International Journal of Engineering Research and Development
***e**-ISSN: 2278-067X, **p**-ISSN: 2278-800X, www.ijerd.com*
Volume 2, Issue 12 (August 2012), PP. 13-18

Study on Effect of Skew Angle in Skew Bridges

Ansuman kar[1], Vikash Khatri[2], P. R. Maiti[3], P. K. Singh[4]
[1,2,3,4]*Department of Civil Engineering, Institute of Technology, Banaras Hindu University, Varanasi*

Abstract—The presence of skew in a bridge makes the analysis and design of bridge decks complex one. The angle of skew has a considerable effect on the behaviour of the bridge. Therefore, there is a need for more research to study the effect of skew angle on the performance of skew bridges. In the present work, the effect of change in skew angles with right bridge is studied by two well established analysis methods; finite element method and grillage analogy method. Longitudinal moment, reaction at support, deflection and transverse moment are computed by FEM and grillage analogy method and results are compared for different skew angles. Simple supported single span bridge is considered in this study. The analysis results shows that as skew angle increases, reaction increases, bending moment decreases but torsion and transverse moment increases up to a certain angle, after which it decreases. The effect of skewness on the behaviour of bridge deck is studied for skew angle 0^0, 30^0, 45^0, and 60^0 and presented graphically using FEM and grillage analogy method. Results are presented for both analysis method for dead load and combined dead and live load.

Keywords—Skew bridge, Skew angle, FEM, Grillage Analogy

I. INTRODUCTION

Skew bridges are common at highways, river crossing and other extreme grade changes when skewed geometry is necessary due to limitations in space. There is a growing demand for skewed steel bridges as the needs for complex intersections and the problems with space constraint in urban areas arise. Skewed bridges are useful when roadway alignment changes are not feasible or economical due to the topography of the site and also at particular areas where environmental impact is an issue. In order to cater to high speeds and more safety requirements of the traffic, modern highways are to be straight as far as possible and this has required the provision of increasing number of skew bridges. If a road alignment crosses a river or other obstruction at an inclination different from 90°, a skew crossing may be necessary. The inclination of the centre line of traffic to the normal to the centre line of river in case of a river bridge or other corresponding obstruction is called the skew angle. The analysis and design of a skew bridge are much more complicated than those for a right bridge. In the skew bridge, the span length, deck area and the pier length increase in proportion to cosec Θ where Θ is skew angle.

The presence of skew in a bridge makes the analysis and design of bridge decks intricate [1]. For bridges with small skew angle, it is frequently considered safe to ignore the angle of skew and analyse the bridge as a right bridge with a span equal to the skew span. However, bridges with large angle of skew can have a considerable effect on the behaviour of the bridge especially in the short to medium range of spans. A significant number of research studies [8] have examined the performance of skewed highway bridges. Nonetheless, there are no detailed guidelines addressing the performance of skewed highway bridges. Several parameters affect the response of skewed highway bridges which makes their behaviour complex. Therefore, there is a need for more research to study the effect of skew angle on the performance of highway bridges.

The effect of skew [4, 7] above angles of about 20^o in single span decks can have a considerable effect on the behaviour of the bridge especially in the short to medium range of spans where the span and width are of the same order. The effects of skew on the response of completed structures have been well documented, with effects being shown to be more significant for skew angles greater than 30◦. Critical values for vertical deflections and bending moments [5] within in-service skewed bridges have been shown to be lower when compared against those in similar right bridges. Conversely, torsional rotations, shears and moments have been shown to be larger for skewed bridges.

A skewed bridge is one whose longitudinal axis is not at a right angle to the abutment. Skew in a bridge can result from many factors, including natural or manmade obstacles, complex intersections, space limitations, or mountainous terrain. Plan of a skew bridge is presented in Fig. 1.

