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Variation of Shear Coefficient and Reaction Coefficient with Span in Skew Bridges

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Abstract:-*Skew bridges are generally provided at oblique intersectionin flyovers and bridges. They are also encountered at oblique intersection of road and rail crossing.The increasing pressure of traffic has led researchers to conduct a lot of research in skew bridges. Studies carried out in skew bridges has shown that skew bridges as compared to right bridges over estimates the live load moment, while live load shear and live load reaction are under estimated. To recognize the effect of span on live loadshear force and live load reaction in skew bridges, a study has been carried out and presented in this paper.The study is carried out on a two lane reinforced concrete T-Beam bridge with 3 longitudinal girders, resting on three supports. IRC loadings as per IRC 6:2000 have been used. Spans as provided inpractical situations in India are chosen. The span has been varied from 12 m to 21 m at 3m intervalwhile skew angle is varied from 0^0 to 40^0at 10^0 interval. These span and skew ranges are mostly encountered in most skew bridges.The results are presented in form of shear coefficient and reaction coefficients. It is observed that with increasing span the shear force shared by outer girder increases. The maximum increase is 13.5% for class 70 R wheeled loading for 40^0 skew. The reactions also show similar behavior.*

Keywords:-*Skew bridge, shear force, bending moment, reaction, RC bridge.*

I. Introduction

Most of the bridges in older days were straight, and skew bridges were averted as far as possible. Lack of knowledge about the structural behavior and construction difficulties were obvious reasons contributing to the designers' choice to favor straight bridges rather than skew bridges. But in the current scenario there is an increasing trend of providing skew bridges rather than curved or straight bridges with long approach road at oblique intersections. There is immense pressure of increasing population due to which the cost of land acquisition for approach roads has hiked many folds. Then there are many problems related to modern day long and heavy trailers. It is difficult for them to negotiate on curve roads even at low speeds. The introduction of curves also increases the distance travelled by the vehicle which in turn affects the economy. In hilly regions due to topographic conditions, it is very difficult to provide curved approaches and many times skew bridge remains the only option. The railway and roadway intersection are often oblique and requires approach road if skew bridge is to be avoided. Also, in old and congested cities due to lack of space, bridges have to be skew in nature if the intersection is not orthogonal.

Hence there is need to study the behavior of skew bridges to understand the mechanism of load transfer from design point of view and the same has been undertaken in this research.

Simply supported bridges with small skew angle (10^0 - 15^0) are frequently observed and generally skew angle is ignored in the analysis. The bridge can be safely analyzed and designed as right bridge as the effect of skew is negligible at such low skew angles. But at higher skew angles, its effects are more pronounced which makes the analysis complicated and the normal load distribution theories are no more applicable.

II. Brief Literature Review

BaidarBakht[6] in (1987) analyzed some "Slab on Girder" skew bridges as right bridges for AASHTO loading. The "I" grider sections of "slab on girder" bridge were made up of RCC. He first laid an approximate method to analyze skew bridges as right bridges in which the skew bridge is replaced by a right bridge of span equal to the skew span and the loads being skewed with respect to longitudinal girders to simulate an approximate equivalence. In his studies it was presented that the error in analyzing skew bridges as right bridges does not depend only on angle of skewness but is characterized by two dimensional parameter which depend on angle of skew, spacing and span of longitudinal girders and their flexural rigidities. He suggested the parameter 'S tan φ' as an appropriate measure of skewness rather than φ alone where, S is spacing of longitudinal girders and φ is skew angle. For comparing the structural response of a skew bridge with corresponding right bridge, he defined parameter

$$\delta = \frac{(\text{Response in skew bridge}) - (\text{Response in right bridge})}{\text{Response in right bridge}}$$

A Large number of skew bridges were analyzed for different spans (upto 60 m) and skew angles between 0^0 and 60^0. The findings are as given below.

(1) The values of δ were negative for longitudinal moments in both internal and outer girders, indicating that the process of analyzing a skew bridge as equivalent right bridge is safe one as far as longitudinal moments are concerned, but such a design may be uneconomical.
(2) For longitudinal girder shears, the value of δ was always nearly positive. This shows that the method of analyzing them as equivalent right bridge is unsafe.

