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Impact of Tendon Placements on Shear Lag Phenomenon in PSC Box Girders

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Abstract: PSC box girders are extensively employed in Modern bridge construction because of their efficiency in structure, torsional rigidity, and durability. Shear lag, however, tends to produce non-uniform stress distributions over the flanges, resulting in local stress concentrations, compromised flexural effectiveness, excessive deflection, and possible cracking. This research focuses on the effect of tendon position on shear lag behavior in a two-span continuous PSC box girder. Six tendon geometries were compared under uniform geometry, material response, and typical bridge load conditions. Results show that the optimized tendon layout enhances uniformity of stress with 35% reduction in shear lag, along with 26% and 21% reductions in peak bending moments and maximum deflections, respectively.

Placement of tendons close to critical web-flange connections improves the transfer of loads, structural rigidity, and performance of the bridge. The conclusions give the advice in designing lighter, shorter-span, and more performing PSC box girders.

Keywords: shear-lag, prestressed concrete, box girder bridge, tendon placement, web-flange junction, finite-element analysis, MIDAS FEA NX

I. INTRODUCTION

The growing need for efficient, durable, and cost-effective bridge systems has resulted in the extensive use of prestressed concrete (PSC) box girders. These bridges are noted for their high stiffness-to-weight ratio and positive torsional rigidity and are used on long-span flyovers, metro viaducts, and expressway bridges. Even though PSC box girders have numerous advantages, they are prone to shear lag, which leads to inhomogeneous distribution of longitudinal stress in the flanges. Shear lag produces localized stress concentrations near the web, inefficient utilization of flange areas, low flexural efficiency, excessive deflection, and cracking under service load.

The prestressing tendon layout has a strong impact on the distribution of stress. Regular tendon layouts tend not to eliminate localized variations in stress, while non-uniform or strategically condensed tendon profiles may improve load transfer, stiffness, and stress uniformity. The current research explores the effect of tendon positioning on shear lag in PSC box girders in terms of finding structural performance and serviceability optimizing configurations.

II. LITERATURE REVIEW

Shear lag in steel and concrete box girders has been extensively researched. Zhou [1,2] proposed finite beam elements with shear lag deformation to enhance accuracy of stress prediction. Kawde et al. [3] demonstrated that girders with higher width-to-span ratios suffer greater shear lag, which emphasizes the importance of geometry. He [4] showed that tendon layout affects longitudinal stress distribution, whereas Chen and Jiang [5,6] showed that shear lag behavior is affected by geometric features and material heterogeneity. Devassykutty et al. [7] linked shear lag to local buckling in composite laminates and showed its structural implications.

Yet, limited research quantitatively investigates the influence of tendon configuration in PSC box girders on shear lag and overall structural behavior. This research fills that gap through comparison of various tendon configurations under typical bridge loads in a systematic manner.

III. OBJECTIVE

The primary objective of this research is to evaluate the effect of tendon placement on shear lag behavior in PSC box girders and identify configurations that enhance structural performance.

Specific Objectives

- 1) To model PSC box girders with both uniformly distributed and concentrated tendon layouts using FEA.
- 2) To assess the effect of tendon positions on longitudinal stress distribution, bending moments, and displacements.
- 3) To compare various tendon configurations to determine patterns influencing shear lag reduction.
- 4) To recommend a tendon layout that enhances stiffness, serviceability, and stress uniformity.

IV. METHODOLOGY

A two-span continuous PSC box girder was studied for six varying tendon configurations. All the models had the same geometry, material properties, and total prestressing force to enable direct comparison of tendon location effects.

