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Influence of Moving Load on the Behaviour of Skewed and Curved Rectangular Box Girder Bridges

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ABSTRACT::In urbanized or hilly areas, the alignment issues are more critical and to resolve such issues and to make smooth passage of congested traffic, construction of skewed and curved box girder bridges is becoming more customary in engineering perspective. However, behavior such bridges is significantly different from that of straight bridges as several parameters such as skew angle, radius of curvature, cross section of box girder etc. are involved in the analysis.The present paper deals with the analytical study of behavior of a single cell skewed and curved rectangular box Girder Bridge using simple finite-element models considering IRC 70 R and dead load as primary forces. The analytical behavior of the bridge has been studied considering the bridge with two spans of 60 m length and varying the parameters namely skew angle and radius of curvature. The results of the study indicate that skew angle and radius of curvature have significant effect on deflection, reaction at support, bending moment and shear stress of box Girder Bridge deck.

KEYWORDS: Box Girder Bridges, skew angle, radius of curvature, rectangular cross-section finite element analysis.

I. INTRODUCTION

Skewed and curved box girder bridges plays important role in highway intersections and interchanges, particularly in complex junction and in crowed urban area where lack of space and required the use of skew and curve geometries. However, the behavior of such type of bridges is significantly different and it is depend upon several parameters such as skew angle and radius of curvature.

Review of skewed bridges

Several research efforts using analytical as well as experimental approaches made over the past two decade to understand the actual behavior of skewed bridges when subjected to static and dynamic loads. Wakefield *et al* [20] done static and dynamic analysis for skewed RC box Girder Bridge to find out bridges response and failure mode of bridges. Kankam and Dagher [14] carried out nonlinear dynamic analysis for skewed slab girder bridges, followed by Maleki [21], who investigated the seismic analysis of single span skewed slab Girder Bridge to find out the effects of deck stiffness on the translational and torsional periods of vibration. Menassa C. *et al* [19] performed finite element analysis to find out the effect of a skew angle on simple-span reinforced concrete bridges. Huo and Zhang [26] studied the distribution factors of reactions at the piers are higher than those for near the same piers. The increase in reaction distribution factor at the piers in the interior beam lines is more significant than that in shear distribution factor when the skew angle is greater than 30°. Gokhan and Abdel-Mohti [2] investigated that for horizontal skewed bridges with larger skew angles (>30 degrees) having larger deformations. Followed by Ahmadi and Gholamreza [28], it found that the existence of skew angle (more than 30^0) leads to significant reductions in moment distribution factor in mid-span of bridges and the effect of skew angle on internal girders is more significant than external girders. Gholamreza and Ahmadi [6] presented that an increase of skew angle causes a reduction in both the exterior and interior support moment girders. The reduction was about 10% for skew angles less than to 20° and it reached 33% for a skew angle of 45°. Iman Mohseni and Khalim Rashid [9] done parametric study to examine the effect of main parameters on the maximum distribution factors of deflection and tensile stress at the mid-span and compressive stress at the intermediate piers of skewed MCB bridges. Ahmed Abdel-Mohti and Gokhan Pekcan [7] found that the relative effectiveness of shear keys in controlling the seismic response of bridges diminishes as the skew angle becomes larger.

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Review of curved bridges

Curved beam theory introduces by Saint-Venant (1843) and extended by Vlasov (1965) for the analysis and design of straight and curved box-girder bridges [15]. In 1969, AASHTO was conducted research work on horizontally box girder bridges, referred as CURT. The CURT research used for the development of the first Guide Specifications for Horizontally Curved Highway Bridges in 1980, and then it was revised in 1993 by AASHTO [1]. Ali [22] researched parametric instability of curved girders. In this paper, investigation carried out for finding instability of a curved girder subjected to equal and opposite periodic moments at the ends. Li *et al* [25] scrutinized the effect of curvature on curved box girder bridges. This paper intrudes the finite stripe method is extended to the elasto-static analysis of circular and non-circular box girder bridges. Further, Senthilvasan *et.al* [12] carried out dynamic analysis of curved box girder bridges under moving truckload. An experimental investigation carried out on a continuous curved rigidity twin-cell box girder under heavy vehicle at different speed and results was recorded in the form of strain and deflections of curved box girder bridges. Choi and Yoo [3] performed parametric studies for curved box girder bridges to find out minimum required for the longitudinal stiffeners. DeSantiago *et.al* [5] carried out finite element analysis for horizontal curved I girder bridges. This analysis performed for typical truckload and dead load as primary load cases. The results such as torsion moment, bending moment and deflection of curved I girder bridges compare with straight bridges, followed by Zhang *et.al* [8], who developed live load distribution formulas to predict positive moment, negative moment, and shear distribution for one-lane and multiple-lane horizontally curved steel I-girder bridges. Samaan *et.al* [18] executed parametric study on 180 continuous curved multi-box girder bridges. This paper presented an expression for impact factor for deflection, reactions, tangential flexural stresses and shear forces for AASHTO truck loading, tracked by Samaan *et.al* [17], who investigated formulas for load distribution factors for maximum deflection and maximum longitudinal flexural stresses due to dead load and AASHTO live loading were deduce.

