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Comparative Study of RCC and PSC Piers

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Abstract

Bridges are special structures that connect two locations, facilitating trade and mobility while overcoming obstacles such as rivers, valleys, and uneven terrain. Their design involves an integration of science, technology, and aesthetics, requiring careful consideration of structural stability, seismic resistance, material efficiency, and sustainability. Bridge piers are critical components of transportation infrastructure, traditionally constructed using Reinforced Cement Concrete (RCC) due to ease of design and construction. Moreover, the demand for longer spans, reduced cross-sections, and enhanced durability has led to the adoption of Prestressed Concrete (PSC) piers. This study compares RCC and PSC piers under identical loading, geometric, and soil conditions, evaluating parameters such as strength, deflection, cracking, durability, and cost. The results show that PSC piers provide superior load capacity, reduced cracking, better deflection control, and improved long-term performance, making them suitable for modern bridge engineering.

Keywords: Reinforced Cement Concrete (RCC), Prestressed Concrete (PSC), CSI Bridge.

1.Introduction

Bridge piers play an important role in the overall safety, serviceability, and durability of bridge structures, as they are responsible for transferring superstructure loads to the foundation while resisting lateral forces induced by wind, seismic activity, water currents, and vehicular impact. Commonly, reinforced cement concrete (RCC) piers have been widely adopted due to their simplicity in design, ease of construction, and proven performance. Although, with the increasing demand for longer spans, slender substructures, and improved structural efficiency, prestressed concrete (PSC) piers have emerged as a viable alternative in modern bridge engineering.

Prestressed concrete piers offer several potential advantages over conventional RCC piers, including higher load-carrying capacity, improved durability, reduced tensile cracking, and better control over deflections. The introduction of prestressing allows for more slender and economical sections, which can be particularly beneficial in seismic regions and for bridges with aesthetic or clearance constraints. In spite of these advantages, PSC piers involve higher initial costs, more complex construction techniques, and stringent quality control requirements, which may limit their widespread adoption in certain projects.

In this context, a systematic comparative study of RCC and PSC piers is essential to estimate their structural behaviour, material efficiency, and overall performance under various loading conditions. This study aims to compare RCC and PSC piers in terms of parameters such as stress distribution, material consumption, displacement and structural efficiency, using analytical and/or numerical methods. The findings of this comparison are intended to provide insights that can assist designers and engineers in selecting the most appropriate pier type based on performance requirements, economic considerations, and site-specific constraints.

1.1 Objectives

- To investigate the axial load, bending moment, and shear force responses of RCC and PSC piers.
- To compare Demand–Capacity (D/C) ratios and identify the governing critical sections affecting overall pier performance.

2. Literature Review

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Three different enhancing alternatives were employed to strengthen three severely damaged RC columns. Based on the experimental results, hysteresis curve, skeleton curve, the failure mood, energy dissipation ability, stiffness degradation, ductility, and strength degradation of both the original and improved test specimens were compared original columns, the ductility and energy dissipation capacity of the three strengthened test specimens were significantly improved. A finite element model based on the Open Sees was developed and validated by a comparison with experimental results.

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RC bridge piers in high seismic regions often tolerate damage due to insufficient design and repeated earthquakes, necessitating effective retrofitting strategies. Two 1:4 scaled RC piers were cyclically tested, retrofitted with HPSC jackets and FRP rebars at the plastic hinge zone, and advance estimated through experiments and SeismoStruct (2024) finite element modelling. The proposed HPSC–FRP retrofit significantly replace stiffness and strength, improves energy dissipation, and enhances seismic resilience, offering a reliable solution for expanding the service life of damaged bridge piers.

3. Methodology

CSI Bridge is an advanced bridge engineering software developed by Computers and Structures, Inc. (CSI) that uses finite element modelling for the analysis, design, and evaluation of bridge structures. It enables detailed 3D modelling of superstructure and substructure components using frame, solid, shell, tendon, and link elements, supporting both linear and nonlinear analyses including geometric and material nonlinearity.

CSI Bridge is a specialized structural analysis and design software used for the parametric modelling of the bridge components such as abutments, decks, piers, tendons, and bearings. It provides flexibility to create the models using predefined templates as well as fully user-defined configurations to meet the specific project requirements. The software supports the entire bridge design workflow, starting from the geometric modelling and material definition to advanced analyses, including seismic and moving load analysis. In addition, CSI Bridge performs code-based design checks within a unified modelling environment, which helps minimize modelling errors, improves accuracy, and increases overall design efficiency.

