redistribution is advantageous for serviceability and long-term economy since it decreases tensile stresses and cracking tendencies in the span region, which are typically critical under moving loads. However, the higher support moments in continuous girders necessitate adequate reinforcement, ductile detailing, and careful prestressing design to ensure crack resistance and durability at the supports. Previous research has consistently emphasized that such redistribution not only enhances safety margins but also increases structural redundancy, making continuous PSC I-girders more resilient under fluctuating live load conditions. Furthermore, the observation that different live load cases govern positive and negative moments (Class 70R and Class A) reinforces the importance of considering multiple traffic loading scenarios in bridge design to capture critical effects accurately (Grubb & Hall, 2019).

Table 8. Comparison of Bending Moment under Dead load

Girder System	Positive Moment (kN-m)	Negative Moment (kN-m)
SSEB	9968.16	-35.14
SSRS	9976.16	-27.16
CGEB	6392.38	-8389.8
CGRS	6408.75	-8370.82

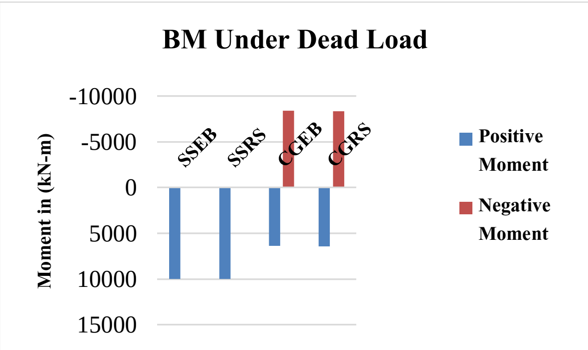

Figure 7. Bending Moment under Dead Load

Table 9. Comparison of BM under Live load

Girder System	Positive Moment (kN-m)	Negative Moment (kN-m)
SSEB	3933.84	-415.03
SSRS	3980.24	-215.87
CGEB	2995.84	-1922.39
CGRS	3663.01	-2311.99

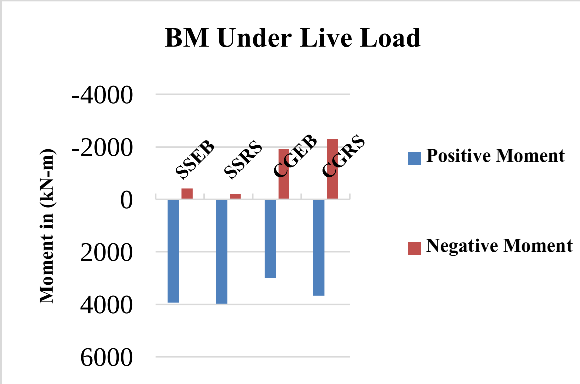

Figure 8. BM under Live Load

Shear Force Results (kN)

The shear force behavior of the PSC I-girder bridge was analyzed under dead load and live load conditions to evaluate the critical transverse forces acting on the girders. Dead load shear forces are generated by the self-weight of structural components such as girders, deck slab, and diaphragms, which produce constant shear demand along the span. Live load shear forces were computed by applying moving vehicle loads in accordance with IRC:6-2017, capturing the influence of axle positions and load distribution across lanes. The analysis was performed for both simply supported and continuous span configurations with elastomeric bearings and roller supports, enabling a comparative assessment of shear demand under different boundary conditions. (Jagandatta et al., 2022), (Rao et al., 2022), and (Sharma et al., 2022) demonstrated that parametric and software-aided modeling using MIDAS Civil allows precise computation of shear envelopes, considering live load positions, prestress effects, and continuity conditions. The maximum shear envelopes obtained from the analysis were checked against the design shear resistance of the PSC sections to ensure compliance with the strength limit states specified in IRC:112-2011.

