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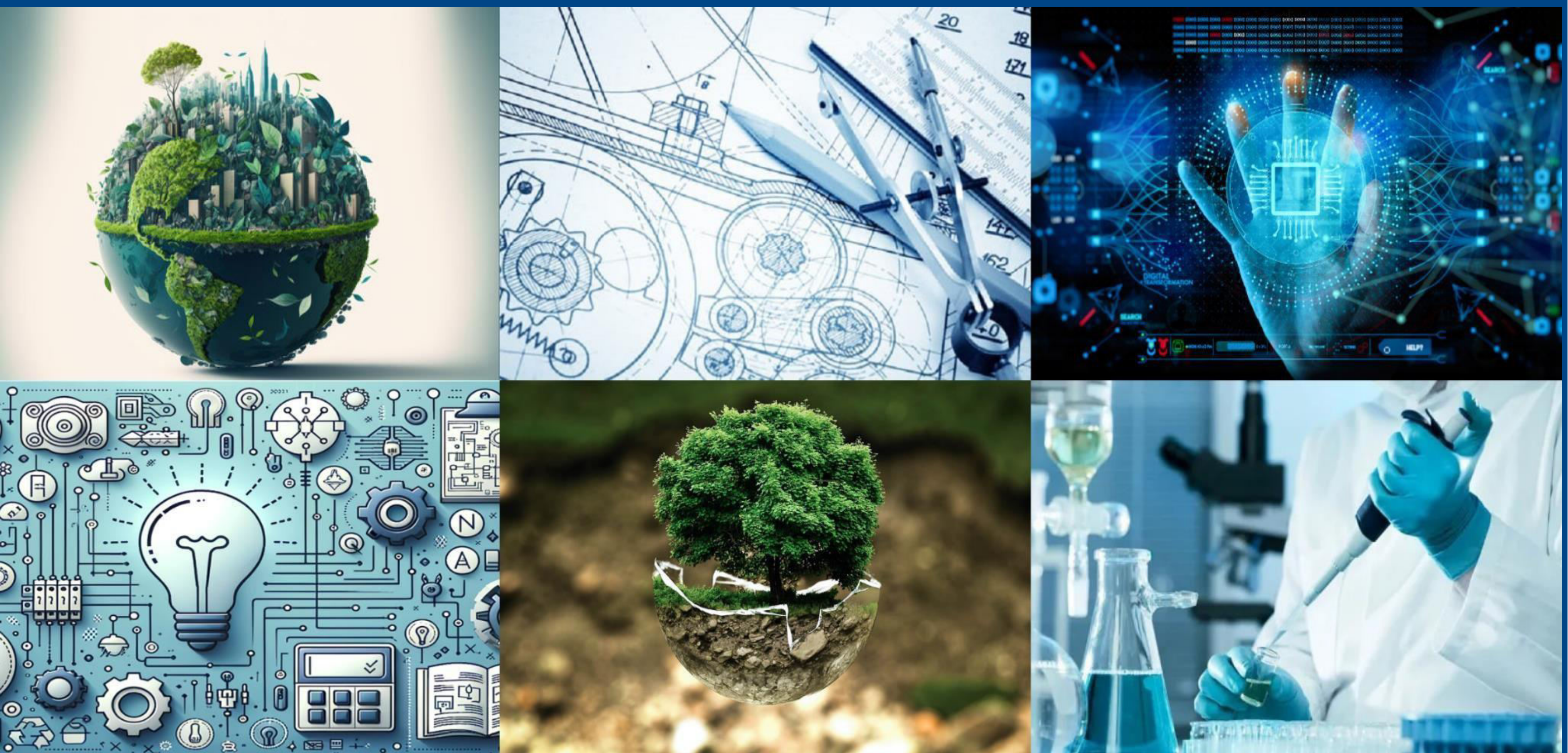

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Effect of Geometric Parameters on the Structural Response of PSC Box Girder Bridges using MIDAS Civil

Dunga Keerthi[1], Krishna Rao Boddepalli[2]

PG Scholar, Department of Civil Engineering, University College of Engineering Kakinada, JNTUK, AP, India[1]

Professor, Department of Civil Engineering, University College of Engineering Kakinada, JNTUK, AP, India[2]

ABSTRACT: This study presents a parametric analysis of prestressed concrete rectangular box girders by varying both span length and section depth. Four span lengths 30 m, 35 m, 40 m and 45 m were examined, and for each span, L/D ratios of 12, 14 and 16 were adopted to modify the effective depth of the girder. All models were developed in MIDAS Civil and analysed under dead load and IRC live loads. For live loading, either one lane of Class 70R or two lanes of Class A was adopted, based on the loading arrangement that governed the critical design effects. The structural system considered is a two-lane simply supported girder, evaluated under two primary cases: dead load plus live load (DL+LL), and dead load plus live load combined with prestressing (DL+LL+PS). Each span–depth model was checked for bending moment (BM), shear force (SF) and deflection to understand how changes in geometry and prestress influence the overall response. The comparison across all configurations shows clear variations with span and depth, and the inclusion of prestress leads to a notable reduction in these response values. The findings provide a clearer understanding of how span length, depth ratio and loading conditions influence the overall efficiency of PSC box girder sections.

