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A Parametric Study on PSC Integral Bridge

Priyadarshani Mishra, Roshni John

***Abstract:** Integral Bridges are jointless bridges in which the deck is continuous and monolithic with abutment walls, and superstructure and substructure connections are monolithic. Bearing-type bridge observed unseating of the deck during the earthquake, necessitating replacement of the bearings and expansion joint, resulting in high maintenance costs. Due to their continuity, integral bridges are less expensive, possess an aesthetically pleasing appearance, and improve riding quality & low maintenance costs. To overcome the problem of the bearing bridge, an integral bridge has been proposed. A literature review of integral bridges and bearing bridges has been conducted and presented. To understand behaviour under different loading conditions, a comparative study was conducted for Integral bridges and bridges with bearings. For the present study, a 2-lane bridge with two spans and an individual span length of 30m is considered. PSC I-girder superstructure and RCC solid circular pier and wall-type abutment are used. For a comparative study, all properties and loadings are kept constant; the only change is made to the support condition between the superstructure and the substructure. A parametric study was conducted to analyse the PSC I girder Integral bridge with different skew angles, and also the effect of No. of Lanes. Analysis of these models has been done using Midas Civil as a computational tool.*

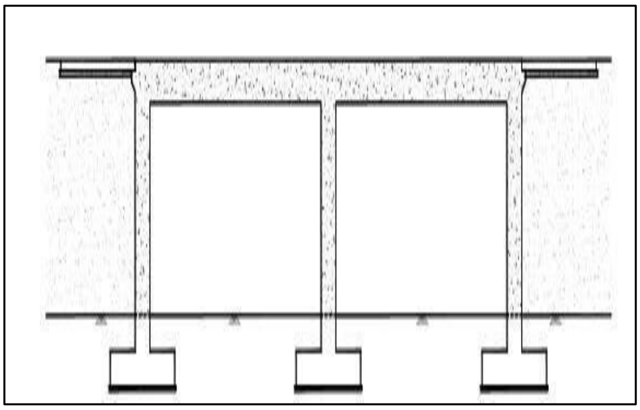
***Keywords:** Integral Prestressed Concrete Bridges, Shear Forces, Bearing Bridges, Bending Moments, Prestressing Forces, Material Properties, Finite Element Analysis, Torsional Effects, Displacement, IRC Loading.*

Nomenclature:
IB: Integral Bridge
IRC: Indian Road Congress
SSI: Soil-Structure Interaction

I. INTRODUCTION

Bridges were constructed without expansion joints and bearings for many centuries. In the 20th century, as engineering and analysis advanced, the addition of joints and bearings in bridge design became sophisticated. Recent years have seen a more analytical approach to bridge design, leading to the construction of new highway bridges that employ sophisticated expansion joints or sliding bearings to mitigate thermal impacts and lateral displacements.

To reduce the bridge's span and transfer the superstructure's load to the substructure, joints are used in bridge construction. These kinds of bridges are known as "Bearing bridges or Jointed bridges." Here, there are issues with the aforementioned inclusion from both an aesthetic and practical standpoint. The primary concern observed in bridges built over the past 50 years is the distress in these components, namely joints and bearings.



[Fig.1: Schematic Representation of the Integral Bridge]

An Integral Bridge (IB) is a structure without expansion joints in the superstructure or bearings over the abutments. Unlike traditional bridge design, where IBs feature a monolithic connection between the superstructure and substructure (piers and abutments), traditional bridge construction employs bearings to support the superstructure, transferring all forces to the substructure or foundation through them. Because of thermal creep or shrinkage-induced movements, traditional bridges with expansion joints and bearings can move and rotate their deck without transferring any force to the foundation, abutment or pier". When an IB is present, the movement of the deck is transferred to the abutment and backfill soil behind it.

