© September 2025| IJIRT | Volume 12 Issue 4 | ISSN: 2349-6002

Analysis of I-Girder Bridge with Varying Curved Angles

Gagan Ramparia[1], P.A Dode[2] and S.A. Rasal[3]

[1]Post Graduate Student, Dept. of Civil Engineering, Datta Meghe College of Engineering, Airoli, Navi Mumbai 400708, Maharashtra, India

[2] Principal, Dept, Datta Meghe College of Engineering, Airoli, Navi Mumbai 400708, Maharashtra, India

[3] Assistant Professor, Dept. of Civil Engineering, Datta Meghe College of Engineering, Airoli, Navi Mumbai 400708, Maharashtra, India

Abstract— **The structural behavior of steel I-girder bridges with varying curve angles is critically important in the design of modern urban infrastructure. Unlike straight bridges, horizontally curved steel I-girder bridges experience distinct torsional forces and complex load responses resulting from their curved geometry. This research project analyses six steel I-girder bridge models, keeping the span length, cross-section, and material properties constant while varying only the radius of curvature. All models are subjected to self-weight, superimposed dead load, and moving loads according to class A vehicle specifications, IRC class 70R and fatigue vehicles, with static and modal analysis performed using MIDAS Civil software. The study compares shear forces, bending moments, and displacement along the girders for each curvature configuration. Results reveal that as curvature increases, both bending moment and deflection also increase, highlighting the influence of curve angle on the structural response of steel I-girder bridges.**

Index Terms— Steel I-girder bridges, horizontally curved bridges, Radius of curvature, Torsional behavior, Shear force, bending moment, Deflection, Static analysis, Modal analysis.

I. INTRODUCTION

The rapid expansion of urban transportation networks has intensified the need for bridge structures capable of adapting to complex roadway alignments and space constraints. Among the various bridge options, curved steel I-girder bridges have become increasingly popular due to their ability to accommodate flexible alignments while maintaining structural efficiency. Unlike straight bridges, the introduction of horizontal curvature significantly changes the structural behavior of these bridges, introducing challenges such as torsional effects, secondary bending, and complex interactions between loads.

Previous studies have demonstrated that the responses of curved bridges—including bending moments, shear forces, and deflections—differ substantially from those of their straight counterparts. Despite notable advancements, there remains a need for more detailed investigations into how varying curve angles affect their performance under realistic loading conditions specified by modern design codes. Such research is crucial to ensure the safety, durability, and serviceability of curved steel I-girder bridges, particularly in urban environments.

This study focuses on analyzing the structural behavior of steel I-girder bridges with different curve angles while maintaining consistent span length, cross-sectional geometry, and material properties. Utilizing MIDAS Civil software, both static and modal analyses are conducted under loading scenarios that include self-weight, superimposed dead loads, and vehicular live loads as defined by the Indian Roads Congress (IRC) codes—specifically Class A, Class 70R, and fatigue vehicles. The results are systematically compared to understand how increasing curvature influences shear forces, bending moments, and deflections. The insights gained from this research aim to contribute to the development of optimized design practices for curved steel I-girder bridges, enhancing their performance and safety in modern urban transport systems. important role in today's urban infrastructure. Their ability to fit into complex roadway alignments and make efficient use of limited space makes them a practical choice for modern cities. However, unlike straight bridges, curved bridges come with unique challenges. The horizontal curvature introduces torsional forces that change how loads are distributed and how the structure behaves, directly affecting its stability and performance. Because of this, designing and analyzing such bridges requires extra care to ensure they remain safe, durable, and reliable throughout their service life.

II. REVIEW OF LITERATURE

M Jagandatta*, et. al* (2022) carried out the analysis and design of a composite single-span PSC-I girder bridge using Midas Civil software under Indian Road Congress (IRC) loadings. The study assessed the bridge's behavior under different loading conditions, including both static and seismic scenarios, while also accounting for time-dependent effects such as creep and shrinkage. Key structural parameters like bending moments, shear forces, and ultimate resistance capacities were thoroughly evaluated. The prestressed components, including tendon profiles and forces, were designed as per IRC specifications, and their performance was found to be within permissible stress limits. The research demonstrated the efficiency of Midas Civil as a comprehensive and reliable tool for modeling, analyzing, and designing prestressed, post-tensioned girders and deck slabs. The software enabled effective prestressing tendon assignment and configuration, proving to be a one-stop solution for safe and optimized bridge design in line with modern engineering standards.

