International Journal of Bridge Engineering (IJBE), Vol. 7, No. 1, (2019), pp. 33-40

EFFECT OF SKEWNESS ON REINFORCED CONCRETE SLAB BRIDGE BY FINITE ELEMENT METHOD

Raghav Sundria[1] and R.K.Tripathi[2]

[1,2] Department of Civil Engineering, National Institute of Technology Raipur
e-mail: [1]raghav.sundaria@gmail.com, [2] rktripathi.ce@nitrr.ac.in

ABSTRACT: Reinforced concrete slab bridge is a common choice for small span bridge. In order to provide greater speed and more safety for present day traffic requirement highways should be as straight as possible. This requirement, along with other requirement for fixing alignment of bridge is mainly responsible of provision of skew bridges. The effect of a skew angle on simple-span reinforced concrete bridges is presented in this paper using the finite-element method. In this paper different span bridges having different width and skewness are studied. For comparison 96 bridge slab models are prepared and their response have been calculated for class A vehicular loadings according to IRC-6: 2014. Maximum value of longitudinal moment, Transverse Moment. Torsional Moment and shear forces of skew bridge are compared with straight bridge of that span. It has been found from this study that maximum longitudinal moment decreases as skewness increase while maximum transverse moment increase as skewness increases for any span. Maximum torsional moment and shear force always increase as skewness of bridge increases.

KEYWORDS: Class A loading, Finite Element Analysis, Skew angle.

1. INTRODUCTION

Reinforced concrete slab are often used as deck for highway bridges. Advantages of using RC Slab Bridge include acceptable cost, smooth deck texture for excellent skid resistant, easy constructability to any geometric requirement and high stiffness to form an integrated superstructure. The deck also serves as the roof for the entire structure to protect the superstructure and substructure from direct access of water and harmful chemical that may rapidly deteriorate the structure. Major loads coming to the reinforced concrete slab bridge are dead load, live load, impact force, wind force and earthquake load according to IRC 6: 2014. This paper focuses on the behaviour of skew slab bridge under wheel load only.

When a road alignment passes through a river or any obstruction at any inclination different than 90-degree, skew Bridge required. Skewness in a bridge can be generated due to natural or artificial obstruction, complex intersection, steep terrain and shortage of space. In early days when design speed and traffic volume were less, then attempts were made to provide square crossing for bridge portion and suitable curves are introduced in approaches. As the increase in design speed as well as traffic volume providing many curves is not desirable for safety requirements. So, skew bridges with straight approaches are preferred. The inclination of the centre line of traffic to the normal to the centre line of the river in case of River Bridge or other corresponding obstruction is called the skew angle as shown in Fig 1. The analysis and design of a skew bridge are different than those for a straight bridge.

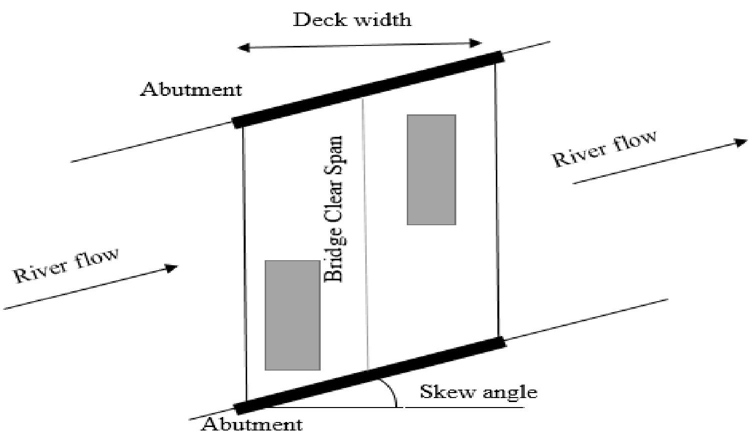

Figure 1. Description of skew bridge

In a skew bridge, span length, deck area and pier length increase in proportion to cosec (α) where, α is skew angle. The force flow in skew bridges is much more complicated than in right angle bridges. Analytical calculation alone does not provide sufficient accuracy for structural design. Numerical analysis needs to be performed, in which a skew bridge can be modelled in several ways with different degree of sophistication.

In right angle bridges load path goes straight toward the support in the direction of span. In skew bridges this is not the case. For a solid slab skew bridge, the load tends to take a short cut to the obtuse corners of the bridge. In bridge decks supported by longitudinal girders this effect occurs too, although less pronounced.