KEYWORDS: PSC Box Girder, Parametric Analysis, IRC Loading, Prestressing Effects.

I. INTRODUCTION

Prestressed concrete (PSC) box girder bridges form an important class of modern highway structures due to their ability to span longer distances with improved stiffness and serviceability. Among these, the rectangular single-cell configuration is widely preferred because it offers balanced structural behaviour, and the efficient accommodation of prestressing tendons, and simpler construction compared to more complex multicell sections. The closed box form provides uniform stiffness in both longitudinal and transverse directions, enabling effective distribution of moving loads and enhanced performance under varying traffic conditions. In bridge design, geometric parameters such as span length, girder depth, web thickness, and flange dimensions play a crucial role in governing bending, shear, and deflection responses. Along with these, material properties and the prestressing layout significantly influence the overall strength and durability of the structure. As the demand for reliable and economical bridge systems continues to grow, understanding how these geometric and structural factors affect the behaviour of PSC box girders remains essential for developing designs that are both efficient and structurally sound.

II. LITERATURE REVIEW

Preeti A. et al. (2023) This study employs the finite element platform CSiBridge v20.0.0 to examine the structural behaviour of a single-cell prestressed concrete box girder subjected to Indian highway loading conditions. The bridge is modelled as a simply supported system in accordance with the provisions of IRC 6:2017, IRC 18:2000 and IRC 21:2000. The parametric variables include skew angles ranging from 0° to 60° at 10° intervals, span lengths from 35 m to 60 m in 5 m increments, and span-to-depth ratios of 10, 12, 14, 16 and 18. The resulting behaviour is evaluated in terms of bending moment, shear force, torsional moment and vertical deflection ratios.

Preeti A. et al. (2023) A study analysed simply supported single-cell RC curved box-girder bridges using FEM modelling in CSiBridge, validating the approach with an existing reference model. The investigation focused on how span length and curvature affect bending moment, shear force, torsion and deflection under dead and IRC live loads.

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Results showed that curvature angles up to about 12° cause only minor changes in structural behaviour, allowing such bridges to be treated as straight for analysis. The researchers also proposed non-dimensional equations to estimate forces and deflections in curved girders using straight-bridge behaviour, offering practical guidance for design.

Manjula R. et al. (2021) A study evaluated the behaviour of box girder bridges using SAP2000 by analysing single-cell, twin-cell and multi-cell configurations. With span and depth kept constant and width varied, the models were assessed according to IRC guidelines for bending moment, axial force and shear force. The findings showed that single-cell box girders recorded lower bending and shear forces than twin- and multi-cell sections, indicating that single-cell designs may offer better structural efficiency and cost-effectiveness in suitable applications.

Tanmay G. et al. (2018) Studied on skew–curved concrete box girders show that skewness and curvature interact in a coupled manner, making their flexural behaviour more complex than straight bridges. Research using 3D finite element modelling has reported increased torsional and warping effects under eccentric IRC live loads, with the inner web often experiencing higher flexural demands. These works also highlight that the critical live-load position and the location of maximum moment shift significantly with changes in skew and curvature.

Haidong H. et al. (2017) This research has also focused on the long-term behaviour of concrete box girders, particularly the effects of non-uniform shrinkage. Experimental and analytical studies show that differential shrinkage strains can introduce additional camber and deflection, which may lead to serviceability issues in large box-girder bridges. Investigations using small-scale specimens have examined how parameters such as section thickness, drying conditions and concrete mix influence shrinkage development. Advanced hydro-mechanical models have been used to predict shrinkage-induced bending in long-span bridges, with validations against field data showing good accuracy. These studies highlight the sensitivity of box-girder behaviour to shrinkage effects and the importance of considering section geometry when evaluating long-term performance.

K. M. Sennah. Et al. (2002) The reviewed study examined the elastic behaviour of box girder bridges and highlighted that the finite element method is the most reliable and versatile tool for analysing their static and dynamic response. The authors emphasized that FEM can account for all key factors influencing structural behaviour, making it the most suitable approach for detailed bridge analysis.

III. OBJECTIVES

- To analyze the shear forces, bending moments, and deflections in PSC box girder bridges with varying span- to-depth ratios.
- To evaluate the influence of span length on the key response parameters, namely bending moment, shear force and mid-span deflection.
- To perform the Parametric study on Prestressed concrete rectangular box-girder bridge using MIDAS.
- To compare the structural responses of models without prestressing (DL+LL) and with prestressing (DL+LL+PS) and quantify the reduction in bending moment, shear force and deflection caused by prestress.

IV. GEOMETRY AND MATERIAL SPECIFICATIONS

In this study, a series of simply supported PSC rectangular box girder models were developed using four different span lengths of 30 m, 35 m, 40 m and 45 m. For each span, three section depths corresponding to approximate L/D ratios of 12, 14 and 16 were considered in order to understand the influence of girder slenderness on the overall structural response. All models were assigned a constant deck width of 8.5 m, with a top flange thickness of 0.25 m, web thickness of 0.30 m on both sides, and a bottom flange thickness of 0.30 m, maintaining uniformity across the entire parametric set. The cross-sectional proportions of the box girder were selected in accordance with the general recommendations provided in IRC:21–2000. Figure 1 presents the cross-sectional view of the rectangular PSC box-girder used in the study, while Table 1 summarises the corresponding sectional dimensions adopted for the different bridge models.