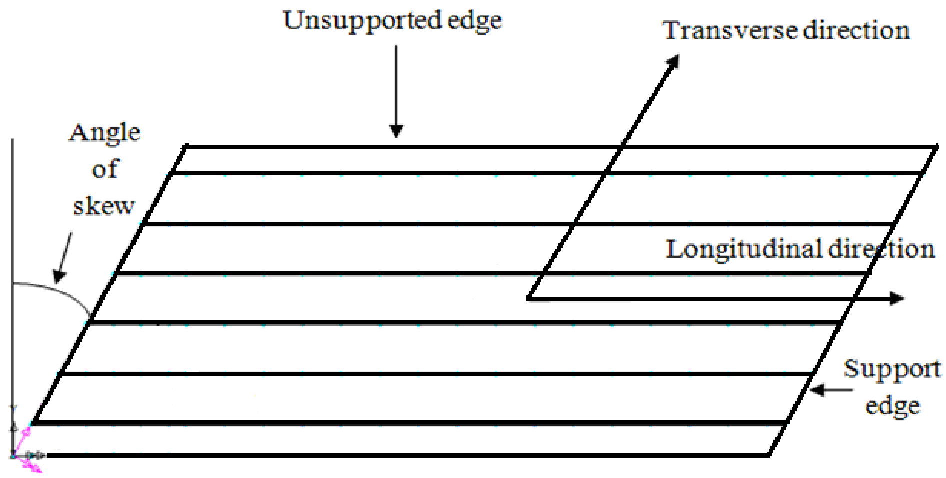


Fig.1 Plan of skew deck slab

Characteristics of skew decks

In normal bridges, the deck slab is perpendicular to the supports and as such the load placed on the deck slab is transferred to the supports which are placed normal to slab. Load transfer from a skew slab bridge is complicated problem because there always remain a doubt as to the direction in which the slab will span and the manner in which the load will be transferred to the supports. With increase in skew angle, the stresses in the bridge deck and reactions on the abutment vary significantly from those in straight slab.

Special characteristics of skew deck slab are

- Variation in the direction of maximum bending moment across width, from near parallel to span at edge and orthogonal to abutments in central region.
- Hogging bending moments near obtuse corners.
- Considerable torsion in decks.
- High reactions and shear forces near obtuse corners.
- Low reaction and possibly uplift near acute corners, especially in case of slab with high skew angles.
- The points of maximum deflection nearer obtuse angled corners.

The magnitude of these effects depends on the angle of skew, aspect ratio of the slab and the type of construction of decks and supports. The shape and edge details can also influence the direction of maximum moments, the deck slab span on to abutments, the stiff edge beams acts as a line of support for the slab which effectively spans right to abutments across full width. The skew is so high that the deck is cantilevered off the abutments at the acute corners. The above characteristics are particularly significant in solid and cellular slab decks because their high torsional stiffness tries to resist the twisting of deck. In contrast, the skew is less significant in beam and slab decks, particularly with spaced beams.

Effect of increase in the skew angle

With increase in the skew angle, the stresses in the slab differ significantly from those in a straight slab .A load applied on the slab travels to the support in proportion to the rigidity of the various possible paths. Hence a major part of load tends to reach the support in a direction normal to the faces of abutments and piers .As a result, the planes of maximum stress are not parallel to the centre line of the roadway and slab tends to warped. The reactions at the obtuse angled end of slab support are larger than other end, the increase in value over average value ranging from 0 to 50% for skew angle of 20 to 50°.The reaction are negative for the skew angle greater than 50°.The reaction on the obtuse angle corner becomes twice the average reaction, thus making the acute angle corner a zero pressure point when skew angle reaches about 60°.

Superstructure behaviour

In stringer bridges (bridges supported by longitudinal-I or bulb-tee beams), the load tends to flow along the length of the supporting beams, and the effect of skew on the bending moments is minimized. In solid slab bridges and other bridges with high torsional rigidity, the load tends to take a “short cut” between the obtuse corners of the span, and slab primarily bends along the line joining the obtuse angled corners. This reduces the longitudinal bending moments, but it increases the shear in the obtuse corners. The same effect occurs in stringer bridges, but is less pronounced.

The width of this primary bending strip is a function of skew angle and the ratio between the skew span and width of the deck (aspect ratio).The areas on either side of the strip do not transfer loads to support directly but transfer the load only to strips as cantilever. Hence the skew slab is subjected to twisting moments. Because of this, the principal moment direction also varies and it is the function of a skew angle and width to span ratio. The load is transferred from strip to the support first over a definite length along the support line from obtuse –angled corners .later the force gets redistributed for full length.