Khallel and Iltani (1990) conducted finite element analysis to determine moments in continuous normal and skew slab on steel girder bridges due to live loads. Their analyses showed that the maximum moment in the girder of a skewed bridge was smaller than that of a normal bridge-approximately 20 % less for a bridge with a skew angle of 60^0. The effect of skew was considered as a reduction factor applied to the normal load distribution factor, in respect of moment estimation in skew bridges.

Alferd G Bishara[8] (1993) carried out the analysis of 36 bridges using FEM. ADINA software was used for this purpose. The bridges were simply supported with composite slab on steel 'I' girders. AASHTO vehicle loading was used. The other features of the bridge are.

(a) Span 22.86 m, 30.48 m and 38.1 m (75, 100, and 125 ft), (b) skew angles (0^0, 20^0, 40^0 and 60^0), (c) widths 11.89 m,17.37 m and 20.11 m (39, 57, and 66 ft) and spacing of girders 2.74 (9 ft). The parameters under investigation were skew angle, span length and complete deck slab width of bridge. Based on this study he also suggested some equations to find the distribution factors for outer and internal girders and compared them with AASHTO provisions. The summary of his study is as follows.

(1) The provisions provided by the AASHTO for load distribution factors are conservative as compared to those obtained by FEM.
(2) The Live load moments in girders of skew bridges are generally lower than the right bridges.
(3) The distribution factor for interior girders is practically insensitive to the change in span length, and the distribution factor of exterior girders is insensitive to the deck-slab total width.

Ali R Khaloo and Mirzabozorg[5] (2003) analyzed simply supported 'slab on girder' bridges with concrete I girders using FEM approach (with the aid of ANSYS software) and AASHTO loadings. The assumptions of his work are

1) The bridge decks consist of slab on five concrete I section longitudinal girders.
2) Slab thickness is constant
3) All materials are elastic and homogenous
4) The behavior of slab and longitudinal girders is composite.

There parameters under study were span length (25m, 30m, 35m), spacing of longitudinal girders, skew angle and internal arrangement of transverse girders. The conclusions of his study are

1) The arrangement of internal transverse diaphragms (CG) has a great effect on the load distribution pattern. The decks with cross girders perpendicular to the longitudinal girders are best arrangements for load distribution in skew bridges.
2) The distribution coefficient for outer longitudinal girders for skew bridges is smaller as compared to the distribution coefficient for right bridges.
3) The effect of spacing of internal cross girders has a little effect on load distribution factors.

PranayVasantraoUrewar et al. (2006) analyzed simply supported T-Girder single lane, two lane and four lane bridges for IRC Class AA (tracked), IRC Class AA (wheeled), and IRC Class A vehicle. The spans were 15 m for single lane, 15 m for double lane, and 21m for four lane bridges. Skew angle for each span was 0^0, 15^0, 30^0, 45^0, and 60^0. The arrangement of cross-girders used in his study was parallel to the abutment and ANSYS software was used to make a FEM analysis. His study shows that there was a significant increase in the bending moments and torsion in outer girder with increase in skew angle. The vertical reaction and shear also increased upto 131 % with maximum skew angle. These results are in contrast to the studies carried out by other researchers and may be due to the arrangement of internal cross girders. This suggests that cross girders orthogonal to the longitudinal girders are most effective in transverse load distribution, especially for skew angle more than 20^0.

Trilok Gupta[1] et al (2007) studied the behavior of T-Beam skew bridges with respect to support reaction and Standard IRC 70-R wheeled loading. The study was based on analytical modeling of T-beam bridges by grillage analogy method. The bridges consisted of three longitudinal girders and were simply supported. The spans used were 8 m, 16 m, 24, and 32 m. Skew angles varied from 0^0 to 60^0 at an interval of 10^0. The results show that there was significant increase in maximum reaction at obtuse end while high negative reactions were also observed at the other end with the increase in skewness. The negative reactions were more pronounced at higher skew angles.