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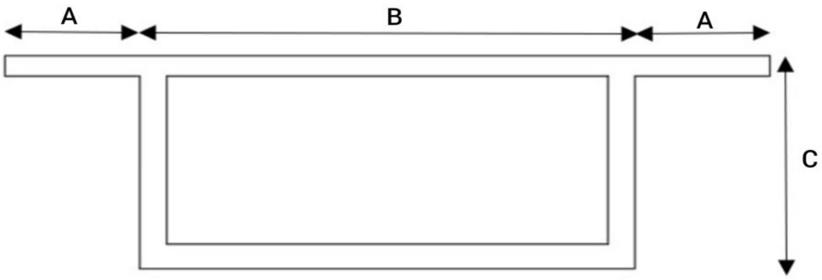

Fig. 1: Cross-section of box girder

Table 1: Dimensions of Cross-section of box girder

S.No	Length (m)	L/D	A (m)	B (m)	C (m)
1	30	12	1.5	5.5	2.6
2	30	14	1.5	5.5	2.3
3	30	16	1.5	5.5	2
4	35	12	1.5	5.5	2.9
5	35	14	1.5	5.5	2.5
6	35	16	1.5	5.5	2.2
7	40	12	1.5	5.5	3.3
8	40	14	1.5	5.5	2.9
9	40	16	1.5	5.5	2.6
10	45	12	1.5	5.5	3.7
11	45	14	1.5	5.5	3.2
12	45	16	1.5	5.5	2.8

After establishing the sectional geometry, the corresponding material properties for concrete, prestressing steel and reinforcement were assigned as per standard code provisions. These values are summarised below.

Concrete Properties
Grade of Concrete = M40
Modulus of elasticity, E = 3.35×10^7 kN/m^2
Poisson's ratio: 0.2
Density: 25 kN/m^3

Rebar Properties:
Grate of steel for Tendons Fe 540
Modulus of Elasticity = 2×10^8 kN/m^2
Poisson's Ratio = 0.3
Thermal Coefficient = 12×10^{-6} /°C

Tendons Properties:
No. of Tendons = 8
Type of Pre-stressing = Post-tensioned
Diameter of the strand = 15.2 mm

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Number of strands = 14
Diameter of the duct = 100 mm
Area of single tendon = 2537.5 mm^2
Ultimate Strength (F) = 1860 MPa
Yield Strength = 1569.06 MPa
Prestress applied = 1395 MPa

V. MODELLING AND METHODOLOGY

The methodology adopted in this study focuses on establishing a consistent and reliable modelling framework for PSC rectangular box girders of varying spans. MIDAS Civil was used to construct and analyse each model, incorporating the geometric data and material properties presented earlier.

MIDAS Civil Software:
MIDAS Civil is a comprehensive bridge engineering software used for modelling, analysis, and design of concrete and steel structures. It allows engineers to define sections, assign materials, model prestressing and apply code-based loads with high accuracy. Its user-friendly interface and reliable analytical capabilities make it well suited for PSC box girder studies like the one undertaken in this project.

For the present work, MIDAS Civil was employed to generate a series of single-span PSC box girder models with spans of 30 m, 35 m, 40 m and 45 m. Each model was assigned the corresponding geometric and material properties described in the previous chapter. The software's ability to handle prestressing, live load simulations and IRC-based load combinations made it particularly effective for assessing how changes in span length and L/D ratio influence bending moments, shear forces and deflections. The analysis workflow allowed the results for different configurations to be compared directly, ensuring a systematic understanding of the structural behaviour.

Loading details of Box girder bridge

1. Dead Load

The dead load represents the self-weight of the PSC box girder, automatically calculated from its geometry and a concrete unit weight of 25 kN/m³. The SIDL consists of a 16.5 kN/m wearing course and crash barrier loads of 7.5 kN/m applied along both deck edges.

2. Live Load

For a two-lane carriageway, Live Load cases were assigned as per Table 6A of IRC 6:2017. Two loading scenarios were evaluated: one with a single lane carrying a Class 70R vehicle and another with both lanes subjected to Class A loading. The lanes and their eccentricities were defined in the model according to the IRC provisions.

MODELLING PROCEDURE

1. Define material and section properties.
2. The geometry of the PSC box girder was prepared by defining the node coordinates, creating the longitudinal elements and assigning the appropriate material and cross-sectional properties to each element.
3. Define time dependant material properties.
4. Define rigid and elastic links and apply boundary conditions.
5. Define the tendon properties, assign the required tendons to the section, establish their profile along the girder length, and finally apply the tendon prestress.
6. Define loading cases (DL, SIDL and LL).
7. Perform the analysis and obtain the corresponding results.