II. LITERATURE SURVEY

Arti Chaurasiya et al. (2023) [1] had the main aim of comparing the use of steel plate girders and prestressed concrete girders in urban locations. The study comprises the design of PSC and steel plate girders for a 30m span. The analysis is performed using the CSI BRIDGE programme. Calculations of bending moment, shear force, longitudinal displacement, vertical displacement, and deflection are part of the study. It was concluded that the girder bending moment varied by 56% and the shear force by 26%. Plate girders have 45% larger vertical displacements than PSC girders. The results show that the PSC girder's bending moment and shear force are significantly higher than those of the Steel Plate girders. The increase is due to the PSC girder's self-weight, which produces a significant bending moment and shear force.

Abdollahnia H, et al. (2020) [2] conducted a study on the fatigue life of H-shaped steel piles for an integral concrete bridge framed in the sea. Using CATIA software, a

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model of the integral bridge, approximately 90 metres long and featuring 42 steel pipes, was prepared. Two stress studies were considered during analysis. The first model in which static analysis has been performed, considering water motion, is still. In the second model, a dynamic analysis was performed to account for wave-clash action in the sea and to extract the total deformation at the top of the piles. By finite element analysis, it was found that, for mechanical behaviour, there was no significant difference between static and dynamic analyses; however, during dynamic analysis, pile deformation was substantial due to the continuous action of sea waves. A finite element and probabilistic approach was used to find fatigue analysis of H-shaped steel piles. It also found that no fatigue damage occurred in any part of the bridge during the static analysis.

Fernando V, et al. (2019) [3] performed a dynamic soil-structure interaction (SSI) analysis using the FLAC(2D) program on a span bridge. Bridges are made up of a series of beam and pile components that interact with the continuous medium through standard and shear soil springs. While introducing elements into the model, the slippage interaction between the abutment and soil was considered. The abutments were supported by piles driven into the bedrock and rock sockets. The middle pier is supported and extended into the bedrock. Based on the SSI analysis, the seismic responses of the foundation-bridge system were computed and compared with those reported in the literature.

Mohamed T. et al (2018) [4] performed a finite element investigation into the behaviour of integral abutment bridges under alternate cycles of seasonal temperature variations on the bridge. Elastoplastic analysis has been proposed and carried out on a two-dimensional FE model of a reinforced concrete multi-span slab bridge. Steel H- H-piles supported the bridge abutment. A multistage numerical Finite Element model was proposed, capable of both bridge construction and backfilling. Due to temperature effects, earth pressures were predicted to vary with bridge length. The results showed that the bridge structure length, the temperature cycle, and the backfill material's stiffness affect the design earth pressures. Still, the relative stiffness between the bridge deck and the abutment has minimal effect.

Quinn B.H., et al. (2017) [5] conducted a parametric analysis of steel girder IABs, comparing the impact of pile orientation on bridges with different skews or lengths using finite-element models. For this study, skew angles of 0, 15, 30, and 45° were used to analyse bridge lengths of 15.2 m, 30.5 m, and 45.7 m. The orientations of H-pile webs, considered horizontal and vertical to the abutment centreline, were investigated and compared. Following thermal reaction of the models, the following findings were obtained: "Weak-axis or strong-axis bending moments of piles, displacements of abutments or piles, ratios of maximum bending moments to yield moments. Outcomes showed that" the optimal orientation of pile does not depend on one factor but also on other factors.

LaFave J.M., et al. (2016) [6] focused on thermal changes consistent with seasonal fluctuations through numerical analysis, elaborating on the behaviour of IABs with composite steel I-girders. The analysis results indicated that expansion length has a primary influence on bridge longitudinal movement under thermal loads, regardless of girder, abutment, or pile design. It also shows that the superstructure girder response (elastic) and the substructure pile response (inelastic) to superstructure temperature change are influenced by parameters such as EEL, pile size, skew, and the rotational limit imposed by the superstructure on the substructure. The results presented here suggest that superstructure geometry should be considered, either directly or indirectly, in IAB substructure design, and that thermally induced stresses and strains should be accounted for in both superstructure and substructure design.