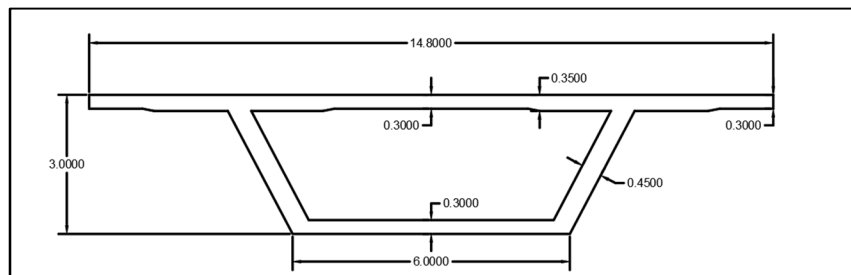


Figure 1: Dimensions of the proposed girder (in m)

A. Bridge Dimensional Details

Dimensional details	For all Models
Bridge Type	2 Span Continuous Box Girder
Span	45 Meter Each
Carriageway width	14.8 Meter
Overall Depth	3 Meter
Web Thickness	0.45 Meter
Top Flange	0.35 Meter thick; Overhang: 0.30 Meter each side
Bottom Flange	6.00 Meter wide $\times$ 0.30 Meter thick

Table. No. 1: Bridge dimensional details

B. Material Details

Property	Concrete	Reinforcing Steel	Prestressing Steel
Elastic Modulus (E)	35,400 N/mm ²	2×10^5 N/mm ²	1.95×10^5
Poisson's Ratio (ν)	0.3	0.3	0.30
Thermal Coefficient (α)	10×10^{-6} /°C	12×10^{-6} /°C	12×10^{-6} /°C

Table. No. 2: Bridge material details

C. Load Parameters

Parameters	Value	Reference
Dead Load	1 kN/m ²	IS 875 (Part 1):1987
Super Imposed Dead Load: Crash Barrier and Utility	10 kN/m	IS 875 (Part 2):1987
Super Imposed Dead Load: Wearing Coat	1.914 kN/m ²	IS 875 (Part 2):1987
Live Load	IRC Class 70R	IRC 6:2017
Wind Load	$F_T = 1.54$ kN/m $F_L = 0.77$ kN/m	IRC 6:2017

Table. No. 3: Load parameters.

D. Prestressing Parameters

To ensure uniform analysis conditions in all models, a constant total prestressing force of 29,000 kN was applied. All models had the same girder geometry and properties; only tendon layout and force distribution differed to be able to study the influence on shear-lag behaviour.

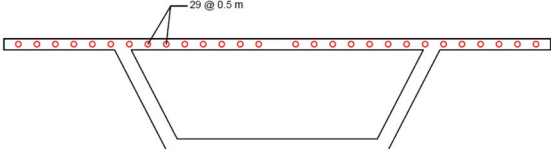
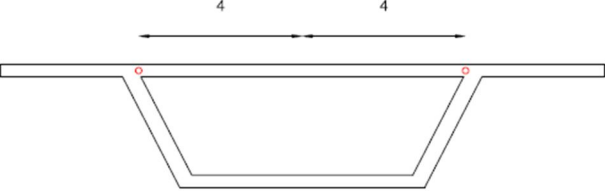
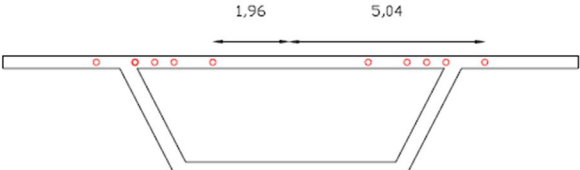
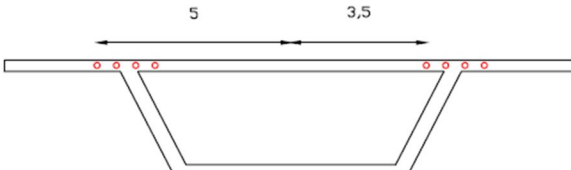
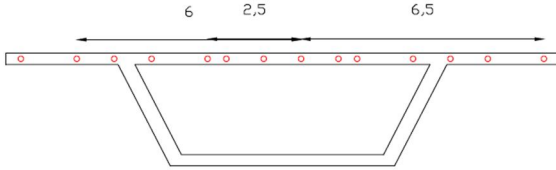
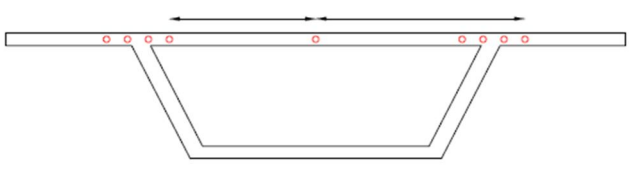
Model 1	Model 2
	
Equal prestressing of 1000 kN applied to all tendons along the span (reference case)	14,500 kN applied at two concentrated groups near the webs-Flange Junction.
Model 3	Model 4
	
2900 kN at selected asymmetric tendon positions.	Forces varying between 3000 kN and 4000 kN
Model 5	Model 6
	
Forces varying between 500 kN and 3000 kN	Concentrated 3500 kN tendons with one central 1000 kN tendon

Table. No. 4: Different Tendon Configurations for Analysis.