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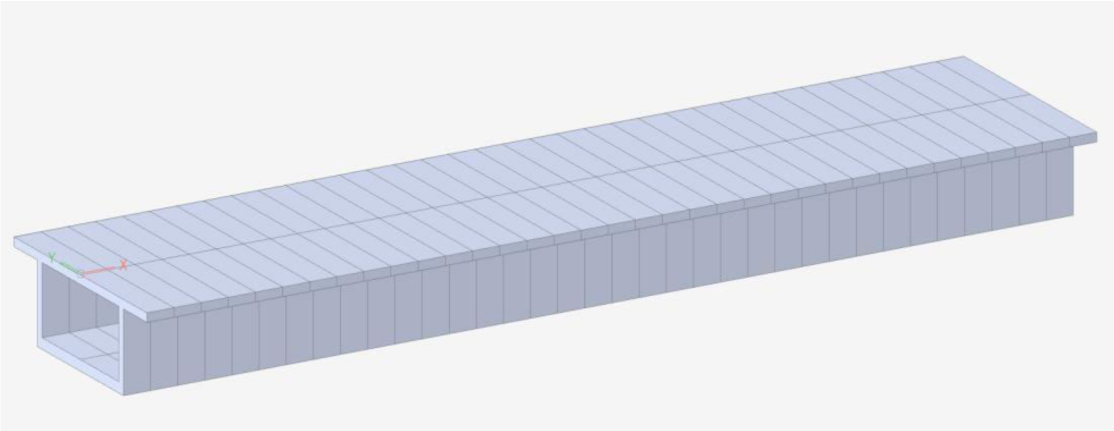

Fig. 2: Finite Element Model of the PSC Rectangular PSC Box Girder

To verify the reliability of the analytical model, a manual calculation was carried out for the 30 m span girder with an L/D ratio of 12. The bending moment, shear force and deflection obtained from the hand calculations were compared with the corresponding MIDAS Civil results. The close agreement between the two sets of values confirmed the accuracy of the modelling approach adopted in this study. Below are the results from manual calculation and from the software.

Table 2: Validation of Structural Response Parameters Using Manual and Software Results

S. No	Structural Parameter	Results form manual calculation	Results from software	Error
1	Bending moment	24,086.41 kN-m	23,479.3 kN-m	2.50%
2	shear force	3163.6 kN	3206.9 kN	1.30%
3	Deflection	13.68mm	14.14mm	3%

The comparison between manual calculations and MIDAS Civil results shows a very small variation, with errors of 2.5% in bending moment, 1.3% in shear force and 3% in deflection. These minor differences confirm that the numerical model is reliable and that the software accurately represents the structural behaviour of the PSC box girder.

VI. RESULTS AND DISCUSSION

A parametric study was performed on PSC box-girder models by varying span length and L/D ratio, and analysing them under DL+LL and DL+LL+PS conditions. The resulting bending moments, shear forces and deflections were compared to assess the influence of these geometric variations.

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Results for DL + LL load case
Bending moment

Table 3: Variation of Bending Moment with Span and L/D Ratio

L/D	Span-Wise Bending Moment Values (kN-m)			
	30M	35M	40M	45M
12	23479.3	31733.3	41667.2	55707.9
14	22989.9	30840.8	40497.2	51408.2
16	21725.7	30171.4	39619.7	49923.4

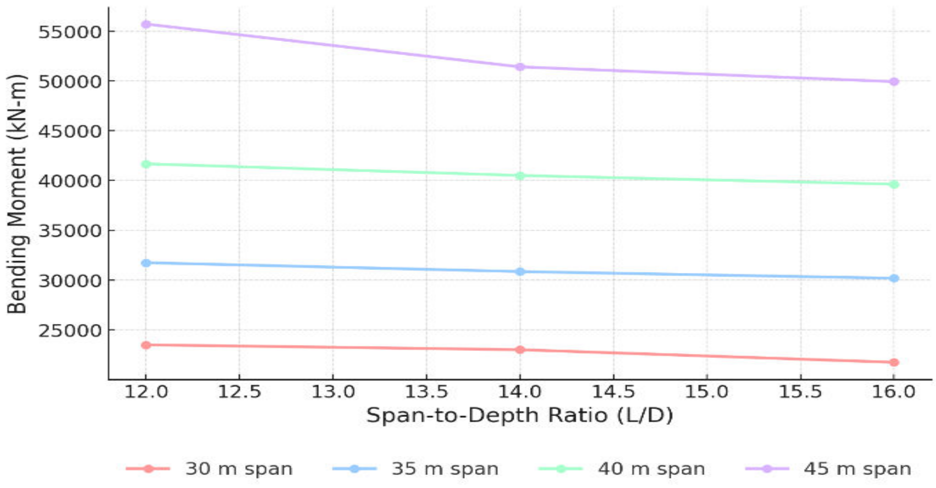

Fig. 3: Span-to-Depth ratio vs Bending Moment for DL + LL Case

Shear force

Table 4: Variation of shear force with Span and L/D Ratio for DL + LL Case

L/D	Span-Wise Shear force Values (kN)			
	30M	35M	40M	45M
12	3206.9	3709.9	4248	5073
14	3140.5	3606.4	4219.5	4686.4
16	2969	3528.8	4040.7	4552.9