2. DESCRIPTION OF BRIDGE CASES

For this study simply supported, single span multiple lane bridge has been modelled. Four span length are considered as 6, 9, 12 and 15m with corresponding slab thickness of 0.5, 0.75, 1, 1.25 m respectively. To investigate effect of width we consider one, two, three and four lane bridge having total width of 5.15, 8.4, 12.4 and 16.9 m. In total width of bridge 0.45 m wide kerb given in both sides. To study effect of skewness in bridge response skewness from 10 degree to 50 degree by increment of 10 degree considered while straight bridge considered as reference for comparison with skew bridges. Total 96 bridge decks are modelled and analysed by finite element method by using SAP2000 software.

For application of live load class A loading used and position of loading is determined by IRC 6-2014. Class A loading consist of 8 loading of 27, 27,114,114,68,68,68, 68 kN at adjacent distance of 1.1, 3.2, 1.2, 4.3, 3, 3, 3m respectively. Critical Location of loading was mentioned in IRC 6-2014 and same has been adopted. All these factors have contributed to make a slab deck a popular choice for culverts. In this study a slab deck of 8.7 m wide carrying a two lane traffic spanning between 8m to 12m has been considered for the analysis.

3. FINITE ELEMENT ANALYSIS

Finite element method is a numerical method for the solution of problems in continuum mechanics in which actual structure is represented as assemblage of finite element interconnected at finite nodal points. For analysis purpose bridge deck can be considered as shell type structure. Shell-type structures are those which have small thickness compared to the other dimensions of the structure or those composed of a group of such relatively thin parts.

To model straight and skewed bridge SAP 2000 software has been used. All the element considered as linear elastic and analysis assume small deformations. Quadrilateral thick shell element used to model slab of bridge having maximum size mesh of 0.3X0.3. To simulate simply support condition hinges were assigned at one bearing location and roller at other. For this analysis M30 grade of concrete has been used having Poisson ratio of 0.2, unit weight 25 kN/m^3 and modulus of elasticity 27386.12 N/mm^2.

Response of bridge by finite element analysis has been reported as maximum of longitudinal bending moment, transverse bending moments, torsional bending moments and joint reactions.

4. FEM RESULTS OF SKEWED VERSUS STRAIGHT BRIDGES

The effect of the increase in skewness of bridge on the maximum longitudinal moments, transverse moments, torsional moments and shear forces due to vehicular loading for a given bridge span and number of lanes. Results obtained for skew angle from 0 degree to 50 degree by finite element method are compared to their corresponding FEM value of straight bridges.

Table 1. Comparison of FEA maximum longitudinal bending moment (kN.m/m) with skew angle

Span	Lane	0°	10°	20°	30°	40°	50°
6 m	single	72.94	71.45	67.17	57.47	49.59	37.95
	two	84.94	83.28	77.1	64.86	53.97	38.18
	three	87.43	85.11	79.04	65.9	54.83	39.25
	four	88.28	85.94	81.15	66.146	53.24	37.46
9 m	single	109.47	107.04	103.11	87.49	75.69	61.145
	two	131.22	129.03	119.54	103.01	87.17	65.03
	three	137.99	131.46	124.41	107.25	88.97	65.41
	four	140.74	137.58	127.95	108.32	88.06	65.55
12 m	single	155.45	151.39	140.125	122.27	104.62	83.5
	two	188.86	184.08	170.4	147.38	122.86	93.59
	three	199.58	194.61	179.58	153.9	126.79	95.29
	four	205.23	200.05	185.49	157.41	128.61	95.82
15 m	single	209.56	204.38	189.07	166.048	141.135	113.19
	two	255.05	249.55	229.26	199.45	165.61	126.66
	three	269.46	261.85	242.1	209.27	170.98	130.51
	four	277.04	269.87	252.62	215.46	174.91	132.18

4.1 Maximum longitudinal bending moment

The maximum longitudinal moment for all skew angle (0-50 degree) for all four lanes have been summarized in Table 1. To compare different moment a ratio $M\alpha/M0$ was defined in which Mα is maximum longitudinal bending moment for a given skew angle (α) and Mo is maximum longitudinal bending moment of straight bridge. The ratio Mα/Mo for the maximum longitudinal moment for each skew angle considered from 0 to 50 degree for each span length considered as 6, 9, 12, and 15m. These data indicate for a given span and lane as the skewness of deck slab increase maximum longitudinal Moment Decrease. As the no of lane increases maximum longitudinal moment decreases with faster rate. While as lane of bridge increase maximum longitudinal moment increase in straight as well as skew bridge deck upto angle 20 degree decrease in maximum longitudinal moment is not much but after 20 degree rate of decrease is high.