Review of skewed and curved bridges

Few researches are available to describe the behavior of skewed and curved bridges. More recently in a study by Wilson *et.al* [23], [24], it was found that for three-span finite element model of curved and skewed reinforced concrete (RC) bridges to identify the behavior under seismic activity. It also found that amplification and reduction of axial compression forces particularly associated with vertical ground motion accelerations in the pier-columns of the bridge substructure and found that subsequent reduction in the column capacity to resist shear and bending demand. Deng *et.al* [27] studied thermal behavior, it carried parametric study to investigate the influence of curvature and skew angle on the stresses induced in the girders and found the impact of having two fixed piers on the design of these curved and skewed bridges.

This paper presentsa simple 3-D finite-element analysis on a series of two-span skewed and curved single cell RCC rectangular box girder bridges. The bridges had different skew angle varies 0^0 to 60^0 along with varies radii (120 m ,150 m, 180 m and 210 m). The purpose of this study intended to scrutinize the effect of skew angle and radius of curvature on the performance of skewed and curved rectangular box girder bridges.The results presented in the form of deflection, reaction at support, variation in torsion moment, bending moment and shear stress with respect to skew angle, for varying radius of curvature, subjected to IRC 70 R and dead load as primary forces. The findings of this study, along with recommendations geared specifically to skewed and curved bridges that may be helpful in design, construction, safety, serviceability and economy of these bridges.

II. FINITE ELEMENT MODELING AND ANALYSIS

Structural component

The bridges examine in this study by vary in skew angle (0^0 to 60^0) and radii of curvature(120 m, 150 m, 180 m and 210 m), however each bridge is constructed with thesame structural components. The bridge superstructure consist of RCC rectangular box girder having width of top and bottom flange is 9.6 m and 5.43 m respectively and total depth of box girder is 2.31 m. The thickness of flanges and webs are 0.381 m. The modulus of elasticity of concrete and Poisson's ratio were taken as 31.6 GPa and 0.2 respectively. Grade and density of concrete considered as M40 and 2500 kg/m^3 respectively. Fig. 1 shows typical cross section of rectangular box Girder Bridge.

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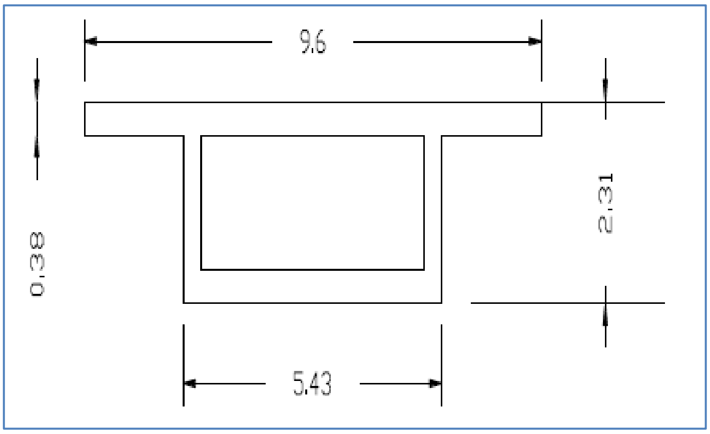

Fig.1. Typical cross-section of skewed and curved rectangular box Girder Bridge

Development of finite element model for parametric study

The analysis of the bridges considered for this study evaluated using 3-D finite element models constructed in SAP-2000 [4]. A four-nodethree dimensional shell element with six degrees of freedom (three displacements and three rotations) at each node used to model the concrete box girder. The three-dimensional shell element has the capability to measure membrane, bending, and torsional actions. Top and bottom shell element of web integrated with the top and bottom slab at connection points to ensure compatibility of deformation. The transverse solid diaphragms at supports modeled using the same element with the size and properties of designated diaphragms.