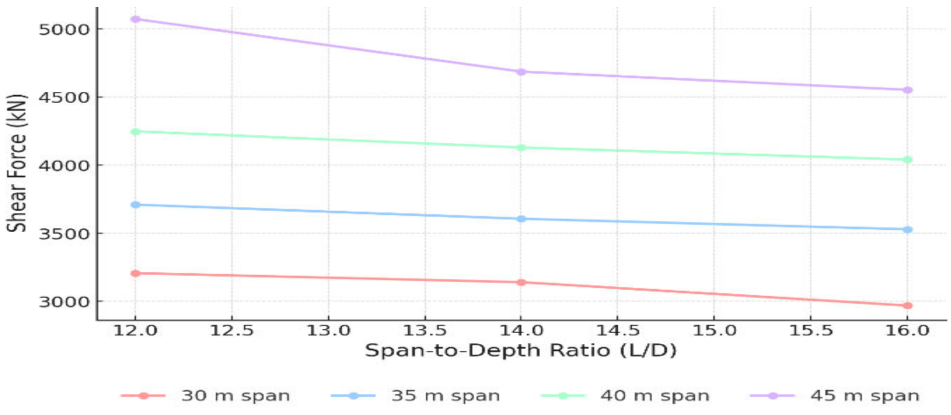

Fig. 4: Span-to-Depth ratio vs Shear Force for DL + LL Case

Deflection

Table 5: Variation of Deflection with Span and L/D Ratio for DL + LL Case

L/D	Span-Wise Deflection Values (mm)			
	30M	35M	40M	45M
12	14.14	22.52	28.2	35.94
14	16.1	25.74	31.73	39.62
16	18.73	29.72	35.76	46.19

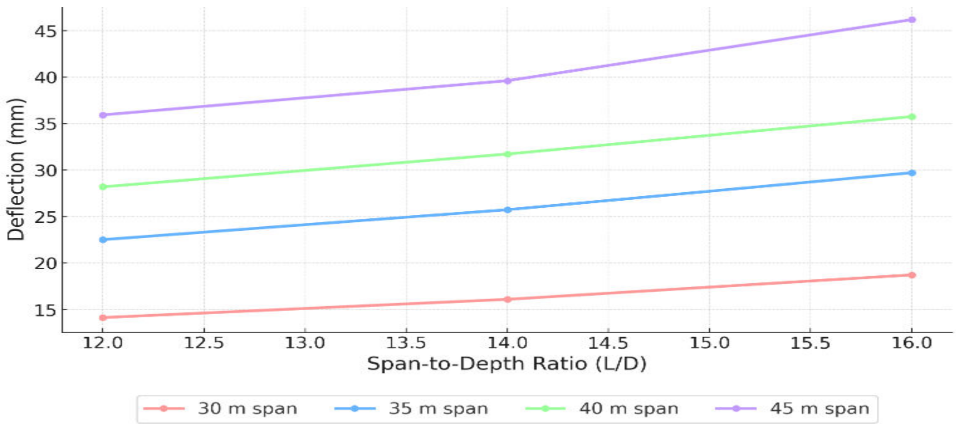

Fig. 5: Span-to-Depth ratio vs Deflection for DL + LL Case

The DL + LL results indicate that bending moment and shear force increase steadily with span length, reflecting the higher structural demand in longer girders. For any given span, both bending moment and shear force show a slight decrease as the L/D ratio increases, which corresponds to a reduction in section depth. In contrast, deflection increases noticeably with higher L/D ratios due to the reduced stiffness of the shallower sections. Overall, the table clearly shows that span length governs the magnitude of internal forces, while girder depth strongly influences the deflection behaviour.

Results for DL + LL + PS load case

This section summarises the structural response obtained under the DL + LL + PS load case for the different span and depth combinations. The outcomes include bending moment, shear force, and deflection for all analysed models.

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Bending moment

Table 6: **Variation of Bending Moment with Span and L/D Ratio for DL+ LL + PS Case**

L/D	Span-Wise Bending Moment Values (kN-m)			
	30M	**35M**	**40M**	**45M**
12	10047.6	15634.6	23171.5	31236.6
14	12274.3	18352.9	24509.4	32877.8
16	12999.2	20450.3	26330.5	34941.3