The shear force results under dead load (Table 10 and Figure 9) show that simply supported systems (SSEB and SSRS) carry lower maximum shear values of about 987.7 kN, whereas continuous systems (CGEB and CGRS) develop comparatively higher shear forces of around 1238.5 kN. This increase in shear for continuous girders is attributed to the redistribution of bending effects, where a portion of the mid-span moment is transferred to supports, thereby intensifying shear demands near the support regions. While the higher shear in continuous systems requires careful shear reinforcement detailing, the overall advantage lies in the reduction of mid-span bending stresses and improved serviceability. Earlier research has also highlighted that continuity generally enhances structural stiffness and performance but at the cost of increased shear forces at supports, which must be adequately addressed in design to prevent web cracking and shear-related failures (Bagade et al., 2020). Thus, the results reaffirm the balance between shear demand and bending moment redistribution in PSC I-girder bridges, where continuous systems provide better long-term performance, provided sufficient shear capacity is ensured.

The shear force results under live load (Table 11 and Figure 10) indicate moderate variation among the girder systems. The maximum shear demand is observed in the continuous girder with roller supports (CGRS), reaching 550.34 kN, followed by the SSRS system at 532.62 kN. The simply supported elastic bearing (SSEB) shows slightly lower shear of 521.77 kN, while the continuous girder with elastic bearings (CGEB) records the minimum value of 501.98 kN. All systems are governed by the Class 70R loading with footway, confirming its critical influence on shear behavior. These results highlight that continuity does not always lead to higher shear forces, as seen under dead load; instead, shear distribution under moving loads is influenced by support conditions and load transfer mechanisms. Previous research has also pointed out that while continuous systems generally improve stiffness and reduce deflections, live load shear demands may vary depending on load placement and support fixity, requiring careful consideration in design. Overall, the results confirm that shear under moving loads is comparatively less severe than dead load shear but remains a crucial parameter for ensuring safety and serviceability of PSC I-girder bridges.

Table 10. Comparison of SF under Dead load

Girder System	Max Shear (kN)
SSEB	987.72
SSRS	987.72
CGEB	1238.5
CGRS	1238.5

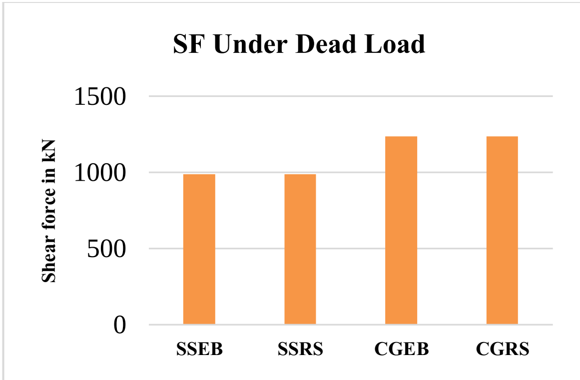

Figure 9. SF under Dead Load

Table 11. Comparison of SF under Live load

Girder System	Max Shear (kN)
SSEB	521.77
SSRS	532.62
CGEB	501.98
CGRS	550.34

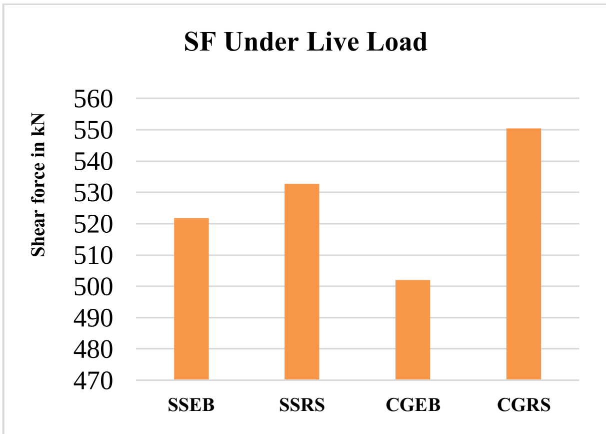

Figure 10. SF under Live Load

Torsional Response (kN-m)