The deflection of the slab is not uniformly or symmetrical as in the case of right deck. There will be wrapping leading to higher deflection near obtuse angled corner areas and less deflection near acute angled corner areas.

For small skew angles, both the free edges will have downward deflection but differing in magnitude .The free edge deflection profile becomes more unsymmetrical as the skew angle increases. The maximum deflection moves towards obtuse angled corners. Near acute angled corner, there could be even negative deflection resulting in S shaped deflection curve with associated twist.

If the width of slab is large, the cantilevering portion from primary bending strip connecting the obtuse –angled corner will also be large. The bending strip also will be very nearly orthogonal to supports. To reduce twisting moment on the load-bearing strip connecting the obtuse angled corners, an elastic support can be given along the free ends for the slab and the support is achieved by provision of an edge beam. If stiff edge beam is provided, it acts as a line support for the slab, which effectively extends right up to the abutment. It provides an elastic support in transverse direction for the slab preventing the cantilever action at the triangular portion in acute angle corner zones for the full width is always preferable.

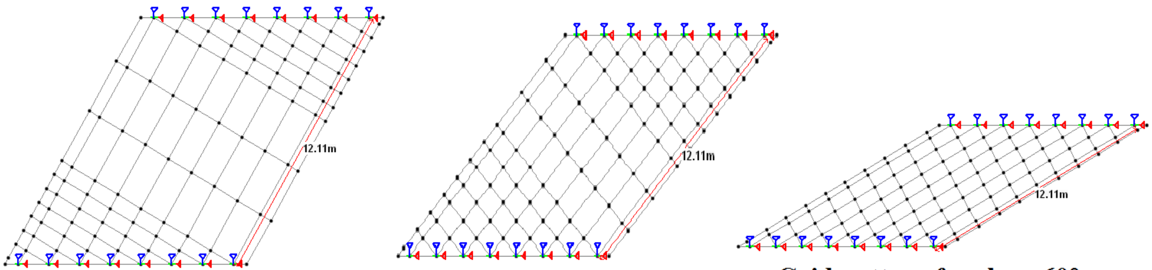
In the present study, transverse bending moment and torsional moment, the reaction forces at the support and deflection of a skew bridge is presented for different skew angle.

II. ANALYSIS OF DECK SLAB BRIDGE

The effect of different skew angles on the behaviour of skewed bridges under dead & live load (70R) [9] using grillage analogy method & FEM are analysed. The skew slab bridges having 30°,45° and 60° skew angle of carriage way 7.5m and skew span 12.11 m is considered for present analysis i.e. reactions, bending moment, deflection under dead and live load with different cases of grid spacing (4 to 12 divisions). Slab thickness is of uniform depth 750 mm. A skew slab bridge is supported on five isolated bearings at each end, adoption of neoprene bearings of spring stiffness of 40t/mm at each support point. The flexibility of support is considered in analysis.

For the analysis, STAAD PRO 2007 is used. In each case the whole slab is discretized in grid of interconnected beams in case of Grillage analogy and grid of interconnected plates in FEM .For sake of convenience in analysis and also comparison of results, the spacing of transverse grid lines are kept constant and only longitudinal grid lines changes to study the variation of deflection, reaction, bending moment for different mesh size. Rectangle sections of all grillage beams are considered with constant thickness of 750 mm.

Grid Pattern



Grid pattern for skew 30° **Grid pattern for skew 45°** **Grid pattern for skew 60°**