Dunja Peric et al. (2016) [7] investigated the behaviour of a three-span integral bridge under the combined effects of temperature and gravity. The bridge model for analysis consisted of the superstructure, two sets of piers, two abutments, and fourteen HP steel piles (seven at each abutment). The bending axis was oriented parallel to the bridge's longitudinal direction. After successful justification and confirmation of the analysed model, several loadings with varying temperature increases were simulated in the presence of different soils adjacent to the abutment. The analysis concluded that the compaction level between soil adjacent to abutments, the magnitude of thermal load effects on internal forces in the substructure, and the maximum bending moment in piles were of concern.

III. AIMS AND OBJECTIVES

A. Aim

The purpose of this research is to understand the behaviour of the PSC integral bridge and the PSC conventional bridge in terms of moment, shear and deflection under IRC loading conditions. Additionally, the study analyses different parameters of the PSC Integral bridge for skew angles ranging from 0 to 20 degrees and varying numbers of lanes. It presents the bridge's structural behaviour in terms of forces and moments.

B. Objectives

i. To analyze and study the PSC IB and compare it with Conventional PSC bridge under "action of Dead loads, IRC loads.

ii. To perform analysis on PSC IB with varying skew angles from 0 to 20 degrees.

iii. To study structural responses presented in terms of ratios of bending moment, shear force, torsional moment, and vertical deflection.

iv. To obtain variation of structural response for bridges under Dead load or moving loads, Bridges acting under the influence of Dead and Live loads for parameters, namely, skew angle, Number of lanes.

IV. PROBLEM STATEMENT

In the present study, two bridges, i.e., the Integral Bridge and the Conventional

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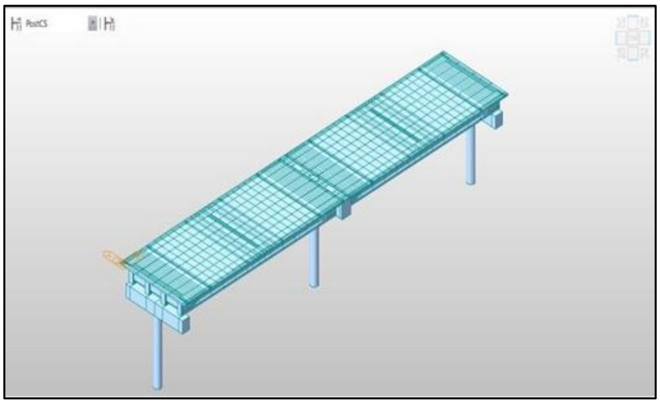
Bridge, are modelled in Midas Civil as computational tools. Properties are kept constant in both bridges for comparison; only the boundary conditions are changed. Brief modelling details of integral and conventional bridges, e.g., cross-section details, material properties, boundary conditions, and loading conditions, are given in this chapter below. To determine the behaviour of PSC integral bridges with variations in skew angles (0°, 10°, and 20°) and number of lanes, using live loads as specified in IRC 6-2017 for Class A and Class 70R vehicles. The following bridges are analyzed and modelled.

A. Integral bridge with PSC I-girder depth of 1.8m,60m span length, having two spans.
B. Conventional bridge with PSC I-girder depth of 1.8m, 60m span length, having two spans.
C. The integral bridge consists of a PSC I-girder with a skew angle varying from 0° to 20°, and a total span length of 60m
D. The integral bridge consists of a PSC I-girder with a total span length of 60m and is analysed for varying numbers of lanes, i.e., 2-, 3-, or 4-lane configurations.



[Fig.2: 3D FEM of PSC Integral Bridge]

E. The Material Attributes Employed in the Model are as Follows

i. Concrete Properties:

- Thermal coefficient - $1.2 \times 10^{-5}/^{0}C$
- Poisson's ratio – 0.2
- "Young's modulus (E) = 3.35 10· kN/m²
- Grade of concrete – M40 = 40 N/mm²
- Weight density – 25 KN/m^3

ii. Tendon Properties:

- Number of strands – 19
- Elastic shortening stress = 20684.274kN/m²
- Diameter of the pre-stressing cable = ASTM 0.5
- Type of pre-stressing - post-tensioning
- Nominal ultimate breaking force= 183.7kN/strand
- Modulus of Elasticity = Eps = 1.968" 108kN/m²
- Shrinkage stress = 48263.31kN/m²
- Permissible initial prestressing force 143.83 kN/ strand
- Total tendon area - 0.00187549 m²
- Wobble coefficient=0.0020/m
- Steel relaxation stress = 34473.79kN/m²
- Creep stress = 34473.79kN/m²
- Anchorage Slip = 6.35 10¯3m
- Pre-stressing Strand diameter = 13mm (0.5" strand)

iii. Steel (Rebar) Properties:

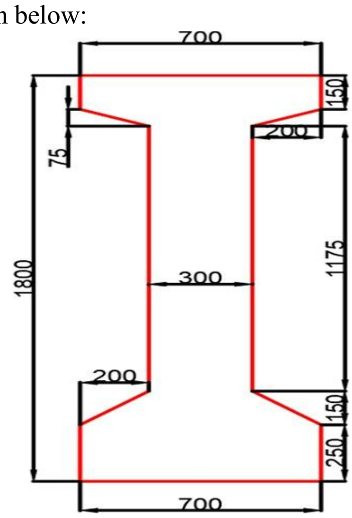
- Grade of prestressing steel = E250
- Grade of steel - 500 N/mm²
- Minimum yield stress = Fy = 5 x 107 kN/m²

V. METHODOLOGY

The study is carried out to investigate an I-girder Integral PSC bridge skewed at different angles using MIDAS CIVIL software, and to compare it with a Conventional PSC bridge. The modelling and analysis have been carried out with MIDAS Civil.

The steps to accomplish our goal are as follows.

A. A PSC Integral I- girder bridges skewed at different angles with an interval of 10 degrees, varying from 0 to 20 degrees, by using MIDAS CIVIL software.
B. "The PSC I girder bridges were examined for dead load, live load, or moving load", taking into account a class 70R and class A vehicle.
C. The cross-section at midspan of the PSC Integral bridge is shown below:



[Fig.3: Cross-Section at Midspan of I-Girder]

D. DL is the self-weight of each bridge component. Dead load is applied by using the self-weight command in Midas Civil. This load consists of a dead load of the crash barrier and a wearing coat over the deck. In the present study, a 75 mm-thick wearing coat is assumed to have a density of 22 kN/m^3.
   i. Intensity of crash barrier load- 10 kN/m
   ii. Intensity of wearing coat load- 1.65 kN/m^2
E. Highway bridges must be designed for the vehicular load specified by the Indian Road Congress (IRC), as formulated in IRC 6:2017. The standard IRC loads specified in the IRC code were grouped into four categories: IRC 70 R loading, IRC Class AA loading, IRC Class A loading, and IRC Class B loading. In this study, IRC 70R or IRC Class A loading is used. A wheel load train, which contains a driving vehicle or two trailers with specified axle spacings, is included in Class A and Class 70 R loading. To ensure secure outcomes for all types of vehicles passing over the bridge, it is recommended to use hypothetical vehicles as live loads.

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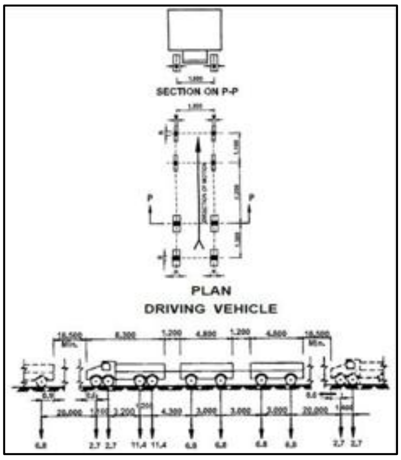
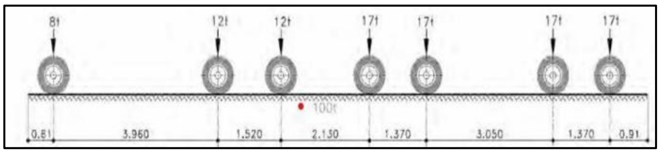


[Fig.4: CLASS a Vehicle (IRC 6: 2017 Clause 204.1)]



[Fig.5: CLASS a Vehicle (IRC 6: 2016 Clause 204.1)]

VI. RESULTS

A. Comparison between Integral and Conventional PSC Bridge

This chapter presents results from finite element analysis for both conventional and integral bridge models under different loading conditions. The responses of both models are discussed in terms of moment and shear forces.