PCI Bridge Design Manual, Chapter 7 section 7.5.4 suggests multipliers for the longitudinal moments and shears to take into account the effects of skew. Few more similar studies have also been carried out by different investigators like Mabsout et al.

(1997), O'Brien E.J (1998) etc to examine the effects of skew angle on the load distribution amongst girders but only a selected few has been presented here. The findings of other studies are also quite similar.

III. Working Strategy

Bridges can be analyzed either by conventional load distribution theories or by using softwares based on modern analysis theories. The current trend is to analyze bridges using softwares which gives very accurate results. These softwares are based on concepts of FEA, matrix stiffness approach or any other approach as suitable to type of problem. Selection of software depends upon the type of problem being analyzed and ease of using the software. The current research has been done usinggrillage analogy method using theSTAAD Pro. software which is very user friendly and based on matrix stiffness approach[10]. More details regarding the software selection can be found in reference no. 10 of this paper.

IV.Parametric study of RC Bridge

4.1Gridline Details for Grillage Analogy[11]

Grillage analogy has been used to analyze the bride. For this the whole bridge is divided into longitudinal and transverse gridlines of suitable grid density.The density and size of gridlines depends upon complexity of various factors like geometry, support conditions, loading, material etc. There is no thumb rule to decide grid properties, yet guidelines from IRC 6: 2000 can be followed to arrive at their suitable size while spacing can be decided from geometric dimensions of the bridge. Figure 1& figure 2 shows grid details in typical cross-section and planof a bridge deck analyzed in STAAD Pro. using grillage analogy.

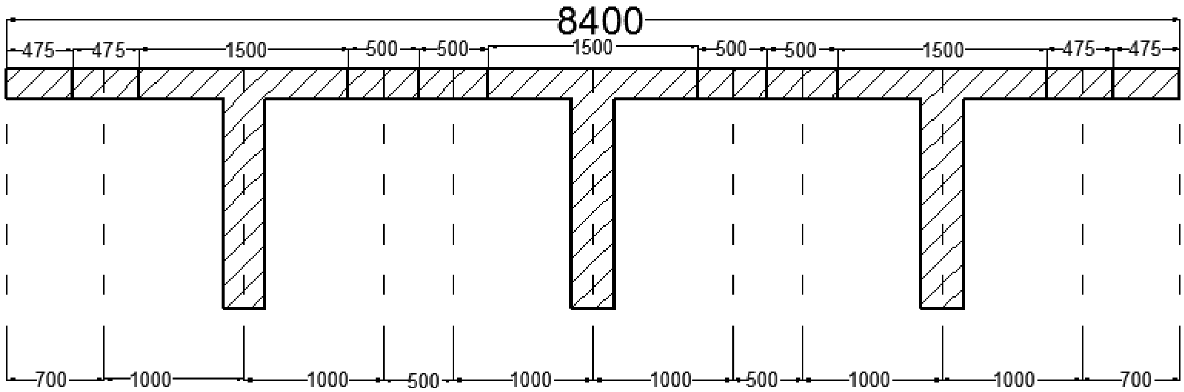

Fig. 1Typical Grillage idealization in longitudinal direction (All dimensions in mm)