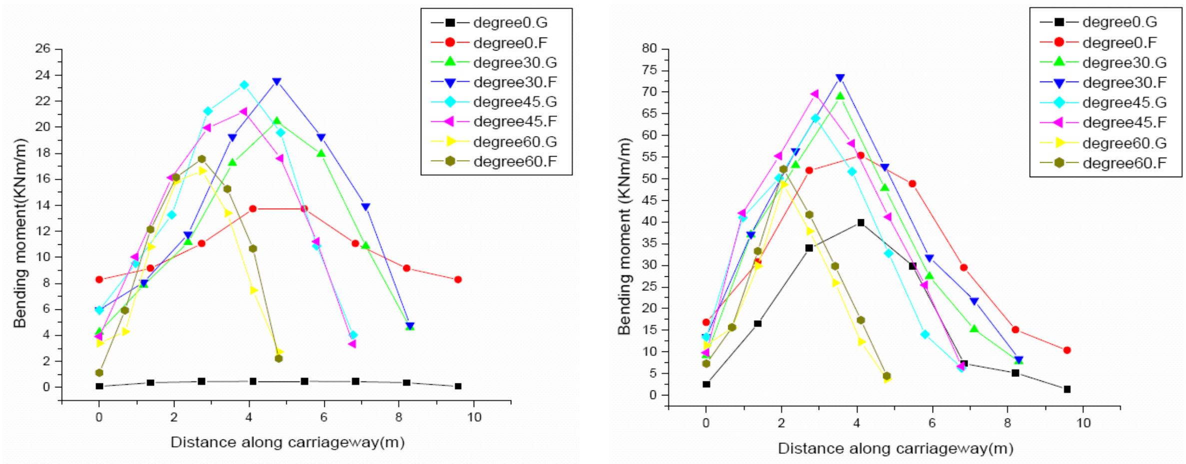
Figure 2. Grid Pattern

All different skewed angle bridges have same grid pattern and same span. STAAD PRO 2007 is the software used for analysis.

a) Grillage analogy i.e. given decking system is converted into series of interconnected beams such that given prototype bridge bridge deck and the equivalent grillage of beams are subjected to identical deformations under loading.
b) Finite Element Method consists of solving the mathematical model which is obtained by idealizing a structure as an assemblage of various discrete two or three dimensional elements connected to each other at their nodal points, possessing an appropriate number of degrees of freedom.

III. RESULTS AND DISCUSSIONS

Analysis results of various skewed bridges are compared with right bridge of same span and their behaviour patterns have been studied. The transverse moment is presented in Figure 3 for different skew angle by two methods FEM and Grillage Analogy.



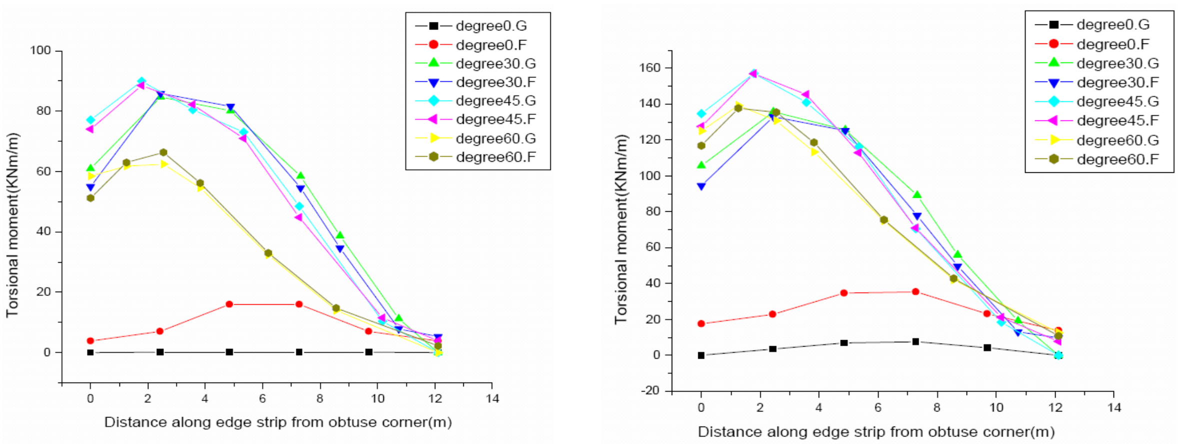
(a) For Dead Load Only **(b)** For Combine Dead and Live Load

Figure 3. Variation of transverse moment for different skew angle

It is observed from Figure 3 that transverse moment increases as skew angle increased to 30° but it remains almost same or same to 45° due to dead load and after it decreases when skew angle reached to 60°. However results by grillage method show almost same value of FEM. In case of live load, transverse moment follows same behavior as in dead load case till 30° but it decreases after that by huge amount. Approximately 20% decreased when it is reached 45° and 40 % and when it reached 60°, comparing to results of skew angle 30°.