4.2 Maximum transverse bending moment

Maximum transverse moment for all skew angle (0-50 degree) for all four-lane summarized in Table 2. As the skewness of bridge increase maximum transverse bending moment also increase and if we increase no of lane of bridge for a given skew angle maximum transverse bending moment also increase. Rate of increase of maximum transverse moment is greater than rate of decrease of maximum longitudinal moment. Ratio of Mα/Mo increase upto 40 degree and fall slightly after that. From the table we can conclude that rate of increase of ratio Mα/Mo increase as span of bridge increase. For 6m span maximum ratio is 1.51 while for 15 m span it is 2.2. As the width of bridge increase rate of increase in maximum transverse moment decrease.

Table 2. Comparison of FEA maximum transverse bending moment (kN.m/m) with skew angle

Span	Lane	0°	10°	20°	30°	40°	50°
6 m	single	22.36	23.46	27.82	29.79	33.2	33.84
	two	27.65	32.5	31.17	36.9	39.73	39.5
	three	31.36	32.75	34.7	37.19	39.83	37.65
	four	30.91	34.26	37.49	39.56	40	38.97
9 m	single	24.62	25.75	41.24	34.45	38.64	41.93
	two	33.73	40.56	38.56	47.43	52.43	50.47
	three	43	43.59	47.84	51.925	54.94	52.25
	four	44.43	48.93	53.17	55.72	56.46	55.22
12 m	single	25.27	26.31	32.74	37.2	44.53	49.55
	two	38.22	45.08	42.98	53.81	60.8	61.59
	three	52.98	55.17	60.9	65.66	70.76	68.33
	four	57.39	63.7	69.28	73.06	75.3	72.85
15 m	single	27.43	28.46	37.265	43.87	50.65	58.285
	two	42.11	49.99	47.59	60.8	71.76	73.25
	three	62.54	65.13	70.94	78.31	85.51	87.11
	four	77.3	79.25	86.79	93.16	97.125	95.48

4.3 Maximum torsional moment

The maximum torsional moment for all skew angle (0-50 degree) for all four lane summarized in Table 3. From the table, one can conclude that for any given span maximum torsional moment increase from 0 degree to 40 degree. After 40 degree maximum torsion moment is approximately constant. If we compare for a skewness single lane bridge have significant less maximum torsional moment while for all other lane maximum torsional moment is approximately constant.

If one compare for a skewness single lane bridge have significant less maximum torsional moment while for all other lane maximum torsional moment is approximately constant. This study also establish that rate of increase of maximum torsional moment is highest for single lane bridge. Ratio of maximum torsional moment for 50 degree skewed bridge and straight bridge is around 4.21, 3.46, 3.03, 2.46 respectively for single lane, two lane, three lane and four lane. It is also established that as the span increase in maximum torsional moment increase.

Table 3. Comparison of FEA Maximum Torsional Moment (kN.m/m) with skew angle

Span	Lane	0°	10°	20°	30°	40°	50°
6 m	single	12.51	16.24	29.84	34.64	41.33	42.43
	two	16.04	17.1	26.42	35.63	43.41	42.9
	three	17.0	17.2	26.5	35.675	42.19	42.89
	four	18.03	17.32	27.35	35.68	42.25	42.82
9 m	single	16.85	24.07	51.27	50.6	61.28	65.11
	two	21.83	27.95	41.67	57.23	69.81	69.97
	three	25.7	28.56	48.96	57.889	69.92	70.078
	four	27.82	29.34	43.03	57.98	68.75	70.3
12 m	single	21.51	32.3	46.48	63.99	77.88	83.94
	two	29.26	39.68	56.87	79.03	96.37	97.68
	three	33.37	43.25	60.43	82.48	97.65	98.99
	four	37.91	44.38	61.65	83.11	98.26	100.11
15 m	single	25.62	40.69	55.88	78.6	96.048	105.65
	two	37.12	51.06	70.94	99.65	123.15	128.51
	three	43.96	57.43	78.12	108.33	130.13	133.54
	four	48.76	60.32	81.19	110.42	131.42	134.71

4.4 Maximum shear force

Maximum shear force for all skew angle (0-50 degree) for all for lane summarized in Table 4. From the table one can conclude that for any given span maximum shear force increases as skew angle increases. As one increase no of lane then maximum shear force also increase accordingly. If one compare maximum shear force between single lane and two lane there is significant increase while after this bridge of any span give constant maximum shear force for any skew angle. Ratio of maximum shear force for 50 degree skewed bridge and straight bridge is around 4.31, 4.66, 4.66, 4.86 respectively for single lane, two lane, three lane, four lane for 6 m span. As we increase span these ratio start decreasing but pattern are same.