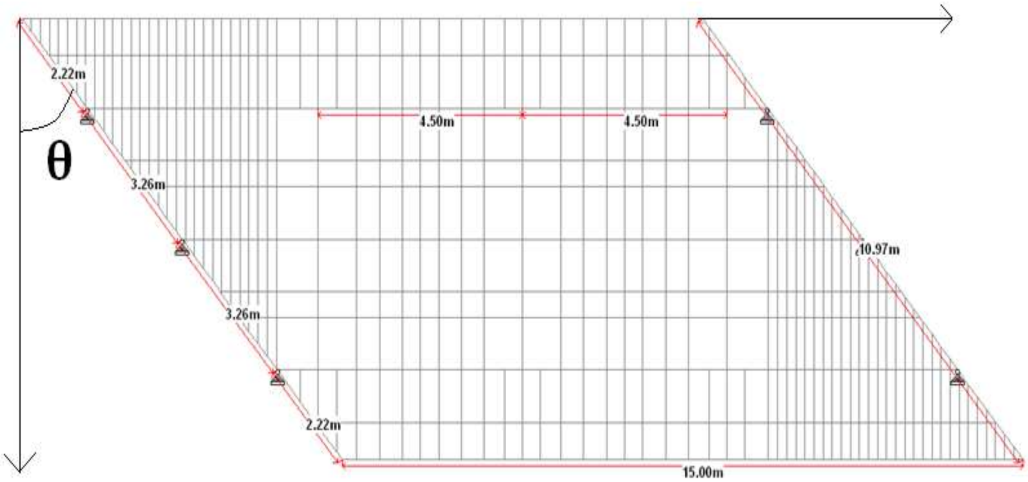

Fig. 2 Typical plan of grillage model of 15 m span (skew bridges, $\theta \geq 15^0$)

4.2Geometric Properties of Bridges[10]

For the purpose of study a two lane reinforced concrete bridge of practical dimensions has been chosen. The bridge is supported on three supports, one below each longitudinal girder. In practice RC T-Beam bridges are generally provided for spans from 12 to 21 m and same has been chosen for the study. Cross Girders are hindrance in the speed of construction. So their spacing is generally kept not less than 4 m and for same reason the spacing of cross girders in the present study is kept between 4.5 m to 6 m. For skew bridges of 0^0 and 10^0, the cross girders (& transverse gridlines) are parallel to the abutment, while for 20^0, 30^0, and 40^0, the cross girder (& transverse gridlines) are provided orthogonal to longitudinal girders for achieving better transverse rigidity. Table 1 shows the cross-sectional details of the bridges under investigation. These cross sections has been used for all spans i.e. 12m, 15m, 18m and 21m. The depth of longitudinal girders has been kept as span/10 while, the depth of intermediate cross girders is kept as 80% of the depth of longitudinal girders. The depth of End Cross girders is kept equal to the depth of longitudinal girders but in practical construction it is slightly less to facilitate the placement of bearing or jacking up for replacement of bearings during the service life.More details about the modelling are available in reference no. 10 of this paper.

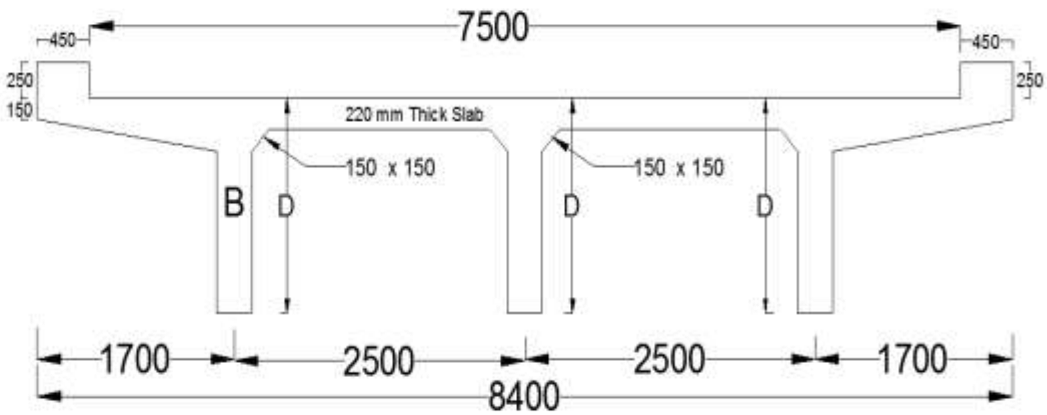

Fig. 3 Typical cross-section of bridge for grillage analogy

Table 1. Dimensions of longitudinal and transverse girders

Longitudinal Beam				Transverse Beams			
S.No	Span(m)	B (mm)	D (m)	Intermediate Cross Beam		End Cross Beam	
				B (mm)	D(m)	B(mm)	D(m)
1	12	350	1.2	300	0.96	300	1.2
2	15	350	1.5	300	1.2	300	1.5
3	18	400	1.8	300	1.44	300	1.8
4	21	400	2.1	300	1.68	300	2.1