Analysis by grillage method, transverse moment of right bridge is negligible in dead load case, so maximum transverse moment in 60° is greater than right bridge which is not true according to FEM. As transverse moment comes in account in live load case, so in both FEM and grillage shows decrease in bending moment than right bridge when skew angle reached to 60°. Transverse moment depends on aspect ratio and skew angle. In grillage, it doesn't shows transverse moment in right bridge, unlike FEM, which shows transverse moment at 0° also. This may be due to bending/load bearing strip which becomes narrow as skew angle increases. There are more chances of upliftment at corners; it can be solved by placing edge beam stiffener over support. The deflection pattern is consistent with that of longitudinal bending moment, it follows same pattern.

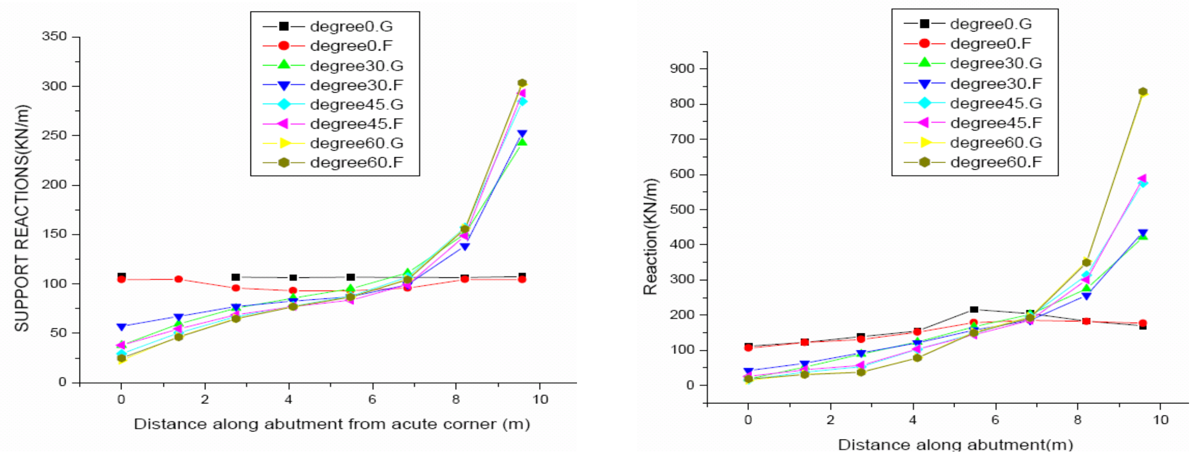
The variation of torsional moment is shown in Figure 4. Torsional moment also shows similar patterns as transverse moment. As angle of skewness increased torsional moment comes into account. It increases with angle of skew. But it increased up to certain angle, and then it is decreased. In combination of dead and live load case, there is almost less/negligible torsion moment in right bridge but increases abruptly to 30° and its increased rate slows down at 45°, later torsion moment decreases at 60°; decreased to 20% of 45° almost equal to skew angle 30°. Like transverse moment, it also depends on aspect span and skew angle. While in grillage method, there is no torsional moment in right bridge and due to live loads, some torsional moment comes into account, but in FEM method torsional moment always persists even in dead load case also.