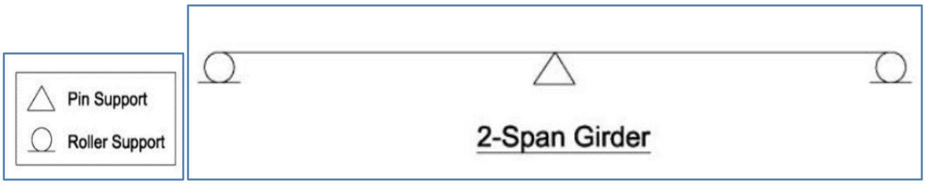

Fig.2. Girder boundary condition

In the presented study, only the superstructure of bridges modeled and the effect of bearing and piers were neglected. The boundary condition used in this analysis such that the middle support treated as a hinge, at the bottom of web, which resist both vertical and lateral displacement and all other supports were treats as roller, at the bottom of web, with prevents only vertical translation (Fig 2.).

Loading condition

The live load used in the parametric study as per IRC: 6-2014 standards truck load IRC-70R. This loading is to be normally adopted on all roads on which permanent bridges and culverts are constructed. The lean load consists of superimposed load having maximum value 17 t for IRC-70R loading [10]. For partially loaded lane, nose to tail spacing between two successive vehicles considered as 30 m for IRC-70R loading. The wheel load applied closed to the curbs at a distance of 1.2 m from inside edge of the curb. The results are obtained in this study for load combination such as dead load+ IRC-70R. Fig. 3 a typical finite element modelling of a single cell skewed and curved RCC rectangular box girder bridges.

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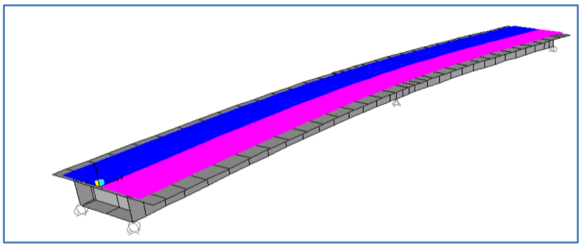

Fig 3. Finite element modeling of skewed and curved rectangular box Girder Bridge.

III. RESULTS AND DISCUSSION

In this parametric study 28 bridges were analyse with various configuration for radius of curvature and skew angle, keeping constant span length. In each run, the maximum deflection, support reaction, maximum bending moment, maximum torsion moment and maximum shear stress were obtained. These obtained results of bridges for various skew angles i.e. 10^0, 20^0, 30^0, 40^0, 50^0 and 60^0 were compared with results of 0^0 skew angle bridges for different radius of curvature.

Combine the effect of skew angle and radius on deflection of bridges

After the conducting the parametric study the deflection of bridges were recorded. Fig 4 shows the effect of skew angle and radius of curvature on the vertical deflection of these bridges.

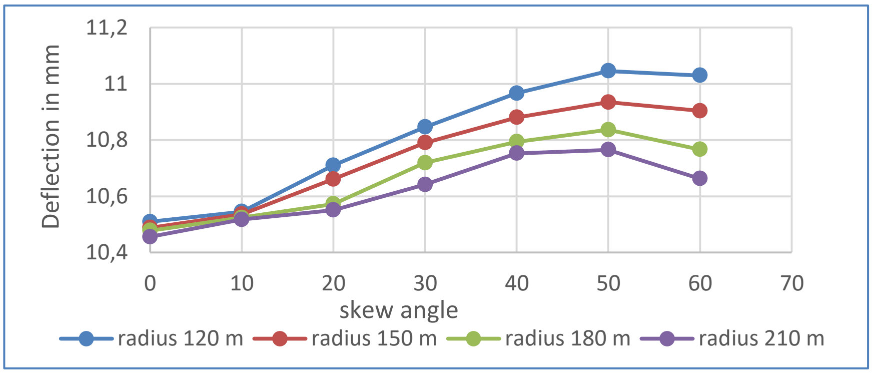

Fig. 4: Deflection of rectangular box girder

The results in Fig. 4. Show that the deflection of bridges increases with increasing skew angle until reaches up to 50^0 skew angle, after 50^0 skew angle it started to decreases. Deflection of bridges decreases with increasing the radius of curvature. The maximum deflection 11.045 mm occurred for 50^0 skew angle and 120 m radius curvature which 5.09% greater than 0^0 skew angle bridges.