Table I: Comparison Between Integral and Conventional PSC I-Girder Bridge

	Integral Bridge	Conventional Bridge
	DL+LL	DL+LL
Moment at midspan (kNm)	4908.5	6901.45
Moment at end of girder (kNm)	2462	0
Torsion Moment(kNm)	985	1104
Shear force(kN)	1044.67	896.5

The following conclusions are derived from the analysis's findings:

Integral bridges are more efficient than Conventional bridges.

i. Bending moments in the superstructure at mid-span are decreased in the integral bridge model under permanent load (Dead load, SIDL Load, and SSDL load). Also, a negative moment is generated at the superstructure end in an integral bridge due to support fixity. Whereas, in a conventional bridge, zero moment is found at the superstructure end location.

ii. The magnitude of torsional moments in an integral bridge decrease as the straight span increases.

B. Effect on PSC Integral Bridge with Different Parameters

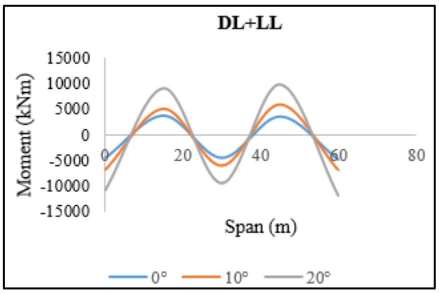
The following parameters are considered for additional research to understand their impact: skew angle and number. of lanes. For skew angles are 0°,10° & 20°, and for No. of lanes: 2, 3, and 4 lanes are considered for an I-girder PSC Integral bridge.

i. Effect on Skew Angle on PSC Integral Bridge

In the following section, all parameters are presented in tabular and graphical form.

Table II: Comparison of Bending Moment for Different Skew Angles

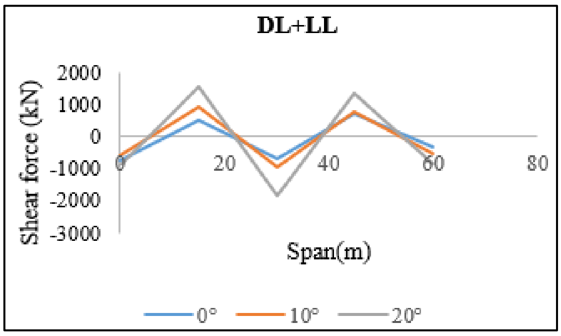
Span(m)	Bending Moment (kNm) 0°	10°	20°
	DL+LL	DL+LL	DL+LL
0	4625	6741	10741
15	3764	5117	8917
30	4635	5965	9465
45	4514	5962	9662
60	4985	6862	11862



[Fig.6: Comparison of Bending Moment for Different Skew Angles]

Table III: Comparison of Shear Force for Different Skew Angles

Span(m)	Shear Force (kN) 0°	10°	20°
	DL+LL	DL+LL	DL+LL
0	756	597	884
15	502	926	1543
30	684	931	1833
45	715	750	1318
60	332	530	845



[Fig.7: Comparison of Shear Force for Different Skew Angles]

Table IV: Comparison of Torsion Moment for Different Skew Angles

Span(m)	Torsion Moment (kNm) 0°	10°	20°
	DL+LL	DL+LL	DL+LL
0	517	3464	4768
15	984	4987	5971
30	929	4306	6744
45	704	4500	5975
60	342	2923	5894