In this study, a typical precast T-beam bridge with a length of 72 m is modelled. The bridge consists of 5 spans with different parameters, as specified in the geometric details. A comparative study is conducted to evaluate the load-carrying capacity of the bridge using Reinforced Cement Concrete (RCC) piers and Prestressed Concrete (PSC) piers. The bridge is modelled using the obtainable templates in CSI Bridge software. The precast T-beam bridge bring about the template allows modification of structural properties as specified in the geometric details adhering to IS 456:2000, IRC 6 and IS 1893:2016 standards. For IS 1893: 2016 zone 5 spectrum, importance factor 1.0, response reduction 5 for beams, soil type II is considered.

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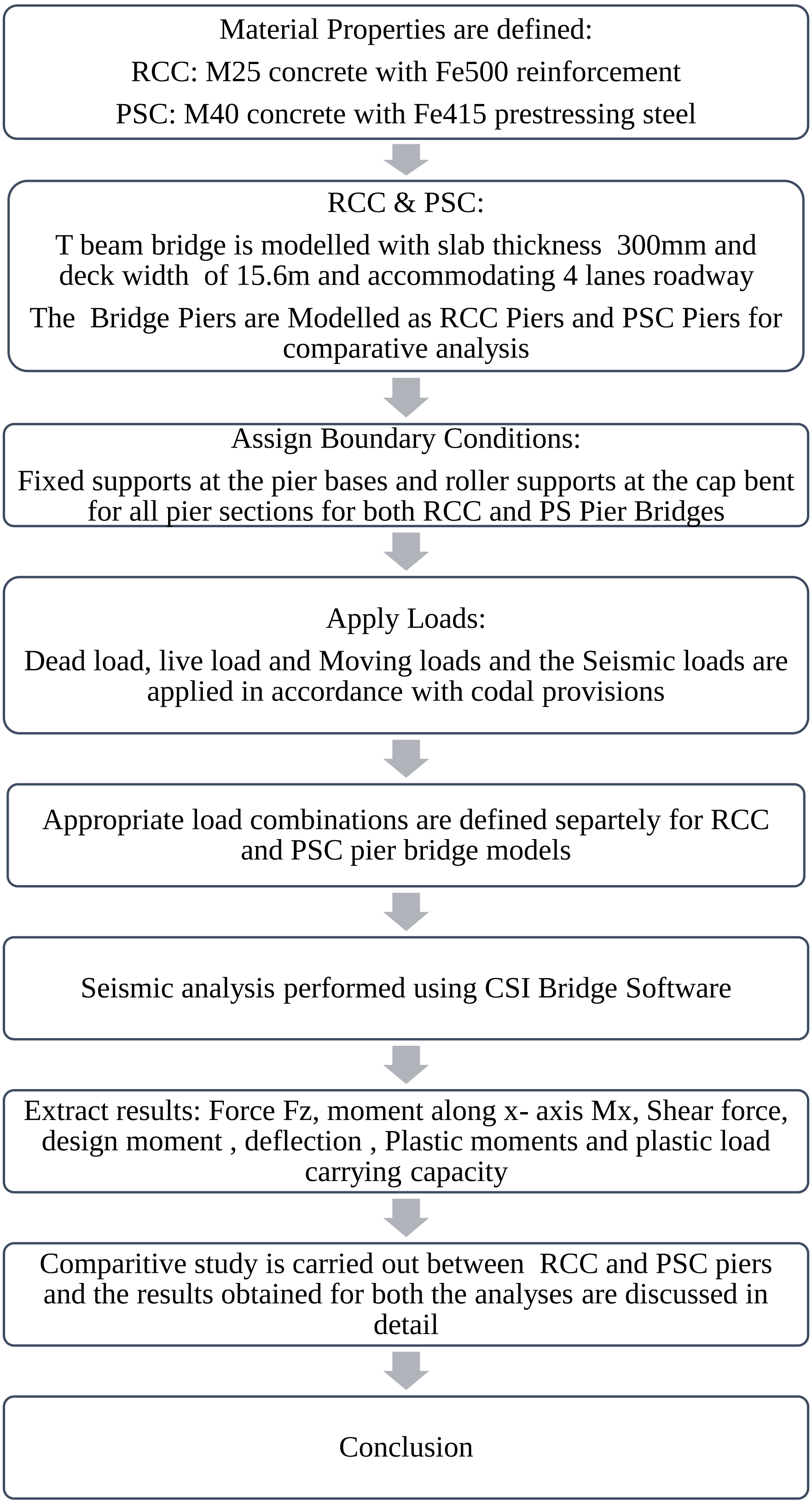


- Piers and abutments were modelled with the following parameters:
    - ➢ Pier height: 8m

- Foundation type: Isolated Foundation is modelled as Foundation springs.