V. RESULTS AND DISCUSSIONS

This study analyzed the shear lag effect in prestressed concrete box girders, evaluating its impact on stress distribution, peak shear lag, bending moments, displacements, transverse shear forces, and overall structural efficiency.

A. Shear lag (Force Distribution Coefficient, FDC)

$$FDC \text{ Calculation} = \frac{\text{Forces at given position on the Girder}}{\text{Average Force}}$$

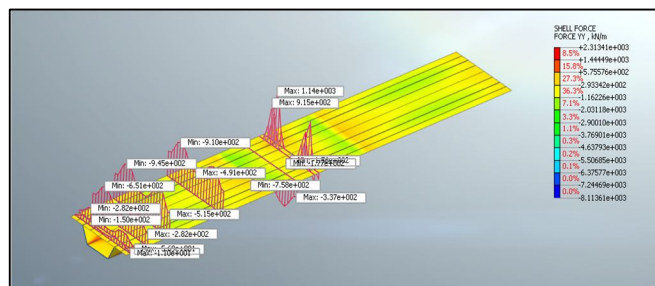


Figure 2: FDC diagram for Model 1

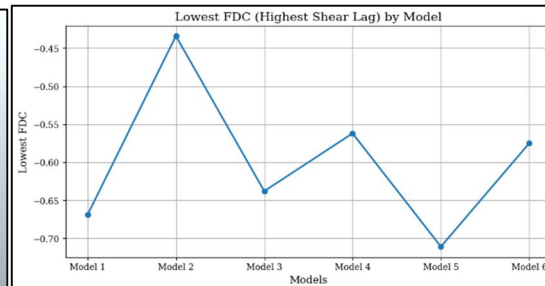


Figure 3: % Change in FDC for all Models.

Model	Lowest FDC (Highest Shear Lag)	% Change vs Model 1
Model 1	-0.669	Reference
Model 2	-0.434	-35.1% (least severe)
Model 3	-0.638	-4.6%
Model 4	-0.562	-16.0%
Model 5	-0.711	+6.3% (most severe)
Model 6	-0.575	-14.0%

Table. No. 5: Table for comparative analysis for Shear lag.

B. Displacement

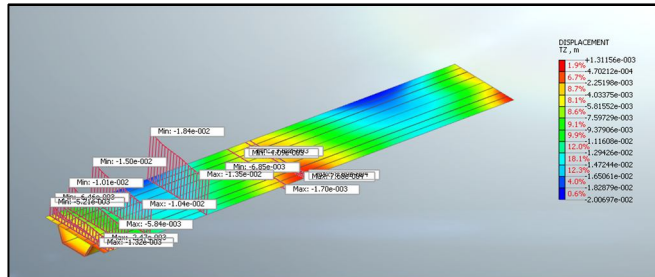


Figure 4: Displacement diagram for Model 1

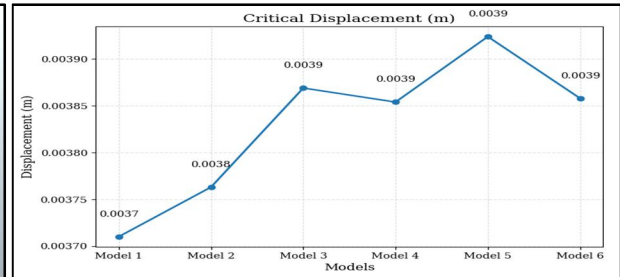


Figure 5: % Change in Displacement for all Models.