Table 1: Ratio of Vertical Deflection of Skewed Bridges to Deflection of 0^0 Skew Bridges.

Skew angle	Radius of curvature in m			
	120	150	180	210
10	1.003394	1.004548	1.004356	1.005906
20	1.019046	1.016462	1.009016	1.009117
30	1.032041	1.028813	1.022965	1.017807
40	1.043479	1.037411	1.030087	1.028393
50	1.050978	1.042551	1.034186	1.029598
60	1.04951	1.039629	1.027481	1.019819

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The above Table 1 shows ratio of vertical deflection of skewed bridges to deflection of 0^0 skew bridges. When skew angle increases from $0^0$to 20^0, the maximum deflection increases 1.3% (avg.). As skew angle increases from $20^0$to 40^0 the maximum deflection increases 3.48 % (avg.).when skew angle increases from $40^0$to 50^0 the maximum deflection increases 3.93% (avg.). Also, when skew angle increases from $50^0$to 60^0 the maximum deflection increases 3.41% (avg.).

Combine the effect of skew angle and radius on support reaction of bridges.

In many researchers found that as providing skew support to the bridges, their chances of load take shortcut toward the obtuse support and their possibility of uplift force act at acute support[6], [26], [14]. In this parametric study support reaction recorded at each obtuse and acute corner.

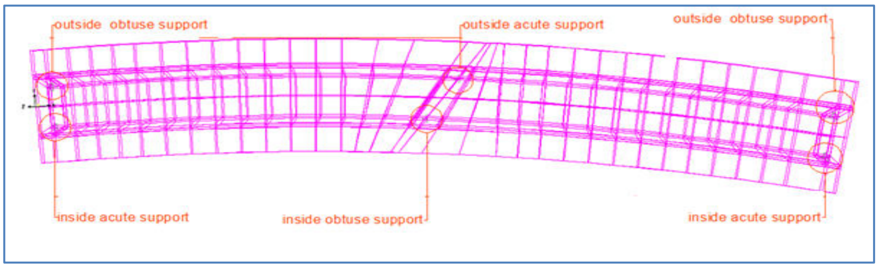

Fig. 5: Position of obtuse and acute support

The above Fig 5 shows the position of obtuse and acute support in skewed and curved rectangular box girder bridges.