3.1 Bridge Geometry details

RCC Piers

1.Total Span of the Bridge = 72m

2. Span details:

Table 1: Section Details of the RCC Bridge

Span Name	(Start) Station	(End) Station	Length
Span 1	0	12.75	12.75
Span 2	12.75	28.25	15.50
Span 3	28.25	43.75	15.50
Span 4	43.75	59.25	15.50
Span 5	59.25	72.00	12.75

3.The Abutment Section is of size = 3m x 2m

4. The Cap bent section is of size = 2m x 1.5m

5. No. of Column Supporting the Cap bent = 3

6. The Column/Pier is of Circular concrete section of Diameter = 1.2m

Table 2: Details of RCC Pier

Column Number	Section	Distance (m)	Height (m)
1	RCC Pier	3.3	8.
2	RCC Pier	7.3	8.
3	RCC Pier	11.3	8.

Frame Sections: The Frame sections are defined as the Abutment, Cap bent and RCC pier as per the requirements.

PSC Piers:

1. Total Span of the Bridge = 72m

2. Span details:

Table 3: Section Details of the PSC Bridge.

Span Name	Station (Start)	Station (End)	Length
Span 1	0	12.75	12.75
Span 2	12.75	28.25	15.50
Span 3	28.25	43.75	15.50
Span 4	43.75	59.25	15.50
Span 5	59.25	72.00	12.75

3.The Abutment section is of size = 3m x 2m

4.The Cap bent section is of size = 2m x 1.5m

5.The Pier is of Circular concrete section of Diameter = 1.2m

The Pier is designed using section designer and the details of the section properties used are shown below:

Table 4: Details of PSC Pier

Column Number	Section	Distance (m)	Height (m)
1	PSC Pier	3.3	8.
2	PSC Pier	7.3	8.
3	PSC Pier	11.3	8.

6.Number of Pier supporting the Cap bent = 3

7.The Reinforcement in concrete section = Tendons with force as 240kN

8.The Concrete grade used for the analysis = M40

The Frame sections are defined as the Abutment, Cap bent and PSC pier as per the requirements.

4. Results and Discussion:

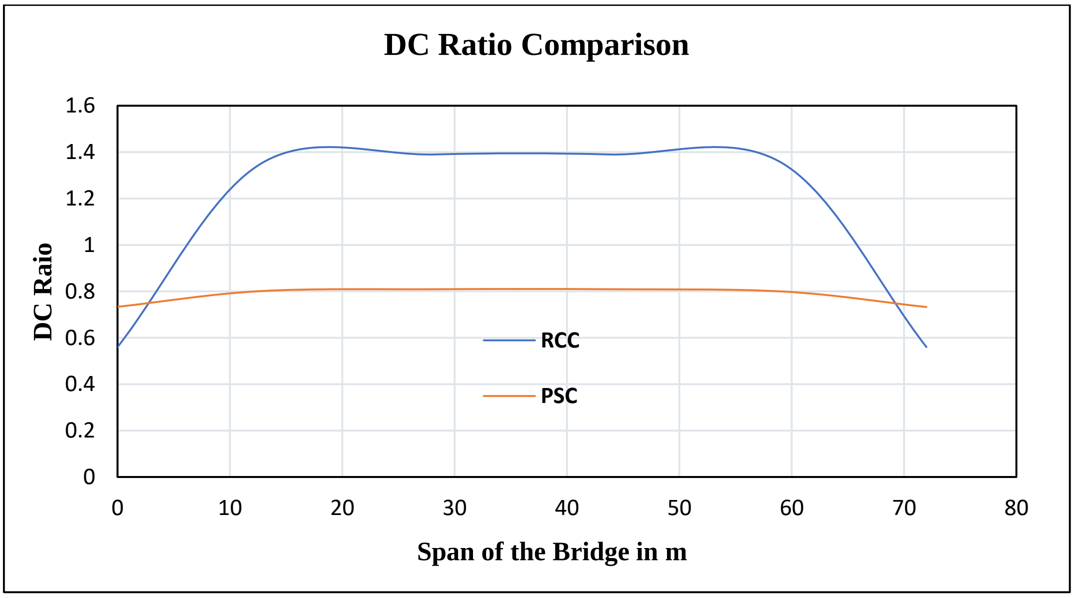
4.1 Results of the Demand Capacity Ratio: A comparison of the demand-capacity ratios of the both bridges is carried out through tabulation, and the results are also presented graphically.