Table 4. Comparison of FEA Maximum Shear Force (kN.m) with skew angle

Span	Lane	0°	10°	20°	30°	40°	50°
6 m	single	18.18	30.33	42	60.13	71.99	78.36
	two	19.98	31.83	47.92	61.64	75.51	78.47
	three	20.1	32.18	47.23	61.98	73.48	78.5
	four	19.95	32.05	48.22	61.85	73.4	78.39
9 m	single	24.18	39.29	58.16	79.36	98.24	112.7
	two	27.45	44.73	66.9	89.84	112.45	119.84
	three	28.29	45	68.6	91.24	112.63	119.95
	four	28.52	46.41	69.09	91.17	110.47	120.27
12 m	single	29.39	45.82	69.03	94.7	117.71	137.17
	two	35.087	55.18	85.07	116.36	146.63	159.71
	three	36.89	59.52	90.05	121.96	148.35	160.96
	four	37.65	60.36	91.92	125.56	148.95	162.9
15 m	single	33.61	52.45	94	114	137.5	163.63
	two	41.66	65.24	101.53	139	177.15	198.6
	three	45.48	72.66	111.22	151.9	188.13	205.39
	four	47.43	75.03	115.33	154.61	188.77	207.31

5. CONCLUSIONS

In this paper effects of skew angle in single-span multilane reinforced concrete slab bridges have been studied and the FEA results are presented in this paper. For this study effect of varying the geometric characteristics of the bridges including the span length and slab width with six distinct skew angles (0-50 degree) have been considered. These results have been compared to straight bridges to study the effect of skewness on the concrete slab bridges. The ratio between the FEA maximum longitudinal moments for skewed and straight bridges have almost one for bridges with Skew angle less than 20°. This ratio decreased to 0.75 for bridges with skew angles between 30 and 40°, and further decreased to 0.5 as the skew angle of the bridge increased to 50°. This decrease in the maximum longitudinal moment ratio is offset by an increase by up to 50% in the maximum transverse moment ratio as the skew Angle increases from 0 to 50°. Maximum torsional moment increase continuously when skew angle increase. For single lane increase in torsional moment with skewness is significantly high in compare to four lane. For single lane torsional moment for bridge with skew angle 50 is 4 time in compare to straight bridge while for four lane this ratio is 2.76 only. Maximum shear force developed in bridge also increase with increase in skewness of bridge. From FEM result it can be concluded that as skewness increase up to 50 degree developed maximum shear force are more than 4 time in compare to straight bridge. Live load models are vehicular models that are used in analysing the vehicular effect on the bridge deck. The live load models represent the nature and size of the vehicles of a region. Different international standards specify a unique and exclusive live load models. Following are the vehicular load models considered as per IRC 6-2016.

REFERENCES

1. Menassa, C.M. Mabsout, K.Tarhini, and G. Frederick. "Influence of skew Angle on Reinforced Concrete Slab Bridges", Journal of Bridge Engineering, 2007.
2. Fu, Gongkang, Yizhou Zhuang and Jihang Feng. "Behavior of Reinforced Concrete Bridge Decks on Skewed Steel Superstructure under Truck Wheel Loads", Journal of Bridge Engineering, 2011.
3. SAP2000 v 14, User's manual SAP2000, Computers and Structures,Inc., Berkeley, Calif.
4. Code for practise for concrete road bridges IRC 6-2014.
5. Mabsout, M., Menassa, C., and Tarhini, K. (2002). "Effect of skewness in concrete slab bridges." 9th Int. Conference on Computing in Civil and Building Engineering, Taipei, Taiwan, 663–668.
6. Mabsout, M., Tarhini, K., Jabakhanji, R., and Awwad, E. (2004). "Wheel load distribution in simply supported concrete slab bridges." J. Bridge Eng., 147–155.
7. Schickel, S., Tarhini, K., and Frederick, G. (1999). "Experimental evaluation of skewness in concrete slab bridges." SEM Annual Conf. on Theoretical, Experimental, and Computational Mechanics, Cincinnati.