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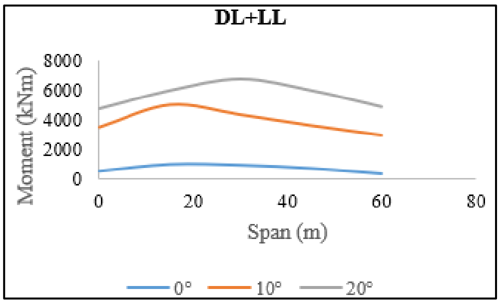
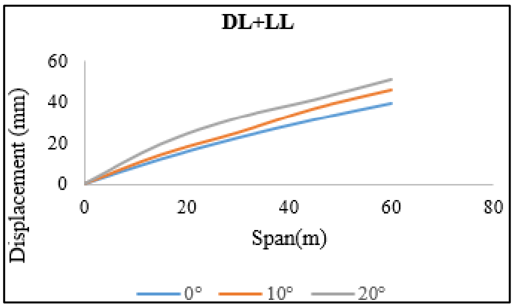


[Fig.8: Comparison of Torsion Moment for Different Skew Angles]

Table V: Comparison of Vertical Displacement for Different Skew Angles

Span(m)	Vertical Displacement (mm)		
	0°	10°	20°
	DL+LL	DL+LL	DL+LL
0	0	0	0
15	11	14	19
30	22	25	32
45	30	36	41
60	39	46	51



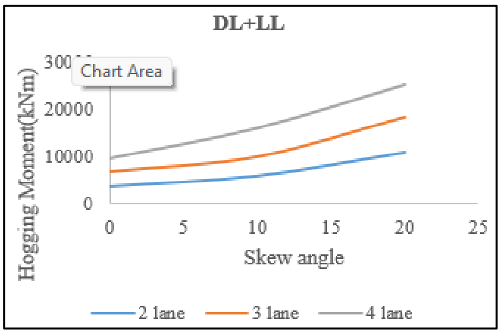
[Fig.9: Comparison of Vertical Displacement for Different Skew Angles]

i. Effect of No. Of Lanes on Skew PSC Integral Bridge

- Bending Moment

Table VI: Hogging Bending Moment

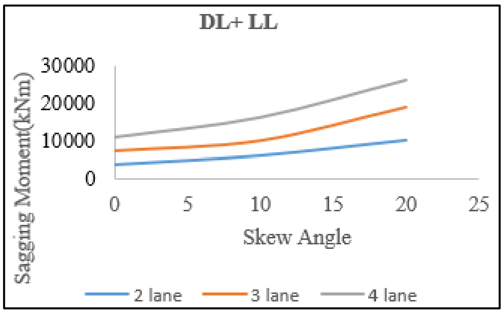
Skew Angle	Hogging Bending Moment (kNm)		
	2 lanes	3 lanes	4 lanes
	DL+LL	DL+LL	DL+LL
0	3779.78	6740.65	9534.03
10	5962.7	9920.78	15873.76
20	10863	18375.85	25013.24



[Fig.10: Hogging Moment]

Table VII: Sagging Bending Moment

Skew Angle	Sagging Bending Moment (kNm)		
	2 lanes	3 lanes	4 lanes
	DL+LL	DL+LL	DL+LL
0	3635.19	7281.42	10741.74
10	5965.98	10017.9	16100.86
20	9954.98	19103.5	26213.79

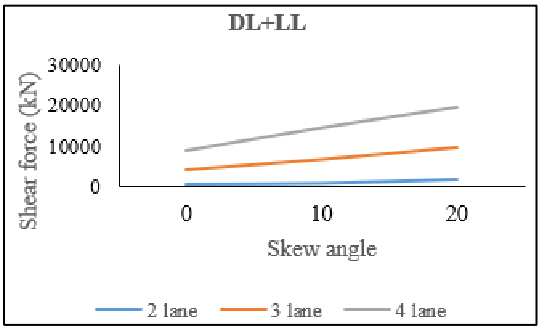


[Fig.11: Sagging Moment]