M. Geethanjali and A. Priya Dharshini (2021) explain the importance of steel-concrete composite structures in bridge engineering. These combine concrete's strength in compression with steel's strength in tension. They are common in small to medium highway bridges. For longer spans, steel truss girders and cable-stayed decks with composite action are preferred. The study focuses on construction and strength, highlighting the role of shear connectors in stability. Composite decks work well under positive bending since the slab handles compression and steel carries tension. In negative bending, issues like slab cracking and steel instability can occur. To fix this, double composite action is used by adding a concrete slab to the bottom flange, improving strength and durability

Jiaxu Han *et al.* (2024) studied steel-concrete composite bridges, highlighting their strength, efficiency, and durability. Combining concrete's compression with steel's tension improves load capacity and stability. These bridges optimize materials, shorten construction time, reduce steel use, and lower costs. Durability can be boosted using protective coatings, weathering steel, high-performance concrete, and prestressing. Simple supported composite beam bridges are cost-effective and easy to build, common in urban areas. Continuous composite bridges offer more stiffness and less deformation but may face floor cracking issues. Overall, steel-concrete composites show good potential for sustainable bridge construction

Anagha Manoharan and Glynez Joseph (2016) used ETABS 2013 for finite element analysis of simply supported skew slabs under various loads, spans, and skew angles. Results showed bending moments decrease by up to 75% with increased skew angle, while torsional moments rise by 60%. Shear forces increased about 30% under knife-edge loading. The study found 20° skew angle causes the highest torsional moment, indicating a higher failure risk, guiding optimal skew bridge slab design.

Mohd Waseem and Mohammad Saleem (May-2019), evaluated the seismic performance of multi-span Box Girder Bridges using CSiBridge software. The study focused on analyzing the dynamic response of up to five 100-meter-long spans, using nonlinear time history analysis with Bhuj earthquake data. Key parameters like deformation, acceleration, shear forces, stresses, and displacement were examined to assess the bridge's behavior under earthquake conditions. The goal was to better understand and improve the seismic resilience of Box Girder Bridges, especially those built before modern seismic standards. The analysis shows that the bridge's seismic response in the x-direction is higher for acceleration, displacement, velocity, and base shear, while the base moment is highest in the y-direction. The bridge deck's acceleration is influenced by its characteristics and applied ground motion. The seismic response closely matches recorded ground motion data across all parameters. Base shear is key in resisting lateral loads during an earthquake.

Syed Habibunnisa*, et. al* (2019) compared straight, curved, and skewed bridges under dead, modal, and moving loads using SAP2000. Curved and skewed bridges showed torsion due to unsymmetrical mass distribution, unlike straight bridges. Modal analysis revealed more torsional modes in curved and skewed bridges. Axial force remained almost constant under dead loads but amplified in straight bridges. Vertical shear and bending moments were similar, with slight increases in curved bridges. Under moving loads, axial force decreased with curvature, while torsion amplified in curved bridges. Skewness had negligible effect on moments.

Nila P. Sasidharan and Basil Johny (2015) analyzed curved concrete box girders using ABAQUS under various loads. The study varied span lengths and curvature radii with a fixed span-to-depth ratio. Results showed reactions decrease with larger radii and shorter spans. Deflections minimized at optimum radius-to-span ratios (e.g., 200m radius for 40m span). Bending stresses reduced with higher radii, but spans over 20m benefit from radii below 200m for strength. Shear stress increased with longer spans and smaller radii, becoming uniform beyond 150m radius.

Jefeena Sali, *et al.* (2016) studied box girder bridges with varying curvature radii using CSI Bridge. Their analysis showed that as radius increases, deflection, bending stresses, and torsion decrease, enhancing stability. Torsional effects rise sharply when the radius falls below 100m, especially for sharp curves. Bending moment and deflection remained mostly unchanged for certain spans under different loads. The study highlights the need to avoid sharp curves or modify cross-sections to maintain structural stability.

Kenneth W. Shushkewich (1998) proposed a simplified analysis method for concrete box girder bridges, combining membrane equations with plane frame analysis. This practical approach suits engineers lacking advanced software and aids in designing single-cell precast concrete segmental box girders. It supports reinforcement and prestressing design for flexure, shear, and torsion, considering web inclination and various load types. Validation against folded plate analysis showed close accuracy, providing an efficient, reliable alternative without complex shear lag or warping torsion calculations.