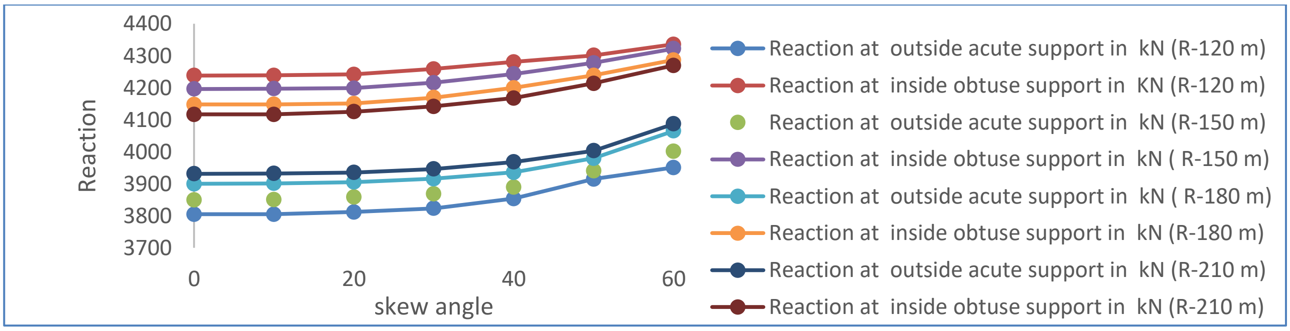

Fig 6 (a): Reaction at outside acute and inside obtuse support

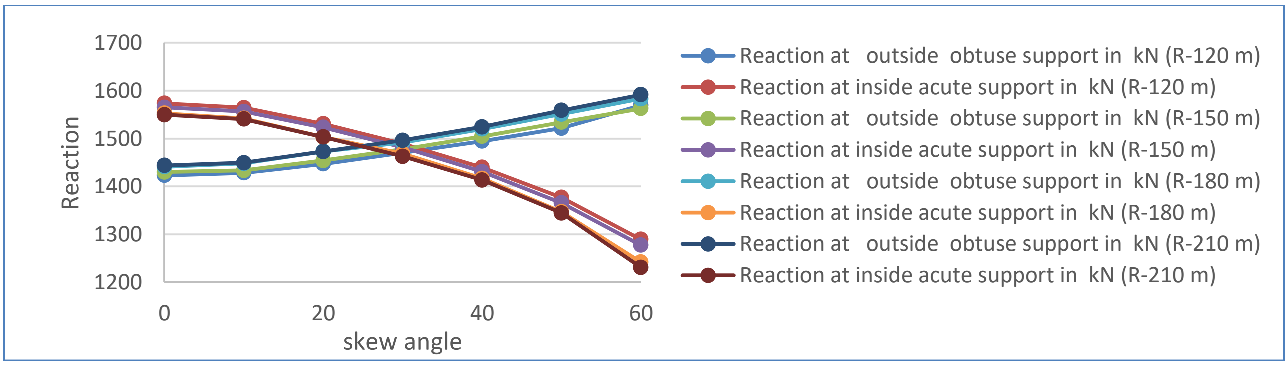

Fig 6 (b): Reaction at outside obtuse and inside acute support

Fig 6: Support reaction for skewed and curved rectangular box girder bridges.

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During this sensitive study found that the reaction at inside obtuse support, outside acute and obtuse support goes on increases with increasing skew angle, while reaction at inside acute support goes on reduces with increasing skew angle (Fig 6). Compare with 0^0 skewed bridges reaction, the average reduction in reaction of inside acute support are 2.89 % when 20^0 skew angle, 8.66% when skew angle 40^0, 19.26% when skew angle 60^0. Average increasing in the reaction of inside obtuse support, outside obtuse and acute support are 0.10%, 1.9%, 0.16% when 20^0 skew angle, 1.15%, 5.32%, 1.05% when skew angle 40^0, 3.09%, 9.91%, 4% when skew angle 60^0 , respectively.

Combine the effect of skew angle and radius on bending moment of bridges.

During this sensitive parametric study, positive and negative bending moment were recorded various skew angle and radius of curvature for this bridges.

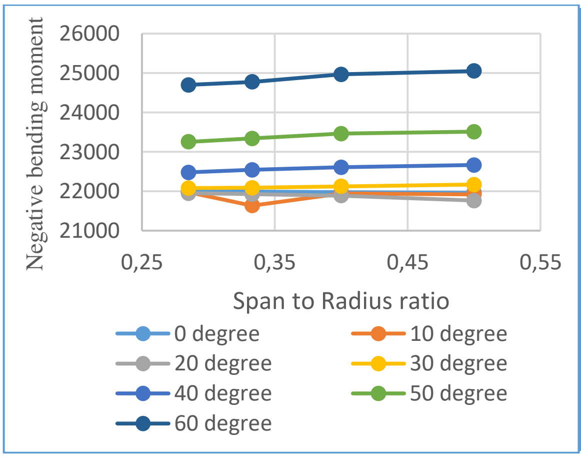

Fig 7 (a)

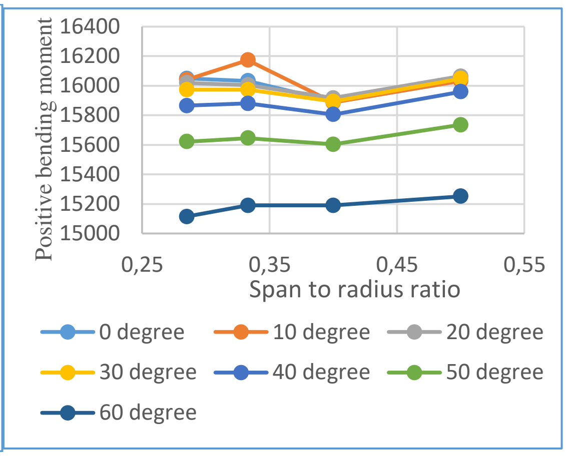

Fig 7 (b)