- Shear force

Table VIII: Shear Force

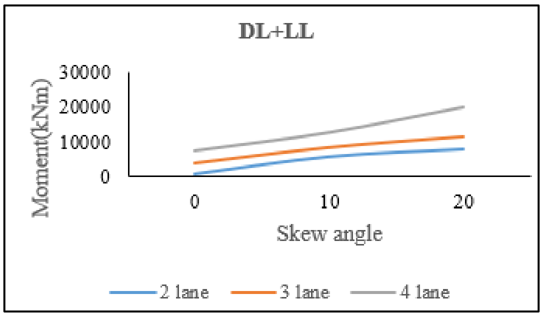
Skew Angle	Shear Force (kN)		
	2 lanes	3 lanes	4 lanes
	DL+LL	DL+LL	DL+LL
0	758.2	3356.78	4706.19
10	980.91	5642.87	7806.94
20	1956.4	7585.39	9926.89



[Fig.12: Shear Force]

Table IX: Torsion Moment

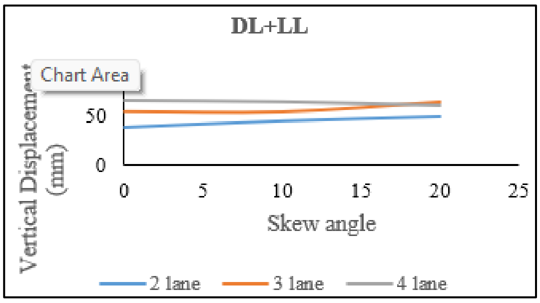
Skew Angle	Torsion Moment (kNm)		
	2 lanes	3 lanes	4 lanes
	DL+LL	DL+LL	DL+LL
0	1060.55	4028.6	7706.19
10	5978.94	8400.2	12806.94
20	9147.9	11389.69	19926.89



[Fig.13: Torsion Moment]

Table X: Vertical Displacement

Skew Angle	Vertical Displacement		
	2 lanes	3 lanes	4 lanes
	DL+LL	DL+LL	DL+LL
0	38.868	55.49	66.2
10	45.97	55.19	64.95
20	50.868	54.18	61.72



[Fig.14: Vertical Displacement]

VII. CONCLUSION

In this study, prestressed bridges skewed at different angles will be studied for their forces and moments. A range of load conditions, including prestressing, dead, and moving loads, was considered to monitor structural parameters, including torsional effects, bending moments, shear forces, and deflections.

The outcomes obtained from the analysis of the integral prestressed bridge are as follows:

A. Under IRC loading, analysis of bending moment, shear force, and torsion in PSC integral skew bridges is the main topic of research.
B. Bending moments in the superstructure at mid-span in the integral bridge are reduced by 39% under permanent load and for moving load cases.
C. Bridges with skew angles lower than 20° are simple enough to design because the skewness of the bridge has an insignificant effect between 10° and 20°.
D. The redistribution of bending moment in PSC Integral skew bridges is maximum near the supports, as the Integral bridge acts as a continuous or monolithic structure, so the structure becomes stiffer at the support and carries more moment. In contrast, fewer moments are transferred to midspan, as observed in the study.
E. Torsional moments showed the most significant impact, increasing by nearly 60% from 10° skew to 20° skew. Since the supports are not in the same line, the leading cause of this is increased eccentricity in the transverse direction.
F. The bridge observed a maximum 57% reduction in deflection under moving and dead loads.
G. As observed, No. of lanes significantly on skew bridges, because each lane contributes to the live load and traffic per IRC loading; as the number of lanes increases, the live load and moments increase.

FUTURE SCOPE

A. Study can be done with different deck systems, like a voided slab and a Box girder.
B. In the present work, Dead load or live loads, i.e, Class A and Class 70R, were considered. For further research, different IRC loadings may be regarded as.
C. The study can be done with the temperature effect and with the inclusion of the settlement of support.
D. In the present Study, only the bridge deck is considered; for further investigation, pier and foundation may be considered.

DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

- **Conflicts of Interest/ Competing Interests:** Based on my understanding, this article has no conflicts of interest.
- **Funding Support:** This article has not been funded by any organizations or agencies. This independence ensures that the research is conducted with objectivity and without any external influence.
- **Ethical Approval and Consent to Participate:** The content of this article does not necessitate ethical approval or consent to participate with supporting documentation.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Author's Contributions:** The authorship of this article is contributed equally to all participating individuals.

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