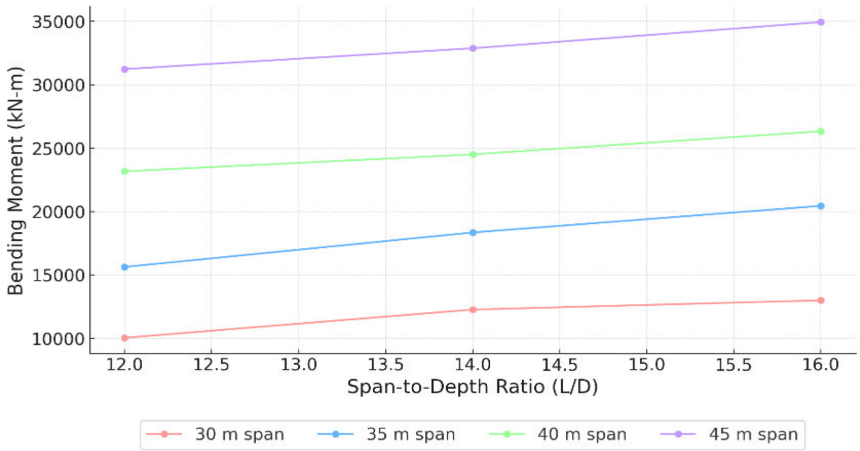

Fig. 6: Span-to-Depth ratio vs Bending Moment for DL + LL + PS Case

Shear force

Table 7: Variation of shear force with Span and L/D Ratio for DL+LL+PS Case

L/D	Span-Wise Shear force Values (kN)			
	30M	**35M**	**40M**	**45M**
12	1775.5	2334.9	2884.7	3162.3
14	2042.4	2518.9	2923.9	3332.8
16	2123.3	2657.8	3024.4	3535.9

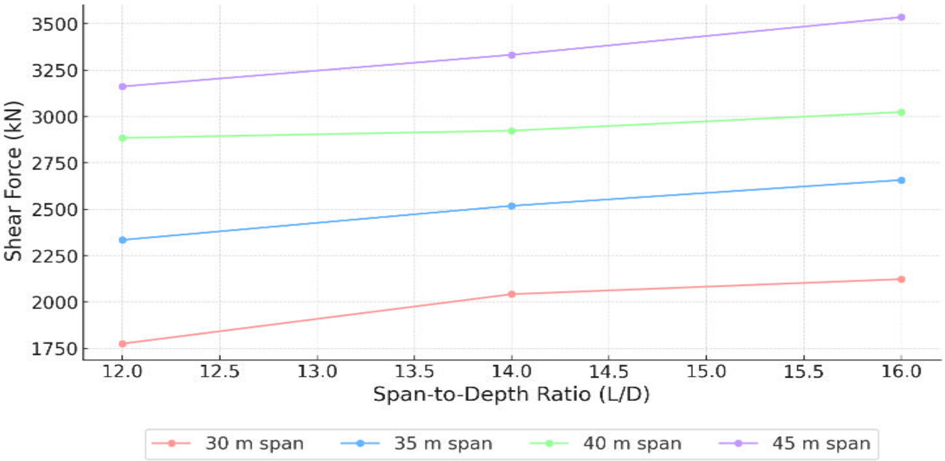

Fig. 7: Span-to-Depth ratio vs Shear Force for DL + LL + PS Case

Deflection

Table 8: Variation of Deflection with Span and L/D Ratio for DL + LL + PS Case

L/D	Span-Wise Deflection Values (mm)			
	30M	35M	40M	45M
12	8.107	13.32	18.08	23.49
14	10.06	15.8	20.3	25.98
16	12.2	19.4	23.25	31.305

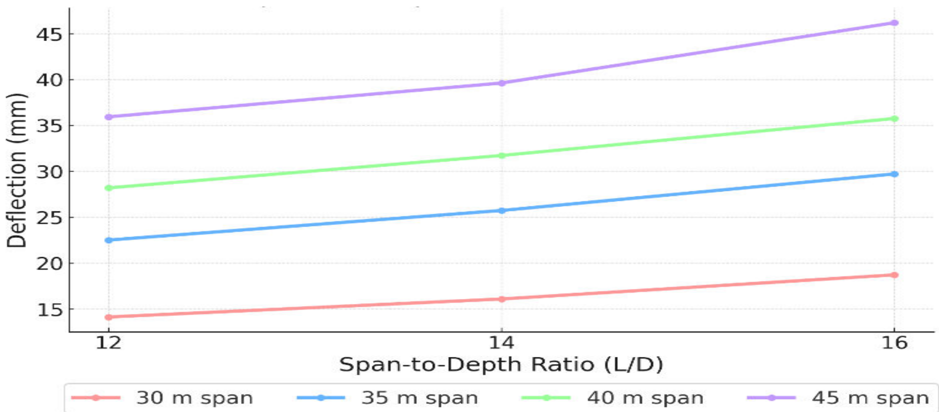

Fig. 8: Span-to-Depth ratio vs Deflection for DL + LL + PS Case

The graph shows with the same amount of prestress applied to all models we can clearly see how geometric parameters influence the structural response under the same prestress condition. we see prestressing reduces the overall response and the resulting values show a clear trend across the different spans and L/D ratios. Bending moment, shear force, and deflection all increase progressively with span length, with the highest values observed for the 45 m models. For any given span, these three parameters also rise as the L/D ratio increases, since the reduction in depth leads to lower stiffness and greater structural demand.

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Percentage Reduction Analysis

To better understand the effect of prestressing across the different geometric models, percentage reductions were computed for bending moment, shear force and deflection. The following graphs illustrate these reductions for each span length and L/D ratio, providing a clear comparison of performance improvements.