Model	Location x (m)	Critical displacement (m)	% Change vs Model 1
Model 1	-7.4	-0.003710	Reference
Model 2	-7.4	-0.003763	1.40%
Model 3	-7.4	-0.003869	4.30%
Model 4	-7.4	-0.003854	3.90%
Model 5	-7.4	-0.003924	+5.8% (worst)
Model 6	-7.4	-0.003858	4.00%

Table. No. 6: Table for comparative analysis for Shear force (in m)

C. Bending Moment

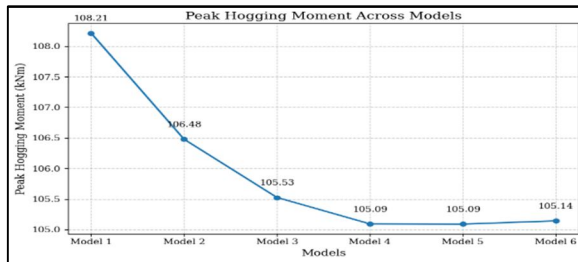


Figure 6: Hogging Bending Moment.

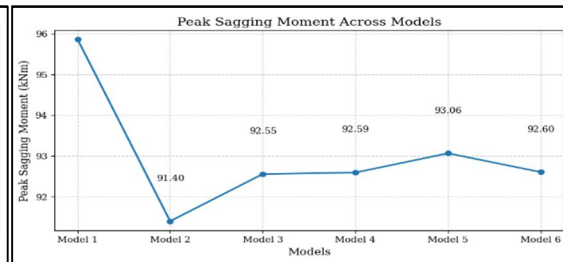


Figure 7: Sagging Bending Moment.

Hogging Bending Moment

Model	Location X (m)	Peak Hogging Moment (kNm)	% Difference
Model 1	5.18	-108.2149	0%
Model 2	5.18	-106.4784	1.61%
Model 3	5.18	-105.5258	2.48%
Model 4	5.18	-105.0935	2.87%
Model 5	5.18	-105.0894	2.84%
Model 6	5.18	-105.1423	2.86%

Table. No. 7: Table for comparative analysis for Shear force (in m)

Sagging Bending Moment

Model	Location X (m)	Peak Sagging Moment (kNm)	% Difference
Model 1	-2.96	95.86069	0%
Model 2	-2.96	91.396	4.66%
Model 3	-2.96	92.55344	3.43%
Model 4	-2.96	92.58846	3.36%
Model 5	-2.96	93.06085	2.92%
Model 6	-2.96	92.60072	3.36%

Table. No. 8: Table for comparative analysis for Shear force (in m)

D. Transverse Shear Force

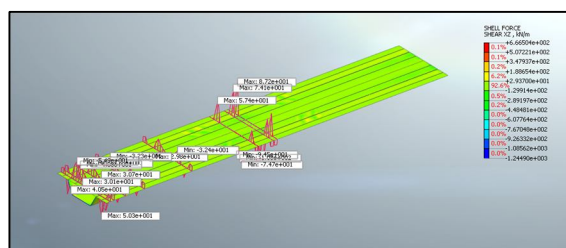


Figure 8: Transverse Shear Force on Model 1.

Model	Location x (m)	Max shear (kN/m)	% Change vs Model 1
Model 1	-2.96	-108.05	Reference
Model 2	-2.96	-109.086	-0.96%
Model 3	-2.96	-108.215	-0.15%
Model 4	-2.96	-108.284	-0.22%
Model 5	-2.96	-107.817	0.22%
Model 6	-2.96	-108.216	-0.15%

Table. No. 9: Table for comparative analysis for Bending moment (in kN-m).

VI. CONCLUSION

This study evaluated the influence of tendon placement on shear lag, bending moments, displacements, and transverse shear in PSC box girders. Key findings include:

- 1) Shear Lag: Model 2 reduced FDC by 35.1% compared to Model 1, while Model 5 increased shear lag by 6.3%, identifying configurations to avoid.
- 2) Bending Moments: Sagging moments decreased up to 4.66% (Model 2), and hogging moments reduced by 1.6–2.87%, highlighting improved longitudinal stress distribution.
- 3) Displacements: Maximum deflections were minimal (<0.004 m), ensuring serviceability.
- 4) Transverse Shear: Variations were negligible (−0.96% to +0.22%), indicating stability under applied loads.