Table 5: Comparison of DC ratio for both RCC and PSC Bridge

Span	Station	DC Ratio	
	m	RCC	PSC
Start Abutments	0	0.56	0.734
Span 2	12.75	1.35	0.802
Span 3	28.25	1.39	0.81

Span 4	43.75	1.39	0.81
Span 5	59.25	1.35	0.8
Span 1	72	0.56	0.733

Figure 1: Comparison of RCC and PSC Bridge for DC Ratio



Discussions:

At the abutments the RCC shows low DC Ratios (0.56) which indicates that the structure is safe and capacity is underutilized. At the mid spans the values rise sharply where the DC ratios exceed unity, which represents that the elements or the structure is under overstressed condition at these sections.

At abutments the PSC section shows higher values (0.733) which are well within limits and utilizing more capacity. At midspans the values are slightly more (0.8-0.81), however the DC ratios remain within unity and is safe.

The Comparative study highlights that the PSC piers performs better than the RCC piers in terms of DC ratio. PSC bridge is safer across all spans whereas the RCC structure show overstress at the mid spans.

4.2 Comparison of Results of Analysis with respect to Load carrying capacity:

The axial load carrying capacity of RCC and PSC bridges is compared by tabulating the results in table, and graphically represented.

Table 6: Comparison of Axial Load and shear force for both RCC and PSC Bridge

Span Name	Station	Axial Load P, kN		Shear Force(V2)		Shear Force(V3)	
	m	RCC	PSC	RCC	PSC	RCC	PSC
Start Abutment	0	200.1	345.28	117.88	209.06	18.1	64.16

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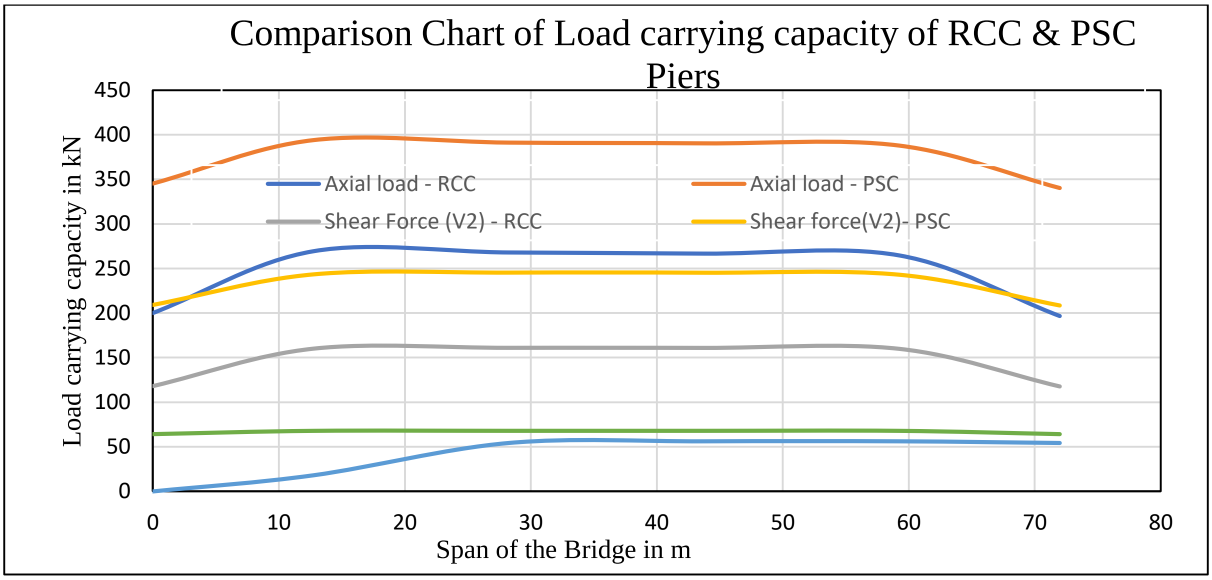
Span 2	12.75	269.4	394.1	159.98	243.39	54.3	67.85
Span 3	28.25	268.02	391.29	160.9	245.38	56.2	67.86
Span 4	43.75	266.71	390.46	160.82	245.25	56.2	67.86
Span 5	59.25	264.73	387.96	159.78	242.99	54.3	67.85
Span 1	72	196.73	340.25	117.5	208.42	18.1	64.16