(a) For Dead Load Only **(b)** For Combine Dead and Live Load

Figure 4. Variation of Torsional moment for different skew angle

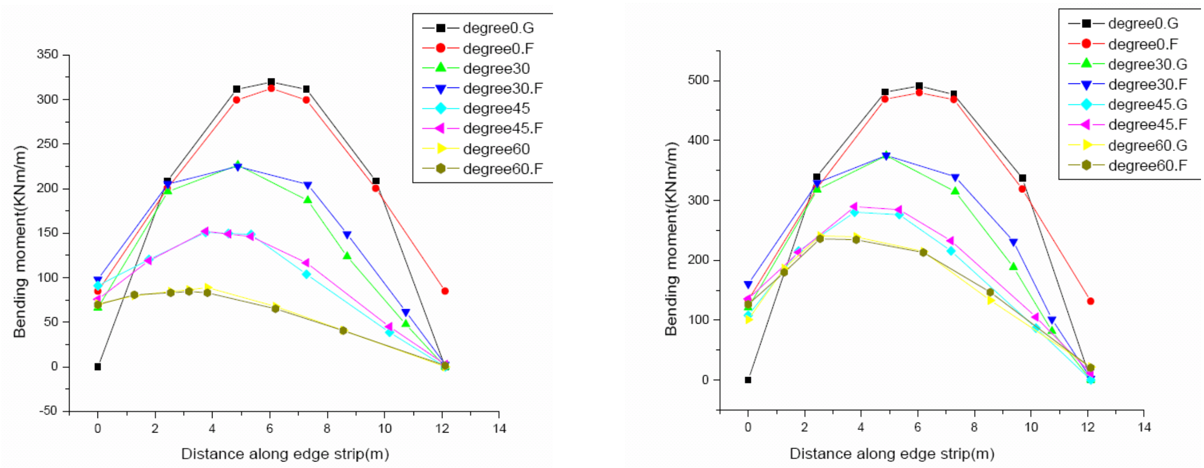
Reaction at support is plotted in Figure 5 for both dead load and combined dead load and live load. Reactions increases with increase in skew angle, both in dead load and live load case. In right bridge, reactions are almost same and in straight line whereas, in skew bridge reaction increases linearly from acute angle to obtuse angle at corner. Reaction force is increased to 60, 70 and 80% for skew angle 30°, 45° and 60° respectively, when dead as well as live load taken into account. Reaction curve is unsymmetrical along diaphragm beam in skew bridge resulting high support reactions near obtuse corners and low support reactions at acute corner. This behavior is caused due to rotation of obtuse corner and reducing the reaction in intermediate support.



(a) For Dead Load Only **(b)** For Combine Dead and Live Load

Figure .5. Variation of reaction at support for different skew angle

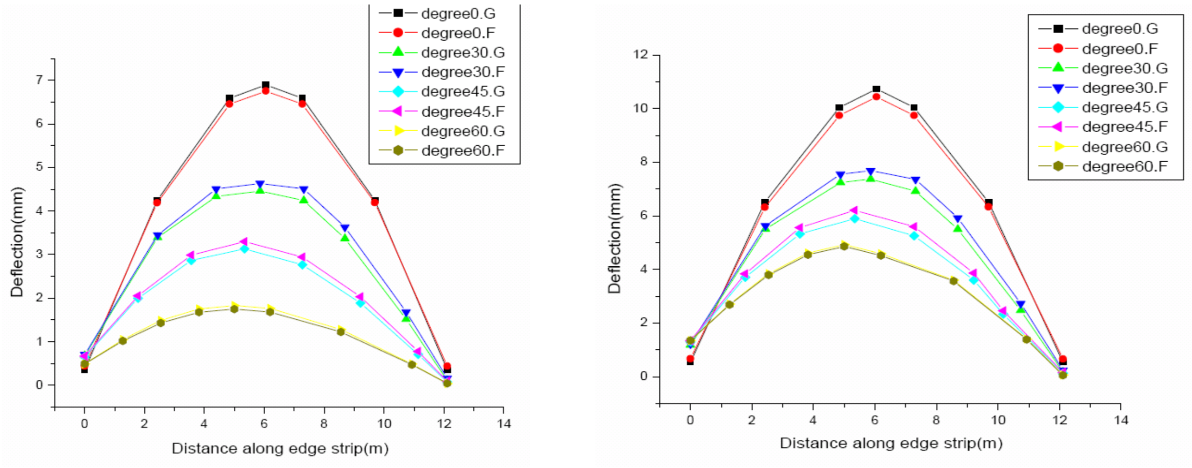
Variation of bending moment is presented in Figure 6 for dead load and combined dead load and live load. The analysis is done by two methods and results are compared. Bending moment is maximum in right bridge, and it decreases as skew angle increases. It reduced to 25%, 50% and 75% as skew angle reduced to 30^0, 45^0 and 60^0.