The torsional behavior of the PSC I-girder bridge was evaluated under dead and live load conditions to quantify twisting moments along the girder length. Dead load-induced torsion primarily results from eccentric self-weight of the deck, girders, and diaphragms, producing relatively uniform torsional moments along the span. Live load-induced torsion was computed by applying moving vehicle loads in accordance with IRC:6-2017, accounting for asymmetric lane loading, axle positions, and transverse load distribution. Analyses were performed for both simply supported and continuous span configurations with elastomeric bearings and roller supports to assess the influence of boundary conditions on torsional demands. The maximum torsional envelopes were compared with the torsional capacity of the PSC sections to verify compliance with IRC:112-2011 strength criteria.

The torsional response under dead load (Table 12 and Figure 11) remains relatively small for all girder systems, reflecting the limited effect of self-weight in inducing twisting. Among the simply supported systems, SSEB and SSRS exhibit torsional moments of about 38 kN-m, whereas the continuous systems (CGEB and CGRS) show slightly lower values, around 29 kN-m. This reduction in torsion for continuous systems can be attributed to improved structural continuity, which provides better restraint against twisting compared to single-span action. Although torsion due to dead load is not critical in magnitude, it is significant for assessing overall stability and ensuring adequate detailing at supports and diaphragms. Earlier studies have also emphasized that torsional effects, while secondary compared to bending and shear, can become critical in regions of geometric irregularities or eccentric loading; hence, their inclusion in analysis is essential for a complete evaluation of PSC I-girder bridge performance.

The torsional response under live load (Table 13 and Figure 12) is significantly higher than that under dead load, highlighting the influence of eccentric and moving traffic loads. The maximum torsion is recorded in the SSRS system at 178.63 kN-m, followed by CGRS at 150.74 kN-m and SSEB at 157.53 kN-m, while the CGEB system shows the lowest torsional effect at 92.05 kN-m. The governing load case for most systems is the Class 70R with footway, except SSEB, which is critical under the Class A loading. This variation indicates that support conditions and continuity play an important role in how torsional effects are distributed in PSC I-girders. Consistent with previous research findings, simply supported systems are generally more vulnerable to torsional effects due to reduced lateral restraint, whereas continuity helps minimize torsional demand by redistributing load effects. Arioli & Gazzola (2017) also demonstrated that neglecting torsional effects can lead to significant instability in bridge structures, emphasizing the necessity of including torsional analysis in design. Nonetheless, the results confirm that torsion under live load, though secondary compared to bending and shear, cannot be neglected in design, as it governs the stability of girders under eccentric wheel loads, skew arrangements, and asymmetric traffic conditions. Proper detailing of diaphragms, cross girders, and torsional reinforcement is therefore essential for ensuring long-term safety and serviceability.

Table 12. Comparison of Torsion under Dead Load

Girder System	Max Torsion (kN-m)
SSEB	38.01
SSRS	37.85
CGEB	28.9
CGRS	28.68

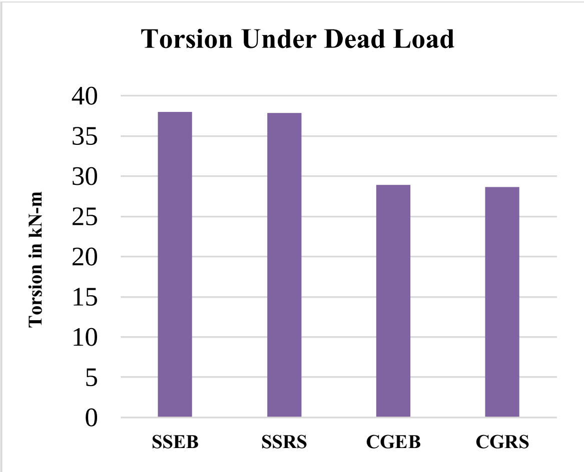

Figure 11. Torsion under Dead Load

Table 13. Comparison of Torsion under Live Load

Girder System	Maximum Torsion in kN-m
SSEB	157.53
SSRS	178.63
CGEB	92.05
CGRS	150.74