4.3 Live Load on Bridge

The Bridge deck was analyzed for “Class A”, “Class 70R Tracked” and “Class 70R Wheeled” vehicles. As per IRC 6: 2000 Table 2, a two lane bridge should be loaded with either one lane of “Class 70R” or two lanes of “Class A. For the transverse placement of the vehicle, guidelines of IRC 6: 2000 clause 207 are followed which suggests that the minimum spacing of vehicle form the face of the kerb is 1.2 m for “Class 70R” and 0.15 m for “Class A” loading. Many other trials of the transverse placement of vehicles were also made to obtain the maximum moments and shear forces in the bridges. The following observations were made during these trials.

(a) For all class of loading, the maximum live load shear occurs in the outer girder, near the obtuse corner and hence the shear coefficient presented in table 2, table 3 and table 4 are for this set of loading.

(b) For “70R Tracked”and“Class 70R Wheeled”vehicle the maximum liveload support reaction occurs at the middle support when the vehicle is placed centrally and hence the reaction coefficient presented in table 5 and table 7 are for this placement of loading.

(c) For "Class A" the maximum live load support reaction is obtained in the outer support at obtuse corner when the vehicle is placed at minimum spacing form the kerb and hence the reaction coefficient presented in table 6 are for this placement of loading.

The loads are placed accordingly to obtain maximum live load shear and maximum live load reaction in the girders and supports of the bridge.

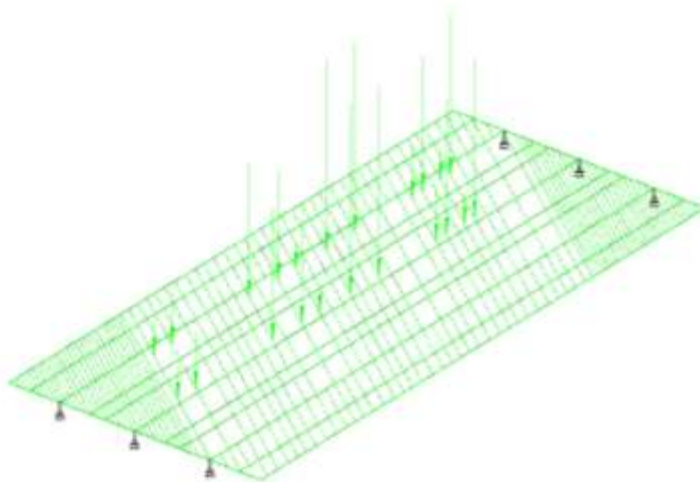

Fig. 4. IRC loading on 21 m span 70 R Tracked Vehicle for 40^0 skew span (Using Staad Moving Load option)

V. Results

5.1 Shear Coefficient and Reaction coefficients

ShearCoefficientsand **Reaction Coefficients**are obtained by dividing the maximum live load shear and maximum live load reaction with the total load of the respective vehicle. For 70 R tracked and 70 R wheeled the maximum shear and reactions are divided by 700 kN and 1000 kN respectively, while for class A loading it is to be divided by 2x 554 kN = 1108 kN as two Class A trains can be accommodated in the bridge. Hence shear coefficient and reaction coefficient when multiplied by 100 directly gives the percentage of total load of that vehicle.

5.2 Variation of shear coefficient with respect to span

The variation of shear and reaction coefficients with span for different skew angles are tabulatedin table 2, table 3 and table 4. Figure 5, figure 6 and figure 7 shows the same in graphical form. It is evident that as the span increasesfrom 12 m to 21 m, the shear coefficients increase in a linear fashion for class A loading for all skew angles while for Class 70 R tracked and wheeled loading it is linear only for 0^0 skew. For bridges with skew above10^0, the variation is linear upto 15 m span and then it increases slowly with span. For 10^0 skew the variation is non uniform for all loadings. This is due to parallel orientation of cross girders with supports.For 0^0 skew the increase in shear coefficient from 12 m span to 21 m span is 6.3% while for 40^0 skew, it is 6.2 % for Class 70 R tracked vehicle. For class A loading the increase in shear coefficient is 8.1% and 8.2 % for 0^0 and 40^0 skew respectively. 10.6% and 13.5% increase in shear coefficient has been observed for class 70 R wheeled loading.