Figure 2: Comparison of Load carrying capacity for RCC and PSC Bridge



Comparison in terms of Axial Load Carrying capacity: Above figure 2 shows load carrying capacity of the Reinforced Cement Concrete (RCC) and Prestressed Concrete (PSC) across all the span.

- At both abutments and mid-spans, PSC members carry significantly higher axial loads (≈340–345 kN at abutments and 388–394 kN at mid-spans) compared to RCC (≈200 kN and 265–270 kN respectively), primarily due to the contribution of prestressing forces.
- The lower axial loads in RCC members can result in higher bending and tensile stresses in critical regions, whereas the higher but well-balanced axial loads in PSC members reflect efficient prestress action, minimizing tensile stresses and cracking.
- PSC piers consistently carry about 40–50% higher axial loads than RCC piers; however, this increased load capacity translates into superior structural utilization, improved crack control, and enhanced durability rather than overstressing.

Comparison in terms of shear force carrying capacity: The above table and data show the comparison of the shear force comparison of Reinforced cement concrete and Prestressed concrete across all the spans.

- The PSC section carries higher loads than the RCC section due to the effect of prestressing.
- In RCC, the load varies from 118 kN at abutments to 160 kN at midspans.
- In contrast, PSC carries loads ranging from 208 kN to 245 kN from abutments to midspans.
- Load distribution in both RCC and PSC is generally uniform, with slightly higher concentration at midspans.

- Shear force (V3) in RCC ranges between 18 kN and 56 kN, indicating a balanced distribution.
- Maximum shear in RCC occurs at Span 3 and Span 4, owing to symmetrical geometry.
- The PSC section exhibits higher shear force values compared to RCC across all spans.
- Prestressing enhances the shear force carrying capacity of PSC, resulting in uniform but higher shear distribution.

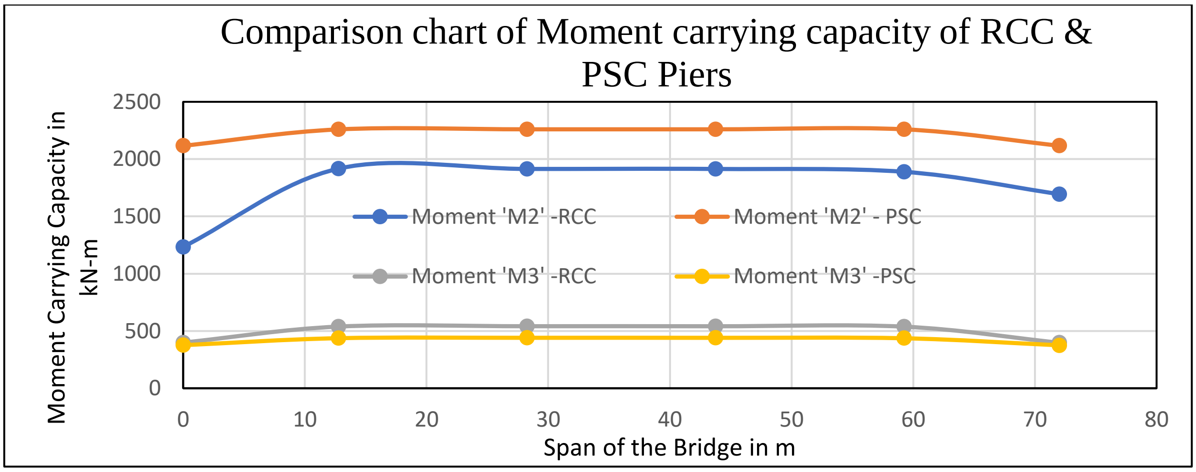
4.3 Comparison in terms of moment- carrying capacity:

A comparison of the Moment carrying capacity (M2 & M3) of the RCC and PSC bridge are tabulated and results are compared.