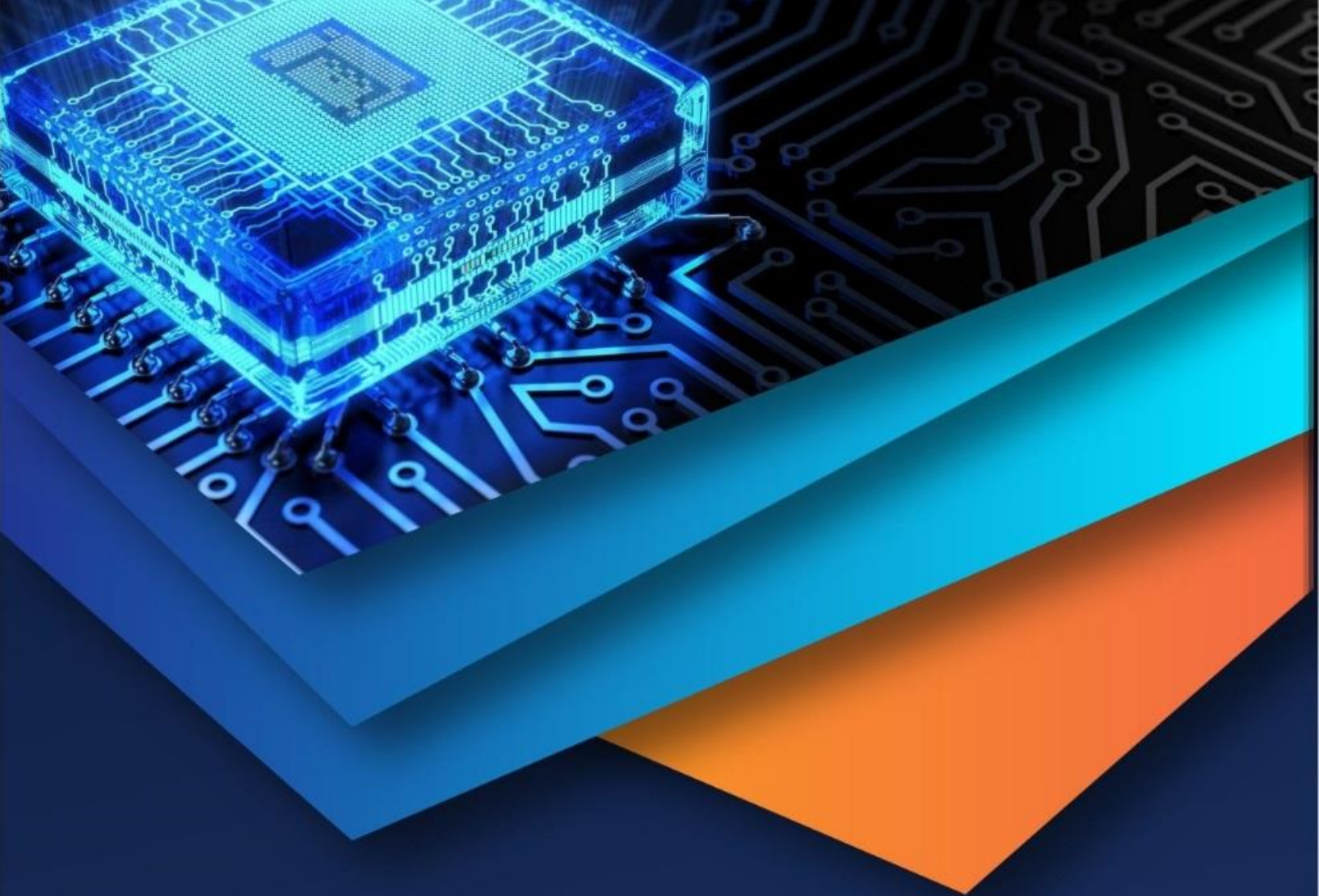
Overall, Model 2 provides the most balanced performance, demonstrating that optimized tendon placement enhances stress distribution, structural efficiency, serviceability, and long-term durability of PSC box girders, emphasizing its importance in prestressed bridge design.

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