Table 2.Variation of shear coefficient with span for 70 R Tracked vehicle

Span (m)	Skew Angle (in degree)				
	0	10	20	30	40
12	0.346	0.354	0.405	0.420	0.452
18	0.380	0.389	0.419	0.436	0.476
18	0.406	0.414	0.440	0.464	0.494
21	0.409	0.417	0.446	0.470	0.514

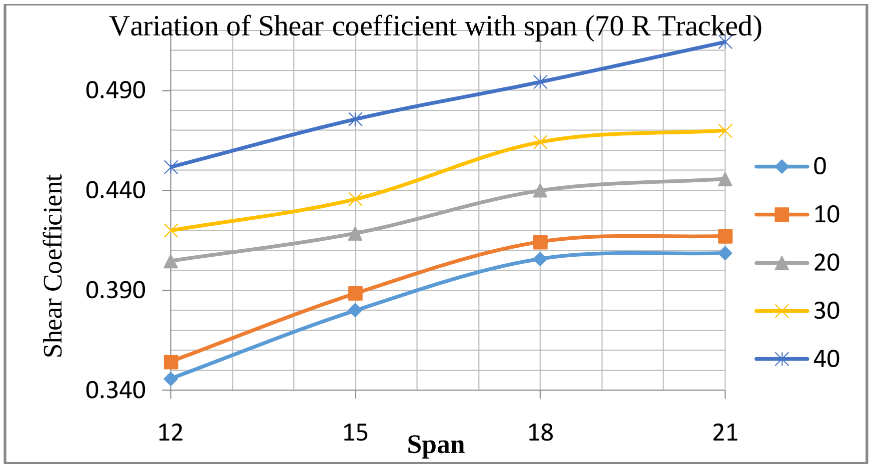

Fig. 5 Variation of Shear coefficients with span (70 R Tracked)

Table 3.Variation of shear coefficient with span for Class A vehicle

Span (m)	**Skew Angle(in degree)**				
	0	**10**	**20**	**30**	**40**
12	0.174	0.178	0.208	0.230	0.241
15	0.203	0.207	0.228	0.240	0.261
18	0.235	0.238	0.260	0.282	0.297
21	0.255	0.259	0.285	0.302	0.323