In an Ayman M. Okeil and Sherif El Tawil (2004), The Researcher carried out detailed investigation of warping-related stresses in 18 composite steel-concrete box girder bridges. The bridge designs were adapted from blueprints of existing bridges in the state of Florida and encompass a wide range of parameters including horizontal curvature, cross-sectional properties, and number of spans. The bridges after which the analysis prototypes are modelled were designed by different firms and constructed at different times and are considered to be representative of current design practice. Forces are evaluated from analyses that account for the construction sequence and the effect of warping. Loading is considered following the 1998 AASHTO-LRFD provisions. Differences between stresses obtained taking warping into account and those calculated by ignoring warping are used to evaluate the effect of warping. Analysis results show that warping has little effect on both shear and normal stresses in all bridges.

Rajendra Thakai, *et al.* (2016) analyzed box girder bridges with rectangular and trapezoidal sections using SAP2000. They studied bending moments and longitudinal stresses under dead and live loads for simply supported and continuous spans. Results showed deeper girders increase bending moments but reduce flange stresses. Trapezoidal girders carry higher bending moments but are less stiff than rectangular ones, which resist bending better. The study highlights balancing stiffness and bending performance when choosing girder shapes.

Tongfa Deng, *et al.* (2018) developed a simplified dynamic model to study vibration in curved girder bridges with isolation bearings using a double-mass system in Matlab. The model captures effects of curvature, central angle, deck width, and damping on vibration frequencies and damping behavior. Results indicate bridge eccentricity decreases with larger radius but increases with central angle and deck width. Higher isolation layer damping improves damping ratios. Vibration modes include displacement in x, y, and torsion, highlighting design sensitivities.

Nidhi Gupta, *et al.* (2019) analyzed RCC box girder bridges with single, double, and triple cells for curvatures up to 60° using finite element analysis. Deflections significantly increased with curvature, especially in single-cell girders, while multi-cell girders resisted well up to 12°. Beyond 12°, deflections rose sharply, often exceeding limits. Bending moments and shear forces intensified in outer girders but decreased in inner girders, with exterior girders most affected. The study highlight the complex behavior of curved bridges and stress the need for sectional modifications to ensure safety and efficiency.

Suyesha Agrawal and Praveen Kumar Gupta (2024) studied seismic performance of curved bridges with varying curvature radii using SAP 2000. Non-isolated bridges with smaller radii showed greater deck displacements. High damping rubber bearings (HDRB) significantly reduced torsion and displacements, improving seismic resilience. Bidirectional earthquakes caused higher responses than unidirectional. HDRB lessened curvature effects on structural parameters. Bridges with curvature below 90° were more vulnerable to eccentric seismic effects, with responses varying based on earthquake characteristics. If more concise or detailed wording is needed or you want to format it for a particular journal style, I can help with that too

Dr. Rajan Suwal and Deepika Sharma (2020) analyzed prestressed box-girder bridges with curvature using a 3D finite element model in SAP 2000. Under self-weight, IRC Class 70R loads, and seismic effects, torsional moments increased linearly with curvature radius. Deflections were similar to straight bridges at large radii but rose sharply (45% higher at radius 50m). Bottom flange stresses exceeded top flange stresses, both varying with curvature. The study provided linear equations to improve preliminary curved bridge design accuracy and efficiency.

Anagha Manoharan and Glynez Joseph (2016) used ETABS 2013 for FEA of simply supported skew slabs under various loads, spans, skew angles, and concrete grades. Bending moments reduced significantly by up to 65% (concentrated load) and 75% (knife-edge load) with increased skew angle. However, torsional moments rose by nearly 60%, and shear forces increased by 30% under knife-edge load. The study highlights 20° as a critical skew angle causing maximum torsion, increasing failure risk and affecting stability.

III. OBJECTIVES OF THE STUDY

The primary aim of this study is to investigate the structural response of steel I-girder bridges subjected to curvature. To achieve this, the following specific objectives are outlined:

1. To perform a detailed parametric study on a steel I-girder bridge with a constant span length while varying the degree of curvature (12°, 24°, 36°, 48°, and 60°).
2. To evaluate the effect of increasing curvature on the key structural response parameters, namely torsional moment, bending moment, shear moment in each girder.
3. To compare the behavior of the bridge under different moving load cases in order to assess the impact of curvature on load distribution.
4. To determine the variations in internal forces induced by bridge curvature, with particular focus on outer girders, and to highlight the importance of incorporating curvature effects in design for ensuring structural safety and long-term serviceability.
5. To analysis the curved bridge with moving case load as per IRC.