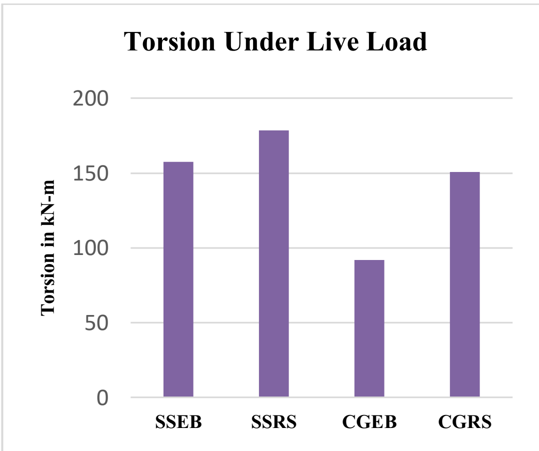

Figure 12. Torsion under Live Load

Seismic Analysis (Response Spectrum Analysis)

The seismic behavior of the PSC I-girder bridge was investigated using Response Spectrum Analysis (RSA) to determine the dynamic response under earthquake excitations. The analysis considered time-independent, linear-elastic behavior of the structure, with modal properties derived from the bridge's mass and stiffness distribution. Both simply supported and continuous span configurations were modeled with elastomeric bearings and roller supports to capture the influence of boundary conditions on seismic demand. The response spectrum was constructed in accordance with relevant codes, capturing the effects of fundamental and higher modes of vibration on lateral and vertical responses. Maximum displacements, bending moments, shear forces, and torsional moments obtained from RSA were evaluated against design limits to ensure structural safety and compliance with seismic provisions.

The maximum displacement (Table 14 and Figure 13) of the PSC I-girder bridge under dynamic loading was evaluated using Response Spectrum Analysis (RSA) to simulate seismic effects. Dynamic displacements were computed considering contributions from the fundamental and higher vibration modes, capturing both lateral and vertical motion of the girders. The analysis incorporated the effects of boundary conditions, including simply supported and continuous spans with elastomeric bearings and roller supports, to assess their influence on structural flexibility. Peak displacement envelopes along the span were identified and compared with code-specified limits to ensure serviceability and structural integrity under seismic excitations (Preethi & Arunakanthi, 2023).

The seismic response of PSC I-girders, evaluated through response spectrum analysis, highlights notable differences based on girder type, support system, and seismic zone intensity. For moderate seismic conditions (Zone II), simply supported systems (SSEB and SSRS) experience maximum displacements of 12 to 17 mm in the X direction and 14 to 19.5 mm in the Y direction, whereas continuous girders (CGEB and CGRS) exhibit slightly lower displacements of 11.9 to 16.9 mm (X) and 13.1 to 19.5 mm (Y), reflecting the benefit of continuity in restraining lateral and longitudinal movements. In high seismic zones (Zone V), the displacement values increase significantly due to amplified seismic forces, with simply supported systems reaching 43 to 61 mm (X) and 50 to 70 mm (Y), while continuous systems show marginally lower values of 42.8 to 60.7 mm (X) and 47 to 70.2 mm (Y). These results indicate that continuous support provides improved stiffness and load redistribution, which reduces overall deck displacement and improves structural stability during seismic events. The slightly higher displacements in the Y direction suggest that lateral seismic forces dominate bridge response, particularly for asymmetric loading or skewed decks. Moreover, the variation between SSEB and SSRS demonstrates that bearing types influence seismic performance, as elastomeric bearings allow more rotation and translation, while roller supports offer different restraint characteristics. Overall, continuous PSC I-girders enhance seismic resilience by limiting excessive deformation, reducing the likelihood of serviceability issues, and contributing to better energy dissipation through the bridge superstructure, as also reported in prior studies (Singh & Maru, 2023). Such insights emphasize the importance of considering both support continuity and bearing type in the seismic design of long-span prestressed concrete bridges, ensuring safety and durability under varying seismic demands.