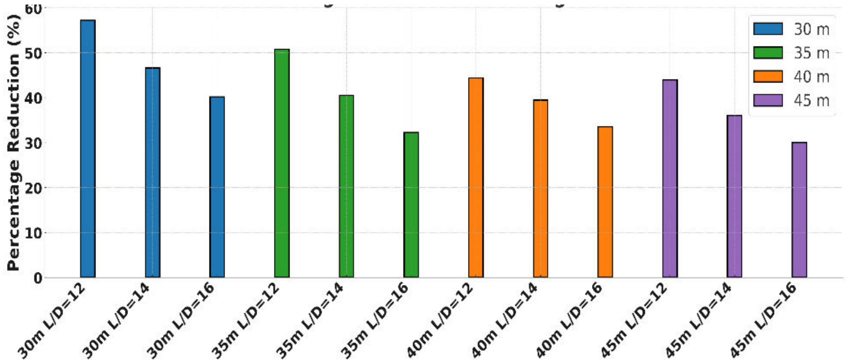

Fig. 9: Percentage reduction in bending moment for all models

The graph shows how the introduction of prestressing significantly reduces the bending moment in PSC box-girder bridges across all span lengths and L/D ratios. The reduction is highest for shorter spans (30 m) because the proportion of prestressing force relative to total applied load is larger. As the span increases to 35 m, 40 m, and 45 m, the percentage reduction gradually decreases since dead load increases faster than the beneficial effects of prestress. For all spans, increasing the L/D ratio (i.e., reducing depth) results in a lower reduction percentage. A shallower section attracts larger bending stresses before prestressing, making the relative improvement smaller. Overall, the graph confirms that prestressing is most effective in deeper sections and shorter spans.

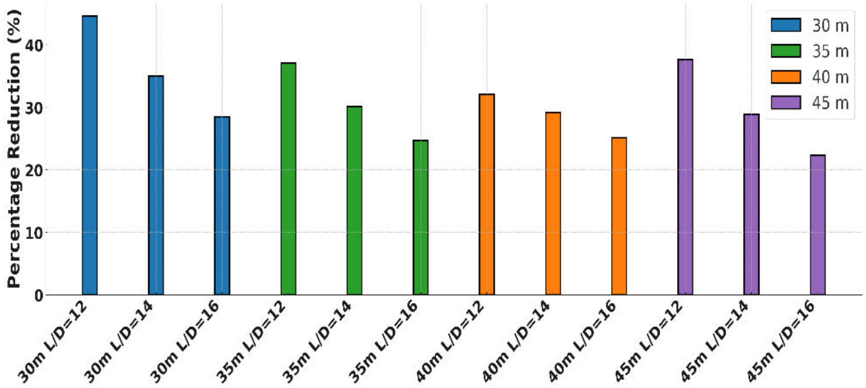

Fig. 10: Percentage reduction in shear force for all models

The shear force reduction graph shows a similar downward trend with increasing span and increasing L/D ratio. Prestressing introduces a uniform compressive force that redistributes internal shear across the section, leading to noticeable reductions compared to the non-prestressed condition. Shorter spans particularly 30 m and 35 m show higher shear reduction due to their relatively higher stiffness and lower self-weight. As spans increase, the permanent loads dominate, reducing the proportional influence of prestressing. For all spans, L/D = 12 has the highest shear reduction, confirming that deeper girders respond more effectively to prestressing.

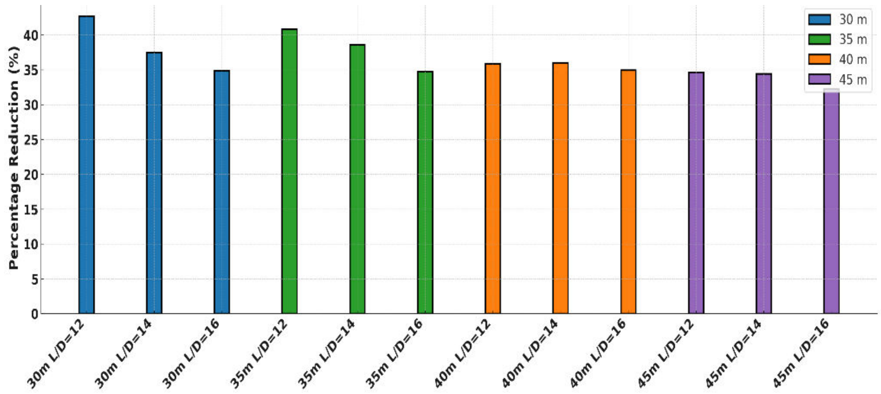

Fig.11: Percentage reduction in deflection for all models

The deflection reduction graph as shows that prestressing greatly enhances serviceability. The pattern remains consistent across all models, with shorter spans and deeper sections exhibiting the highest reductions in mid-span deflection. Deflection decreases by nearly 35–40% for 30 m spans, while 45 m spans exhibit reduced effectiveness because their geometric flexibility reduces the impact of prestress-induced camber. For each span, L/D = 12 exhibits the maximum reduction in displacement due to its higher flexural rigidity. The results confirm that both span length and girder depth strongly influence the serviceability benefits of prestressing.