IV. METHOD OF ANALYSIS

The analysis of the I-girder bridge with varying curve angles (12°, 24°, 36°, 48°, and 60°) was performed using MIDAS Civil software. The bridge geometry was modeled for each curve angle, incorporating appropriate supports and restraints. Analysis was conducted to evaluate structural responses including torsion, displacement, shear, and axial forces under standard loading conditions. The study compared these responses across different curvatures to assess the impact of increasing curve angles on load distribution and structural behavior. This approach enabled a detailed understanding of the effects of curvature on I-girder bridge performance.

V. STRUCTURAL MODELLING

Analysing the data: Following data are used in the model

1. Span of Bridge :- 40 metre
2. Width of Deck Structure: - 12 metre
3. No. of Steel I-Girder: - 5 Girder
4. Type of Bridge: - Steel Composite I-Girder
5. Deck Thickness :- 0.22 metres
6. Grade of Concrete: - M40
7. Grade of Steel : - fe540
8. Curve Angles: -12°, 24°, 36°, 48°, and 60°
9. Vehicle Type: - IRC Class A and IRC Class 70R

10. No.of Lane :- 3 Lane
11. Width of crash Barrier: - 0.5 metre

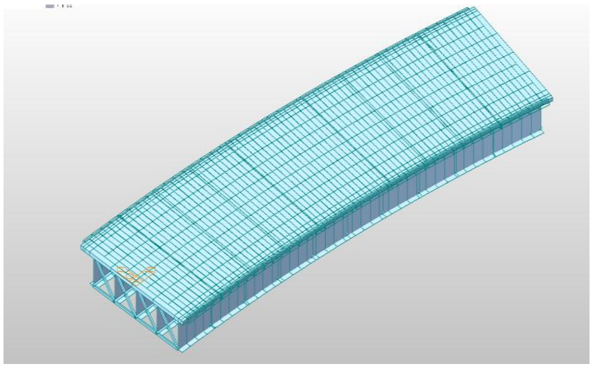

Fig 1: 12 Degree curve bridge

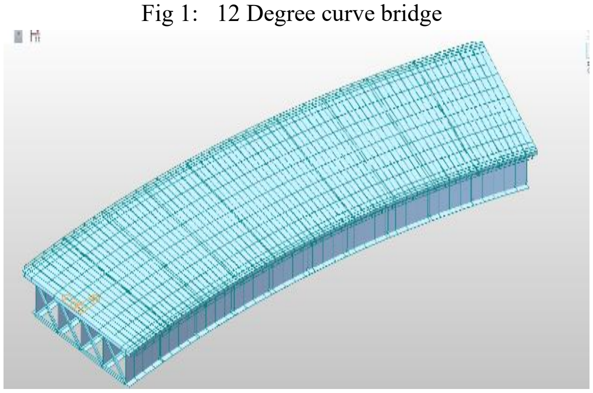

Fig 2: 24 Degree Curve Bridge

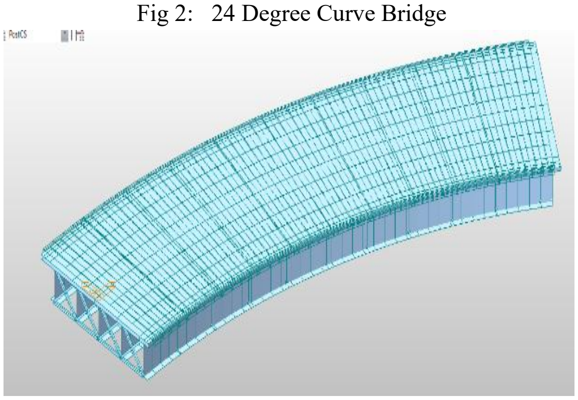

Fig 3: 36 Degree curve Bridge

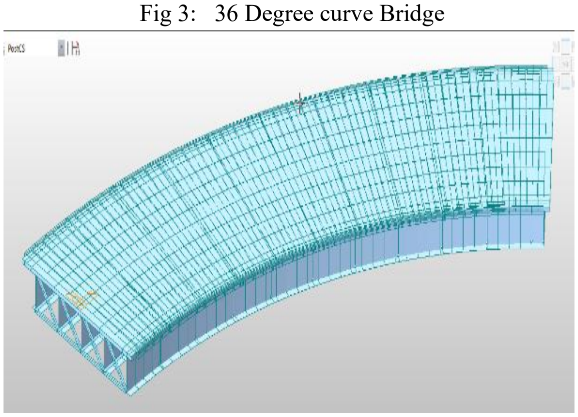