The dynamic characteristics of the PSC I-girder bridge were determined by evaluating its natural periods and corresponding frequencies of vibration. Modal analysis was conducted to extract the fundamental and higher modes, capturing the bridge's global and local vibrational behavior. Both simply supported and continuous span configurations with elastomeric bearings and roller supports were analyzed to investigate the influence of boundary conditions on modal properties. The natural periods indicate the time required for the bridge to complete one cycle of free vibration, while the associated frequencies provide insight into the structure's susceptibility to dynamic excitations, including vehicular loads and seismic forces. These modal parameters were used to construct the response spectrum for seismic analysis and to ensure that the bridge's dynamic response remains within acceptable limits as per relevant IRC guidelines.

The natural period analysis for different girder support systems shows (Table 15 and Figure 14) a clear influence of support conditions on the dynamic characteristics of PSC I-girders. For the fundamental mode (Mode 1), simply supported systems (SSEB and SSRS) exhibit higher periods of 2 to 4.43 sec, indicating more flexible behavior, whereas continuous systems (CGEB and CGRS) demonstrate lower periods of 1.94 to 4.01 sec, reflecting increased stiffness due to continuity. Across higher modes, the differences in periods decrease, with Mode 4 onwards showing convergence around 0.6 to 0.1 sec, suggesting that higher-mode vibrations are less sensitive to support type. Overall, simply supported systems tend to have longer fundamental periods, implying greater displacement and susceptibility to lateral excitation under dynamic loads, such as seismic or vehicular vibrations. Continuous girders, with reduced fundamental periods, exhibit enhanced stiffness and improved resistance to dynamic effects. The trend observed in the graph, where periods sharply decrease from the first to the fourth mode and then stabilize, aligns with the typical dynamic behavior of long-span PSC I-girders, where the first few modes dominate the response, and higher modes contribute marginally to overall displacement. This analysis emphasizes the importance of considering support continuity in the dynamic design of bridges, as it significantly affects fundamental period, seismic response, and vibration control.

The natural frequency analysis for different girder support systems (Table 16 and Figure 15) reveals the significant influence of support conditions on the dynamic response of PSC I-girders. For the fundamental mode (Mode 1), simply supported systems (SSEB and SSRS) display lower frequencies of 1.42 to 3.13 rad/sec, indicating more flexible behavior, while continuous systems (CGEB and CGRS) exhibit slightly higher frequencies of 1.57 to 3.24 rad/sec, reflecting increased stiffness due to structural continuity. As higher modes are considered, the differences in natural frequencies become more pronounced in intermediate modes (Modes 2 to 6), with continuous systems consistently demonstrating higher frequencies, implying enhanced resistance to vibrational excitation. From Mode 7 onwards, the frequencies of all systems gradually converge, indicating that higher-mode vibrations contribute marginally to overall dynamic response. This trend, where the first few modes dominate the system's behavior and higher modes show minor variation, is consistent with prior studies on long-span PSC I-girders (Patidar, 2022; Qassim & Ali, 2021). Overall, continuous girder systems exhibit higher natural frequencies across most modes, highlighting improved stiffness, reduced dynamic displacement, and better performance under seismic and vehicular loads. These results emphasize the critical role of support continuity in the dynamic design and vibration control of PSC I-girder bridges.