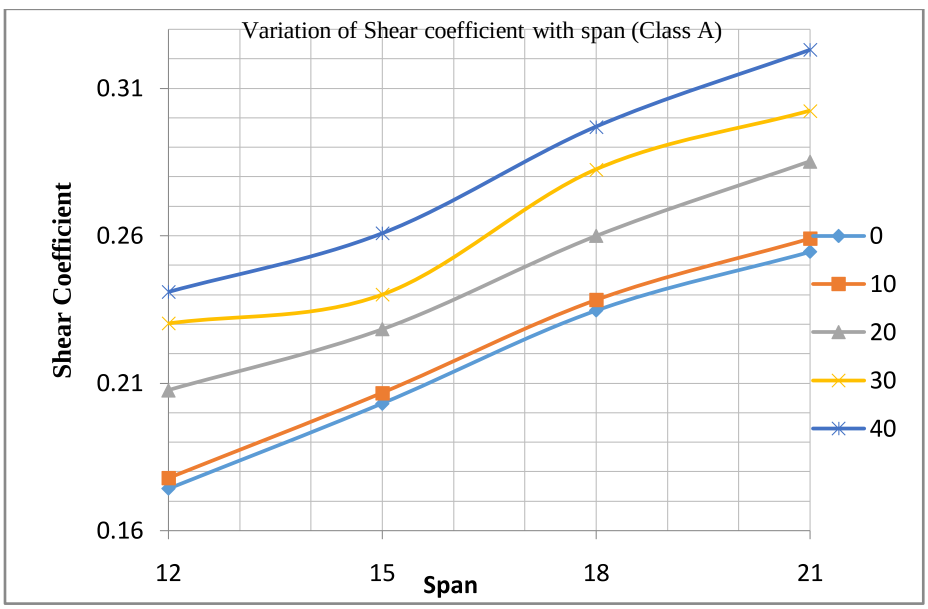

Fig. 6Variation of Shear coefficients with span (Class A)

Table 4.Variation of shear coefficient with span for 70 R Wheeled vehicle

Span (m)	**Skew Angle(in degree)**				
	0	**10**	**20**	**30**	**40**
12	0.240	0.244	0.281	0.293	0.306
15	0.291	0.296	0.320	0.333	0.354
18	0.328	0.332	0.355	0.377	0.400
21	0.346	0.352	0.379	0.400	0.441

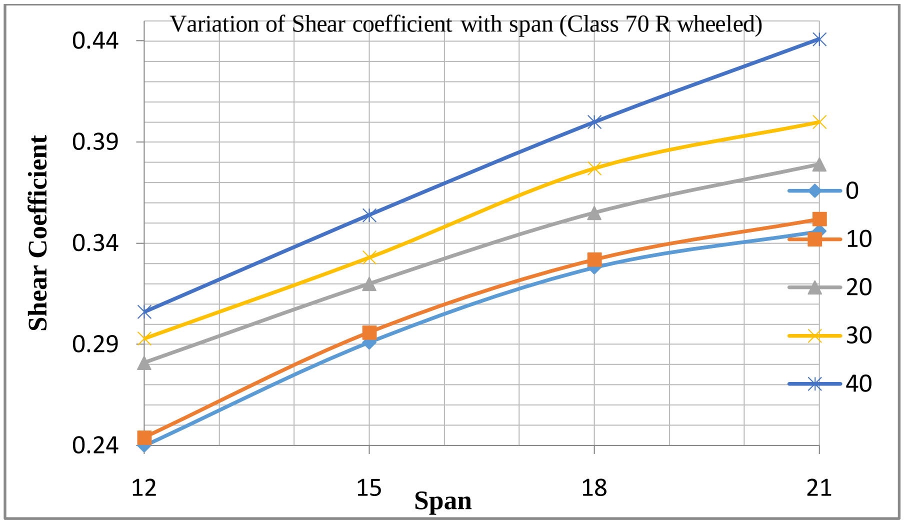

Figure 1:Variation of Shear coefficients with span (Class 70 R wheeled)

5.3 Variation of reaction coefficients with span

Figure 8, figure 9 and figure 10 shows the variation of reaction coefficients with respect to span for different skew angles for Class 70 R Tracked, Class A and Class 70 R wheeled loading, while table 5, table 6 and table 7 shows the values in tabulated form. It can be observed that for class 70 R Tracked vehicle, reaction coefficients do not vary much with span, but for class A and Class 70 R wheeled it shows a small increment. For class A loading the increase in reaction coefficient from 12 m to 21 m is 7.6 % and 4.7 % for 0^0 and 40^0 skew. 4.1 % and 4.7 % increase in reaction coefficient has been observed for class 70 R wheeled loading.

Table 5.Variation of reaction coefficient for70 R Tracked vehicle

Span (m)	Skew Angle(in degree)				
	0	10	20	30	40
12	0.537	0.603	0.636	0.703	0.739
15	0.529	0.595	0.654	0.709	0.745
18	0.516	0.582	0.643	0.700	0.738
21	0.540	0.598	0.650	0.699	0.736