Fig 4: 48 Degree Curve Bridge

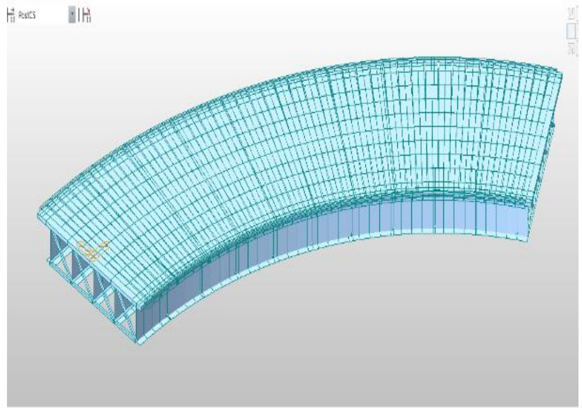

Fig 5: 60 Degree Curve Bridge

Sr.no	Curvature of Bridge	Radius of Bridge. (m)
01	12	191.335
02	24	96.195
03	36	64.721
04	48	49.192
05	60	40

VI. RESULTS AND DISCUSSION

The analysis results reveal significant insights into the structural behaviour of I-girder bridges subjected to varying curve angles. As the curvature increases, notable changes in internal forces and deformation patterns are observed.

Bending moments in the outer girders increase with the curve angle, indicating higher stress concentrations due to the eccentric load path and torsional effects inherent to curved geometry. Conversely, inner girders experience comparatively lower bending demands but are subjected to complex torsional effects that influence their overall stability.

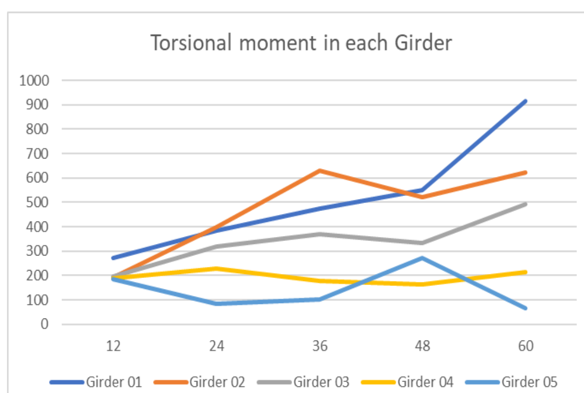

Fig 6: Maximum Torsional moment in each girder

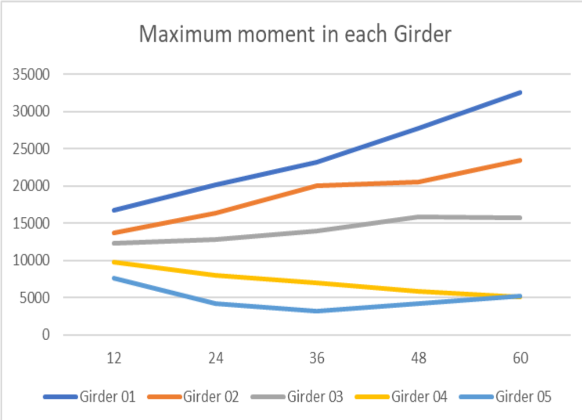

Fig 7: Maximum moment in each Girder

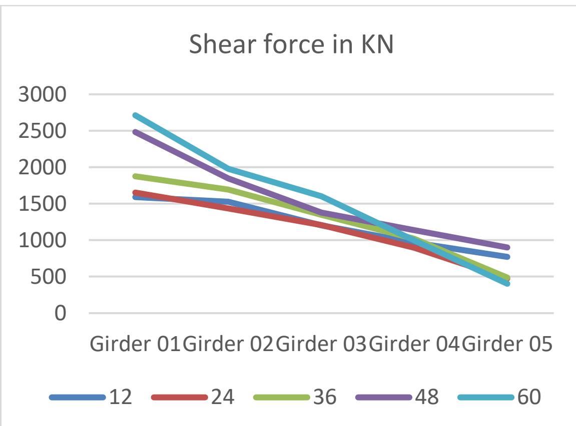

Fig 8: Maximum shear in each girder

The analysis highlights a clear impact of varying curve angles on the structural responses of the I-girders. The outermost Girder 01 experiences the highest increase in torsional moment demands, with response values rising sharply from 273.13 Kn-m at 12° curvature to 914.19 Kn-m at 60°, indicating significant torsion effects due to the curved geometry.