Table 14. Seismic Performance of Girders in Terms of Maximum Displacement

Seismic Zones	Girder System	Max. Displacement in X direction (mm)	Max. Displacement in Y direction (mm)
Zone II	SSEB	12.03	13.94
	SSRS	17.06	19.44
	CGEB	11.89	13.1
	CGRS	16.86	19.5
Zone V	SSEB	43.31	50.18
	SSRS	61.42	70
	CGEB	42.82	47.15
	CGRS	60.69	70.19

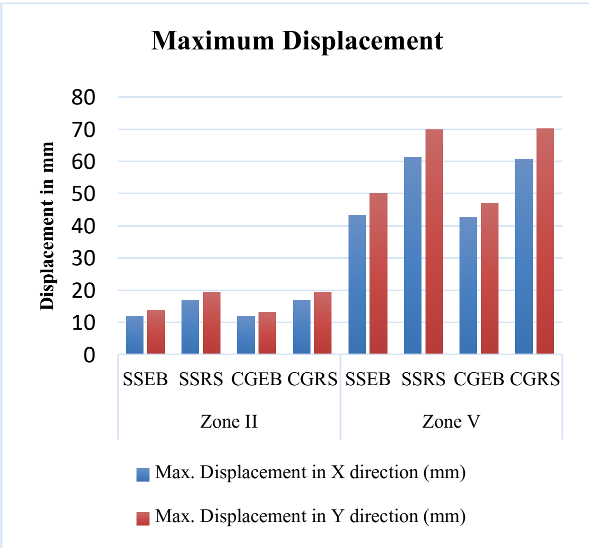

Figure 13. Maximum Displacement under Seismic Load

Table 15. Natural Periods of Vibration for Different Girder Support Systems

Period in (sec)				
Mode	SSEB	SSRS	CGEB	CGRS
Mode 1	2.004359	4.427992	1.938611	4.01121
Mode 2	1.734008	2.949479	1.727375	2.915139
Mode 3	1.388915	2.458026	1.349862	2.448674
Mode 4	0.603608	0.609123	0.601969	0.606868
Mode 5	0.503375	0.505451	0.46848	0.467454
Mode 6	0.460938	0.48888	0.378384	0.392925
Mode 7	0.347503	0.34651	0.329013	0.32825
Mode 8	0.333975	0.330823	0.322395	0.322451
Mode 9	0.329776	0.328575	0.319787	0.318224
Mode 10	0.322835	0.322094	0.300318	0.297808
Mode 11	0.322131	0.321712	0.277988	0.275195
Mode 12	0.302117	0.299664	0.236018	0.236014
Mode 13	0.282627	0.281213	0.235856	0.235851
Mode 14	0.235932	0.235931	0.226653	0.225818
Mode 15	0.235874	0.235868	0.224834	0.224143
Mode 16	0.222773	0.222585	0.213536	0.21345
Mode 17	0.204174	0.205073	0.196398	0.197928
Mode 18	0.177468	0.176727	0.168335	0.16669
Mode 19	0.149812	0.148859	0.134141	0.134439
Mode 20	0.129427	0.129435	0.12076	0.118558