VII. CONCLUSIONS

The key findings from the parametric study are summarised below, highlighting the influence of span length, depth ratio and prestressing on PSC box-girder behaviour. These conclusions reflect the overall trends observed across all analysed models.

- Bending moment, shear force, and deflection increase consistently as the span length increases from 30 m to 45 m, showing that span length has a major influence on overall structural demand.
- For any given span, increasing the L/D ratio (i.e., decreasing the section depth) results in noticeably higher deflections due to the reduction in stiffness of the girder.
- Bending moment and shear force exhibit slight but consistent changes with L/D ratio. In the non-prestressed case they reduce as L/D increases, while in the prestressed case they rise gradually because shallower sections provide less resistance.
- Prestressing significantly reduces bending moment, shear force, and deflection values in all models, demonstrating its strong contribution to improving the structural behaviour of PSC box girders.
- The effectiveness of prestressing is more pronounced in shorter spans and deeper sections, where the relative contribution of prestress is higher compared to the applied external loads.
- Models with L/D = 16 consistently exhibit the largest deflections and higher force effects in the prestressed case, indicating the sensitivity of shallow girders to structural deformation.
- Overall, both span length and girder depth play a decisive role in the behaviour of PSC box-girder bridges, while prestressing helps to control the response without altering the underlying trends.

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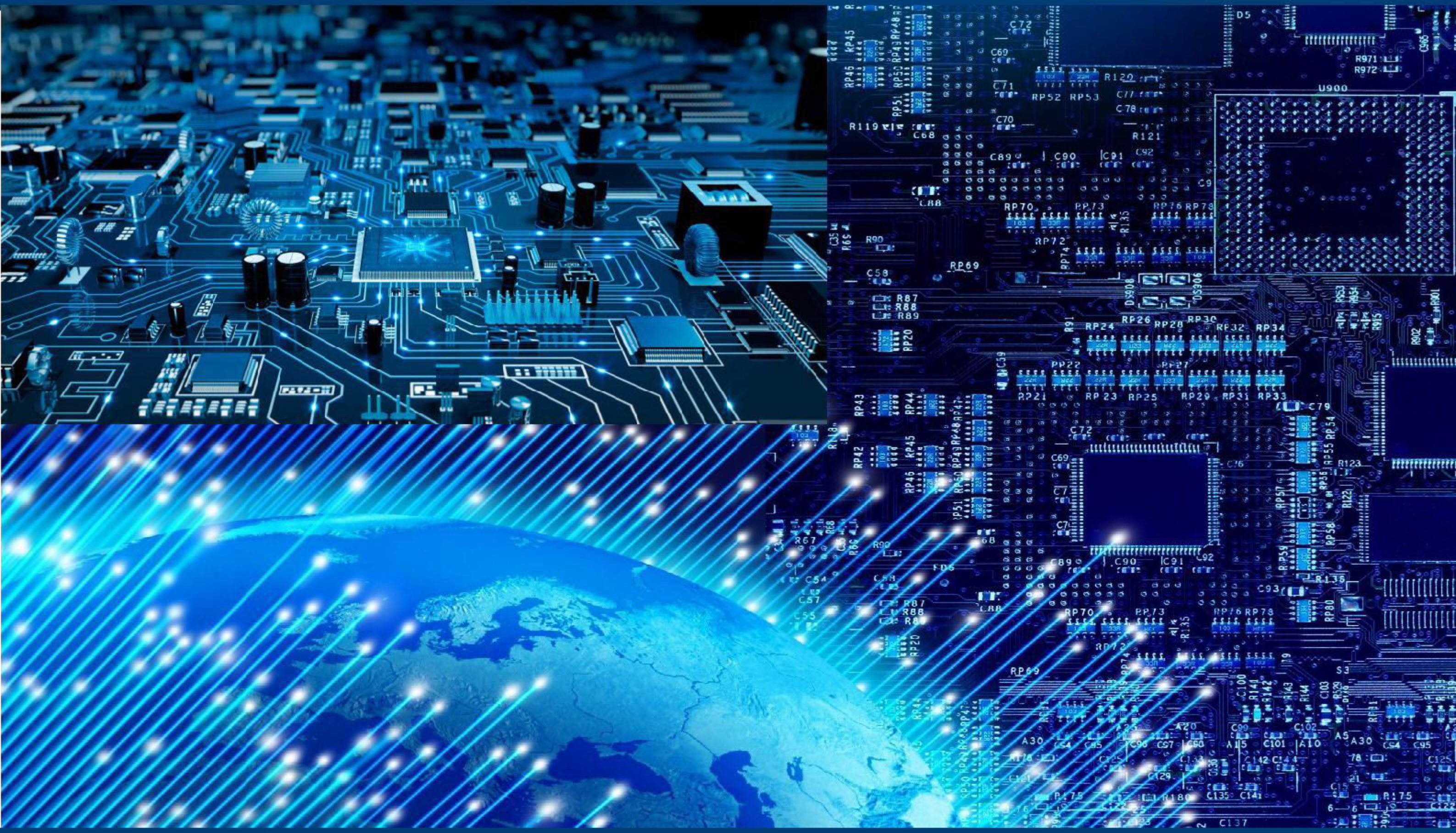

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