(a) For Dead Load Only **(b)** For Combine Dead and Live Load

Figure 6. Bending moment along the span for different skew angle

The deflected shape of the span due to dead load and combined dead and live lad is presented in Figure 7. Maximum deflection usually occurs nearer to obtuse corner in skew bridges, but as aspect ratio is more, maximum deflection comes nearer to mid span, but as skew angle increases it shift towards obtuse corner where as in right bridge maximum deflection is coming at mid span of strip.



(a) For Dead Load Only **(b)** For Combine Dead and Live Load

Figure 7. Deflection of the slabs along the span of the deck slab

IV. CONCLUSIONS

With increase in the skew angle, the stresses in the slab differ significantly from those in a straight slab .A load applied on the slab travels to the support in proportion to the rigidity of the various possible paths. As a result, the planes of maximum stress are not parallel to the centre line of the roadway and slab tends to warped. The reactions at the obtuse angled end of slab support are larger than other end, the increase in value over average value ranging from 0 to 50% for skew angle of 20 to 50°.The reaction are negative for the skew angle greater than 50°.The reaction on the obtuse angle corner becomes twice the average reaction, thus making the acute angle corner a zero pressure point when skew angle reaches about 60°. Reaction increased with increasing skew angle. It increased around 80 %, when it reached 60° compared to right bridge. As skew angle increases, there are more chances of corner up-liftmen. Bending moment decreases with increasing skew angle, it decreased around 75% as compared to right bridge. Transverse moment increases as skew angle increases but up to certain angle after which it starts decreasing. Again it increases as skew angle increases to 30° but decreased to 20% and 40%, in 45° and 60° respectively. Torsion moment follows same pattern as transverse moment; it decreases after 45°. Maximum deflection occurs nearer to obtuse angled corner but as aspect span is more it comes nearer to the middle of the span and shifts towards obtuse angled corner as skew angle increases.

REFERENCES

[1]. Ansuman Kar , "Analyasis of skew bridges using computational methods" *M. Tech Dissertation*, Department of Civil Engineering, Institute of Technology, Banaras Hindu University, Varanasi, 2012.

[2]. B. Bakhit, "Analysis of Some Skew Bridges as Right Bridges", J. Structural Engineering. Vol. 114(10). 1988.

[3]. H. Marx, N. Khachaturian, W. Gamble, "Design Criteria for Right and Skew Slab and Girder Bridges" Transportation Research Record, Vol-1319, 1991.

[4]. Saif Laith Khalid Alomar, "Comparison between grillage model and finite element model for analyzing bridge deck" Master of Engineering Thesis, Faculty of Civil Engineering University Teknologi Malaysia, June-2009

[5]. C. Menassa, M. Mabsout, K, Tarhini and G. Frederick. , "Influence of Skew Angle on Reinforced Concrete Slab Bridges", Journal of Bridge Engineering, ASCE. March-April 2007.

[6]. M. S. Qaqish, "Effect of Skew Angle on Distribution of Bending Moments in Bridge Slabs" , Journal of applied Science 2005

[7]. Maher Kakish, "Bending moment distribution at the main structural elements of skew deck-slab and their implementation on cost effectiveness", M. Tech thesis, College of Engineering, Al-Balqa University, Salt, Jordan

[8]. S. Ibrahim and I. Harba, Effect of Skew angle on Behavior of Simply Supported R. C. T-Beam Bridge Decks", ARPN Journal of Engineering and Applied Sciences, VOL. 6, NO. 8, Aug. 2011.

[9]. Patrick Théoret, Bruno Massicotte and David Conciatori, "Analysis and Design of Straight and Skewed Slab Bridges", Journal of Bridge Engineering. March 2011.

[10]. M. Mabsout, C. Menassa and K. Tarhini , "Effect of skewness in concrete slab bridges", 9th Int. Conference on Computing in Civil and Building Engineering, Taipei, Taiwan. pp. 663-668, 2002.

[11]. Vikash Khatri, P. R. Maiti, P. K. Singh, Ansuman Kar, "Analysis of Skew Bridges using Computational Methods" International Journal of Computational Engineering Research, vol-2, issue no-3, pp-628-636. 2012.