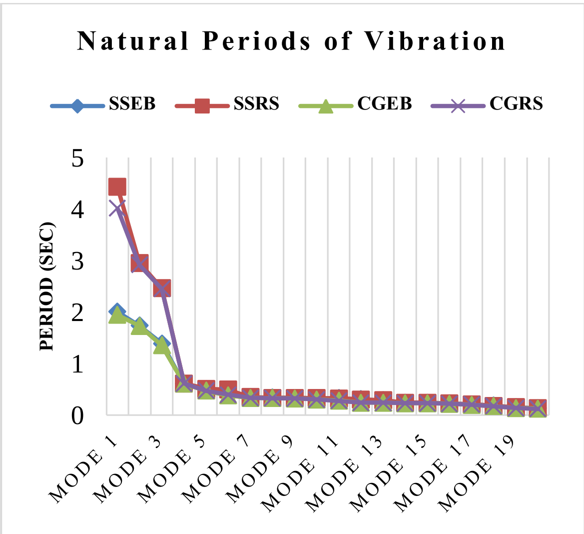

Figure 14. Natural Periods of Vibration

Table 16. Natural Frequencies of Vibration for Different Girder Support Systems

Frequency in (rad/sec)				
Mode	SSEB	SSRS	CGEB	CGRS
Mode 1	3.13476	1.418969	3.241076	1.566406
Mode 2	3.623503	2.130269	3.637419	2.155364
Mode 3	4.52381	2.556192	4.654687	2.565954
Mode 4	10.409377	10.315129	10.437721	10.353471
Mode 5	12.482125	12.43085	13.411847	13.441293
Mode 6	13.631297	12.852196	16.605294	15.990782
Mode 7	18.080929	18.132781	19.09705	19.141468
Mode 8	18.813334	18.992584	19.489077	19.485721
Mode 9	19.052861	19.122538	19.648056	19.74453
Mode 10	19.462512	19.507332	20.921771	21.098073
Mode 11	19.505063	19.530488	22.602337	22.831718
Mode 12	20.797209	20.967465	26.621582	26.622132
Mode 13	22.231387	22.343172	26.639925	26.640469
Mode 14	26.631386	26.631417	27.721662	27.824103
Mode 15	26.637895	26.63859	27.945862	28.032045
Mode 16	28.204372	28.228283	29.424537	29.436337
Mode 17	30.773706	30.63876	31.992068	31.744863
Mode 18	35.404624	35.553054	37.325416	37.693847
Mode 19	41.940403	42.208873	46.839998	46.736444
Mode 20	48.546212	48.543321	52.030204	52.996877

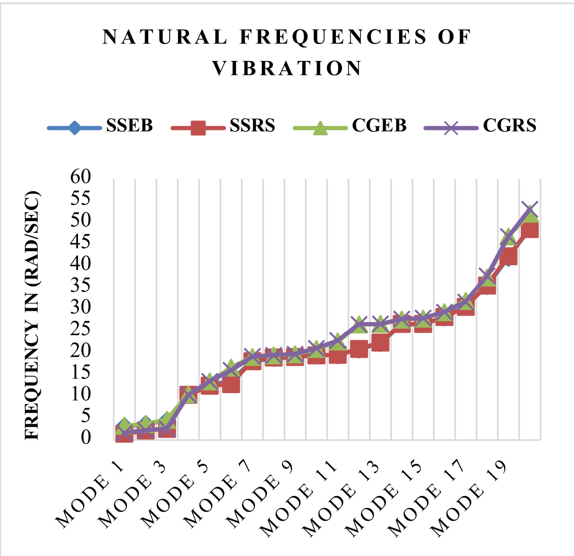

Figure 15. Natural Frequencies of Vibration

Conclusion

The comprehensive analysis of the three-span PSC I-girder bridge demonstrates the significant impact of support conditions and bearing types on structural performance. Continuous girder systems (CGEB and CGRS) exhibited superior stiffness and serviceability, with up to 45% reduction in dead load deflections and markedly lower live load deflections compared to simply supported systems (SSEB and SSRS). Moment redistribution in continuous girders effectively reduced positive mid-span bending while inducing substantial negative support moments, consistent with established research emphasizing improved redundancy, ductility, and long-term durability in continuous PSC bridges. Shear and torsional responses revealed that while maximum shear forces increased near supports in continuous systems, torsional effects were minimized, particularly in elastomeric bearing configurations, highlighting their effectiveness in controlling eccentric load effects.

Seismic performance analysis indicated that continuous girders with elastomeric bearings achieved lower maximum displacements and higher natural frequencies, contributing to enhanced dynamic stability under both moderate and high seismic zones. Overall, the continuous girder with elastic bearings (CGEB) emerged as the most efficient and resilient configuration, offering optimal balance between strength, serviceability, and seismic response, whereas roller-supported systems displayed relatively higher deflections, torsion, and seismic displacements. These findings corroborate earlier studies on long-span PSC I-girders, reaffirming that continuity and appropriate bearing selection are critical for ensuring safety, durability, and performance under static, dynamic, and seismic loads.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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