Table 1: Percentage increase for torsional moment for each girder

Girder	Model 01	Model 02	Model 03	Model 04	Model 05
	12°	24°	36°	48°	60°
Girder 01	273.13	40.20%	73.10%	101.70%	234.7%
Girder 02	193.62	105.4 %	225.5%	169.60%	221.3%
Girder 03	195.23	64.25%	89.58%	71.21%	151.7%
Girder 04	187.3	22.60%	-4.751%	-12.60%	13.67%
Girder 05	184.05	-53.43%	-45.62%	48.02%	-65.12%

Girder 02 also shows a strong upward trend in response values, increasing from 193.62 Kn-m to 622.18 Kn-m, confirming the substantial influence of curvature on outer girders.

In contrast, the inner girders (Girder 03 and Girder 04) show comparatively lower response magnitudes and more moderate increases, reflecting their less exposed positions relative to curvature-induced load effects.

Table 2: Percentage increase for bending moment for each girder in Kn-m

Girder	Model 01	Model 02	Model 03	Model 04	Model 04
	12°	24°	36°	48°	60°
Girder 01	16738.71	20.40%	38.59%	65.81%	94.57 %
Girder 02	13687.89	19.27%	46.39%	50.34%	70.96 %
Girder 03	12251.57	4.52%	14.22%	29.50%	28.07 %
Girder 04	9784.31	-18.5%	-28.58%	-40.29%	-47.4%
Girder 05	7613.3	-44.2%	-58.41%	-45.38%	-31.6%

The analysis shows that there is variation in bending moments of each girder with increasing curve angles. It is observed that the outermost Girder 01 experiences the maximum increase, with bending moment demands rising progressively to a peak increment of 94.57% at 60°. Girder 02 also shows a significant rise, reaching 70.96%. In contrast, the inner girders (Girder 03 and Girder 04) show moderate changes, while Girder 05 records negative increments, indicating reduced bending moments under curvature. Overall, the table highlights that curvature primarily amplifies bending demands in the exterior girders, emphasizing their critical role in design considerations.

Table 3: Parentage increases in shear force for each girder in KN

Girder	Model 01	Model 02	Model 03	Model 04	Model 04
	12°	24°	36°	48°	60°

Girder 01	1590.22	40.20%	73.10%	101.70%	234.7%
Girder 02	1527.08	105.4 %	225.53%	169.60%	221.3%
Girder 03	1202.51	64.25%	89.58%	71.21%	151.7%
Girder 04	964.17	22.60%	-4.751%	-12.60%	13.67%
Girder 05	770.93	-53.43%	-45.62%	48.02%	-65.12%

The analysis shows the percentage increase in shear force for each girder under varying curvature angles. The outer girders show the most significant rises, with Girder 01 increasing by 234.7% and Girder 02 by 221.3% at 60°, indicating a strong sensitivity of exterior girders to curvature. Girder 03 also experiences a notable rise of 151.7%. In contrast, Girder 04 records only minor changes, while Girder 05 initially shows negative increments but later reaches 65.12%. Overall, the results confirm that curvature greatly amplifies shear demands on outer girders, highlighting the need for enhanced design consideration.

VII. CONCLUSION

This study comprehensively investigates the effects of varying curve angles on the structural response of I-girder bridges. The analysis demonstrates that increasing curvature significantly influences the distribution of internal forces, particularly increasing bending moments and torsional effects on the outer girders.

The study of I-girder bridges with varying curve angles reveals that curvature significantly influences the distribution of internal forces, including torsional moments, bending moments, and shear forces. The outer girders, particularly Girder 01 and Girder 02, experience notable increases in these forces as the curve angle increases from 12° to 60°

In contrast, inner girders exhibit comparatively moderate or even reduced force demands, reflecting their positional advantage relative to curvature-induced load effects. The study reveal the critical necessity to incorporate curvature effects in structural analysis and design, as neglecting them may result in underestimating the demands on the most stressed girders, potentially compromising bridge safety and serviceability.