Table 7: Comparison of Moment M2 both RCC and PSC Bridge

Span Name	Station	Moment (M2) in kN-m		Moment(M3) in kN-m	
	m	RCC	PSC	RCC	PSC
Start Abutment	0	1234.42	2115.98	399.71	375.79
Span 2	12.75	1915.82	2258.22	539.47	438.39
Span 3	28.25	1913.29	2258.86	542.56	441.98
Span 4	43.75	1913.27	2258.86	542.31	441.76
Span 5	59.25	1888.42	2258.86	538.78	437.67
Span 1	72	1694.09	2117.02	398.28	374.73

Figure 3: Comparison of Moment carrying capacity for RCC and PSC Bridge



Comparative Evaluation of Moment Carrying Capacity for RCC and PSC systems: The above graph shows the comparison of the Moment carrying capacity comparison of the Reinforced Cement Concrete (RCC) and Prestressed Concrete (PSC) across all the spans.

- The RCC systems carries moment ranging from 234kN-m at the abutments to 1913 kN-m at the mid span indicating the uniform loading due to symmetry of the sections.

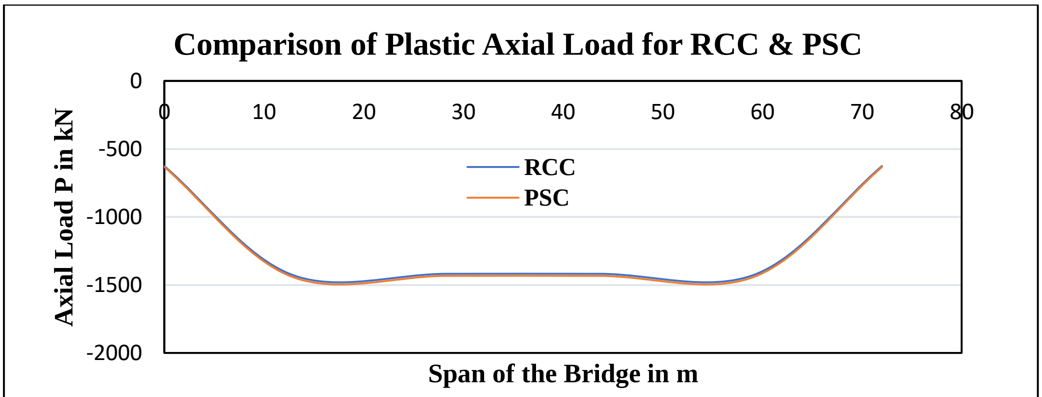
- The maximum moment occurs at Span 3 & 4 which shows higher flexural demand at the mid span. Higher bending moments are a direct result of prestressing, which pre-compresses the section and enhances flexural resistance.
- PSC piers consistently carry ~20–30% higher bending moments compared to RCC, but this translates into better stiffness, ductility, and durability.
- RCC exhibits higher bending moments across all spans compared to PSC, with values ranging from 399–543 kN·m at the start and midspan, whereas PSC moments lie between 375–442 kN·m.
- PSC consistently carries nearly 20% lower moments than RCC across all spans, indicating superior torsional moment resistance relative to RCC. PSC shows lower and more uniform moment distribution, demonstrating the effectiveness of prestressing in stress redistribution and overall structural efficiency.

4.4 Comparison of Results of Analysis with respect to Hinge Formation & Plasticity: A comparison of the Plastic Axial Load carrying capacity of the RCC and PSC bridge are tabulated and results are compared.

Table 8: Comparison of Axial load carrying capacity in Plastic state

Span Name	Station	Axial Load Capacity in kN	
	m	RCC	PSC
Start Abutment	0	-624.82	-632.95
Span 2	12.75	-1422.65	-1438.2
Span 3	28.25	-1417.76	-1433.41
Span 4	43.75	-1417.76	-1433.4
Span 5	59.25	-1422.51	-1438.03
Span 1	72	-624.94	-633.18

Figure 4: Comparison of Plastic Axial Load for RCC and PSC Bridge



Comparative Evaluation of Axial Load Carrying Capacity in Plastic state for RCC and PSC systems: The comparison of the Axial load carrying capacity comparison of the Reinforced Cement Concrete and Prestressed Concrete in Plastic state across all the spans.