Fig 7: Graph of bending moment vs span to radius ratio Resit

After examination of Fig 7 observation made that negative branding moment increase while positive bending moment reduces with increasing skew angle for respective radius of curvature. This investigation shows that negative bending moment (Fig. 7(a)) for 60^0 skewed bridges are increases 13.14% (avg.) while positive bending (Fig. 7(b)) reduces 5.12% (avg.) compare to 0^0 skewed bridges. It is also observed that negative branding moment reduces while positive bending moment increases with increasing radius of curvature. For 60^0 skewed bridges, negative bending reduces from 14.07% to 12.29% simultaneously positive bending moment increases from 4.99% to 5.83% when radius of curvature increases 120 m to 210 m.

Combine the effect of skew angle and radius on shear stress of bridges.

The maximum shear stresses for 0^0 skew are 3.85 N/mm^2, 3.85 N/mm^2, 3.86 N/mm^2 and 3.86 N/mm^2 for various radii of curvatures.

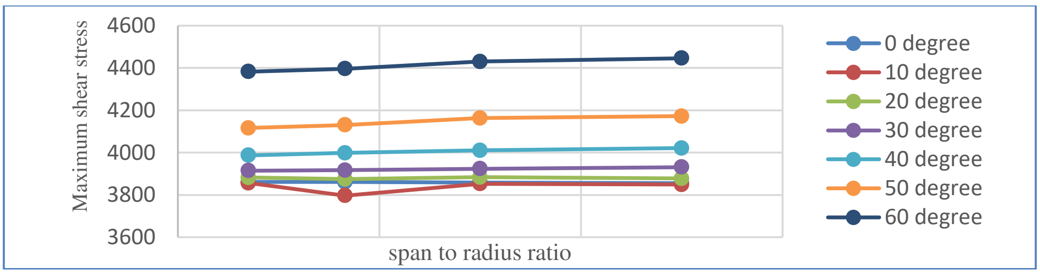

Fig 8: Graph of maximum shear stress vs. span to radius ratio

The results in Fig 8 shows the graph of maximum shear stress vs. span to radius ratio. This analysis shows that shear stress are directly proportional to skew angle while inversely proportional to radius of curvature. Shear stress increases 0.5 % for 20^0 skew angle, 3.75% for 40^0 skew angle and 14.37% for 60^0 skew angle for respective radius of curvature.

IV. CONCLUSION

The analysis of skewed and curved rectangular box girder models is carried out in SAP2000 software by varying skew angle and radius of curvature for constant span length. The analysis performed for rectangular single cell box Girder Bridge using simple finite-element models subjected to IRC 70 R truckload and dead load as primary forces. During this parametric study, the variations in deflection, reaction at support, bending moment, torsion moment and shear stress were computed. After the examinations of these results, the following conclusions are made.

1. During the comprehensive parametric study for skewed and curved box girder bridges, point out that the combine effect of skew angle and radius of curvature cannot be neglected for design consideration.
2. During the sensitive study related to deflection of bridges observed that the effect of both geometry (i.e. skew angle and radius) on deflection was negligible. It is also observed that the maximum deflection occurred for 50^0 skew angle which is 4.16 % (avg.) greater than 0^0 skewed bridges.
3. In a comparative study between obtuse and acute support, inside obtuse support were found to induce higher reaction than outside acute support. It is also observed that, gathering of reaction at inside obtuse support while dispersing of reaction at inside acute support and there possibility of uplift forces acting at inside acute support.
4. Comprehensive study associated with flexure response of skewed and curved box girder bridges observed that negative moment of this bridges goes on intensification while positive moment of this bridges goes on diminution with increasing skew angle, vice versa for increasing radius of curvature.
5. Shear stress for skewed and curved box girder bridges is directly proportional to the skew angle while inversely proportional to radius of curvature.
6. The effect of skew angle can be minimize by increased the radius of curvature.

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