REFERENCES

[1] M Jagandatta, G Yaswanth Kumar and S Suresh Kumar, “Analysis and Design of Composite Single Span Psc-I Girder Bridge Using Midas Civil”, IOP Conf. Series: Earth and Environmental Science | March-2022.

[2] M. Geethanjali, A. Priya Dharshini, “Analysis And Design Of Composite Steel Bridge Girder”, International Research Journal of Engineering and Technology (IRJET) Volume-08 Issue-03 March-2021.

[3] Gang Zhang, Zhuoya Yuan, Yuhang Ding1, Feng Xu, Chenhao Tang1 and Shichao Wang, “Fire behaviour of composite steel truss bridge girders: numerical investigation and design strategies”, Advances in Bridge Engineering | 2024.

[4] Jiaxu Han, “Study on Steel and Concrete Composite Structure Bridge”, Highlights in Science Engineering and Technology | Volume 106 | 2024.

[5] Anagha Manoharan and Glynez Joseph, “Analysis of Skew Bridge with Varying Skew Angles”, International Journal of Scientific & Engineering Research, Volume: 07 Issue: 10 | Oct-2016.

[6] Mohd Waseem and Mohammad Saleem (May-2019), “Seismic Analysis of Box Girder Bridge using CSiBridge Software”, International Journal of Management, IT & Engineering, Volume: 09 Issue: 05 | May-2019.

[7] Syed Habibunnisa, Komma Hemanth Kumar Reddy, Mukkala Priyanka, “Dynamic Analysis of Horizontally Curved Bridges”, International Journal of Innovative Technology and Exploring Engineering (IJITEE) | July-2019.

[8] Nila P Sasidharan and Basil Johny, “Finite element analysis and parametric study of curved concrete box girder using ABAQUS software”, IJRET: International Journal of Research in Engineering and Technology, Volume: 04 Issue: 10 Oct-2015.

[9] Harwinder Kaushal, Er. Harish Sharma, Dr. Sandeep Chandel, Er. Susheel Kumar, Er. Madhu Bala, “Structural Stability Analysis of Bridge Structure Using FEA”, International Journal of Innovative Research in Engineering and Management (IJIREM) Volume-10, Issue-4 | August, 2023.

[10] Jefeena Sali, Kashif Quamar Inqualabi and Reji P Mohan, June, "Parametric Study of Behavior of Box Girder Bridges under Different Radius of Curvature", International Journal of Science and Research |Volume 5 Issue 6| June 2016.
[11] Kenneth W. Shushkewich, "Approximate Analysis of Concrete Box Girder Bridges", ASCE, Journal of Bridge Engineering Vol.114, No.7 Pg. 1644-1657 | July-1998.
[12] Ayman M. Okeil, Sherif El Tawil, "Warping Stresses in Curved Box Girder Bridges: Case study", ASCE, Journal of Bridge Engineering Vol.9, No.5 Pg.487-496 Sep-2004.
[13] Rajendra Thakai, Raghunath Deshpande, Shantinath Bedkihal, "Parametric Study on Behavior 0f Box Girder Bridges Using Finite Element Method", International Research Journal of Engineering and Technology (IRJET) | Volume: 03 Issue: 01 | Jan-2016.
[14] Tongfa Deng, Junping Zhang and Mahmoud Bayat, "Simplified Method and Influence Factors of Vibration Characteristics of Isolated Curved Girder Bridge", Tech Science, | 2018.
[15] Dr Rajan Suwal and Deepika Sharma, "Parameters of Pre-Stressed Box Girder Bridge under Different Radius of Curvature", International Journal of Innovative Research in Engineering & Management (IJIREM) | Volume-7 Issue-5| Sep-2020.
[16] Nidhi Gupta, Preeti Agarwal and Priyaranjan Pal, "Analysis of RCC curved box girder bridges", Applied Innovative Research | Vol. 1, pp. 153-159| Jan-2016.
[17] Suyesha Agrawal and Praveen Kumar Gupta, "Effect of radius of curvature on the seismic response of curved bridges", IOP Conf. Series: Earth and Environmental Science 1326 | 2024.