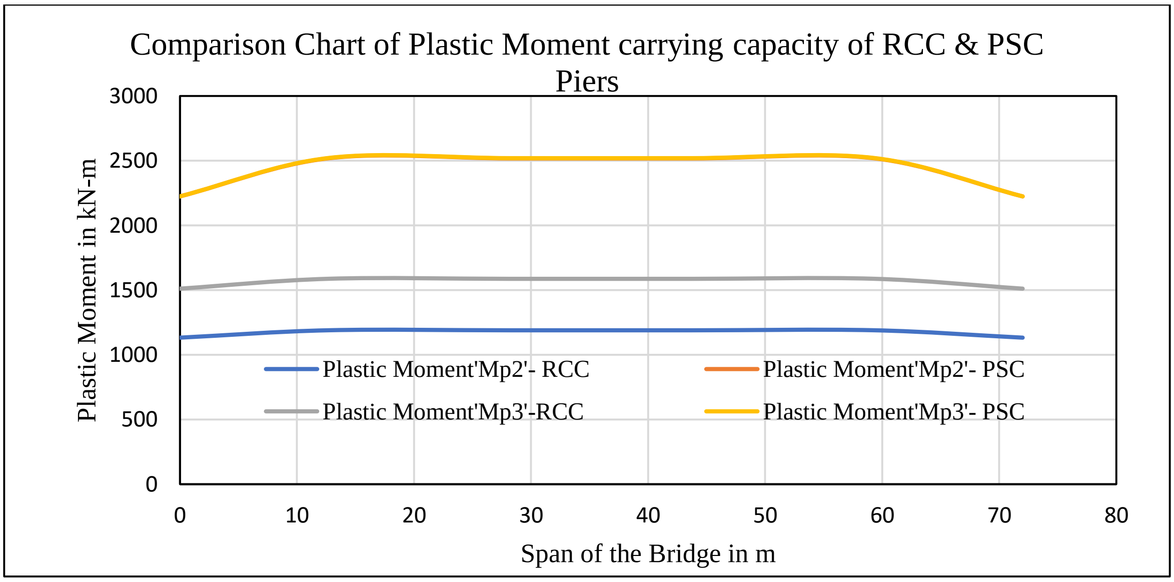
- PSC sections exhibit a slightly higher load-carrying capacity than RCC across all spans, with axial loads ranging from –632 kN to –1438 kN for PSC compared to –624 kN to –1422 kN for RCC.
- Both bridge types show lower axial loads at the start and end abutments, while the midspan experiences the maximum axial load.

4.5 Comparisons in terms of Moment Carrying Capacity in Plastic state: A comparison of the Moment carrying capacity (M2 & M3) of the RCC and PSC bridge are tabulated and results are compared.

Table 9: Comparison of Plastic moment carrying capacity for the both RCC and PSC Bridge

Span Name	Station	Moment (Mp2) in kN-m		Moment (Mp3) in kN-m	
	m	RCC	PSC	RCC	PSC
Start Abutment	0	1133.14	2225.309	1510.86	2225.757
Span 2	12.75	1191	2520.799	1588	2521.62
Span 3	28.25	1190.6	2518.992	1587.47	2519.816
Span 4	43.75	1190.6	2518.988	1587.47	2519.812
Span 5	59.25	1190.99	2520.734	1587.98	2521.562
Span 1	72	1133.15	2225.4	1510.87	2225.847

Figure 5: Comparison of Moment carrying capacity in Plastic state for RCC & PSC Bridge



Comparative Evaluation of Moment Carrying Capacity of Plastic state for RCC and PSC system: The comparison of the Moment carrying capacity of the Reinforced Cement Concrete and Prestressed Concrete in Plastic state across all the spans.

- PSC has higher Moment carrying capacity than the RCC sections across all spans. The moment capacity ranges from 1113kN-m to 1191kN-m for RCC and for PSC it ranges from 2225kN-m to 2520kN-m. For both the bridges the start and end abutments have Moment compared to the mid span.
- PSC shows significant higher moment carrying capacity compared to RCC due to its prestressing action which reduces the tensile stresses and enhances stiffness.
- Mid Spans experiences higher moments compared to start and end spans. PSC exhibits higher load capacity.

Conclusion:

The overall comparative evaluation indicates that PSC piers are better suited to meet higher flexural and axial load demands. They are especially advantageous for critical spans subjected to large moments and forces, while RCC piers may be adequate for less demanding spans. Although PSC piers exhibit higher strength, load-carrying capacity, and improved structural performance due to prestressing, RCC design procedures are well established and standardized in existing codes. In contrast, PSC design requires careful detailing and advanced understanding, which can limit its widespread adoption in practice.

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