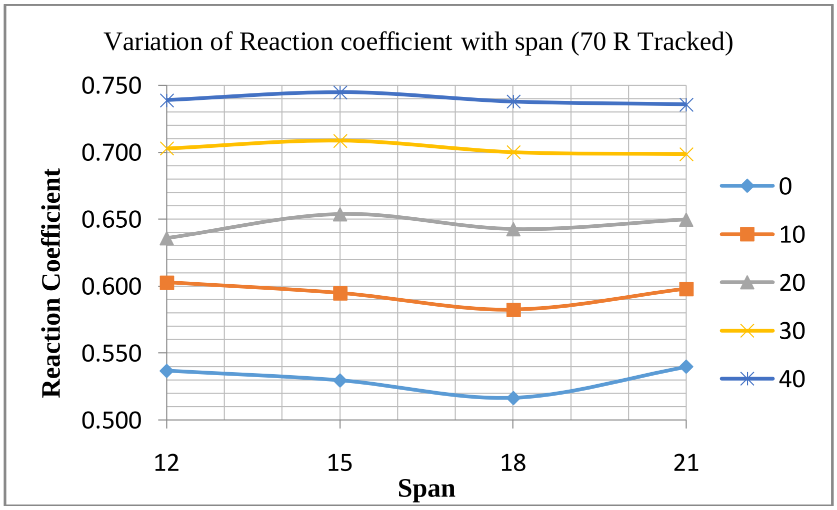

Fig. 8Variation of Reaction coefficients with span (70 R Tracked)

Table 6.Variation of reaction coefficient for Class A vehicle

Span (m)	Skew Angle(in degree)				
	0	**10**	**20**	**30**	**40**
12	0.231	0.260	0.286	0.329	0.372
15	0.260	0.288	0.316	0.353	0.390
18	0.287	0.311	0.339	0.371	0.401
21	0.307	0.328	0.351	0.380	0.419

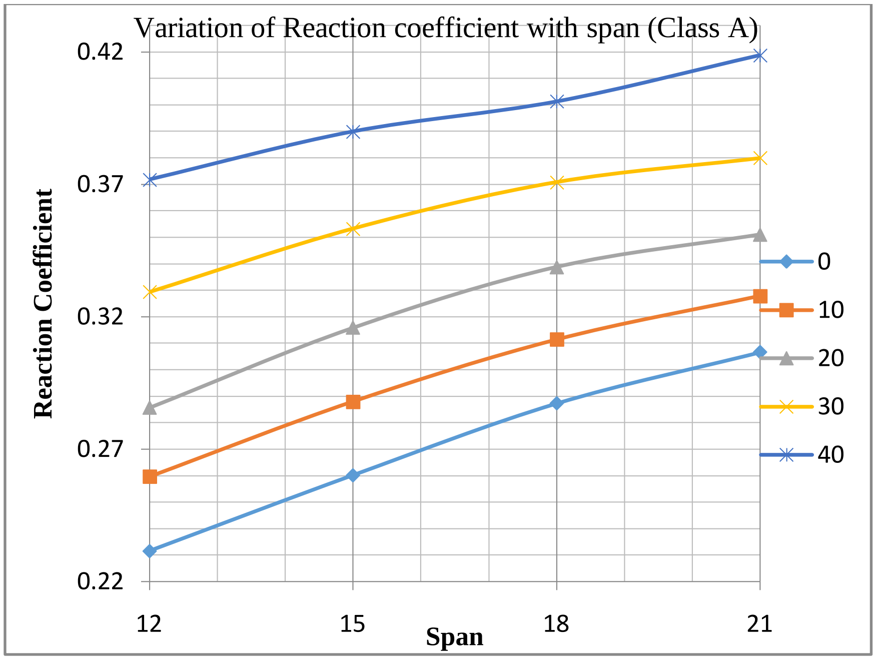

Fig. 9Figure 5.26 Variation of Reaction coefficients with span (Class A)

Table 7.Variation of reaction coefficient for 70 R wheeled vehicle

Span (m)	Skew Angle(in degree)				
	0	**10**	**20**	**30**	**40**
12	0.352	0.389	0.398	0.434	0.498
15	0.362	0.396	0.432	0.470	0.519
18	0.371	0.402	0.435	0.475	0.535
21	0.393	0.423	0.457	0.491	0.545

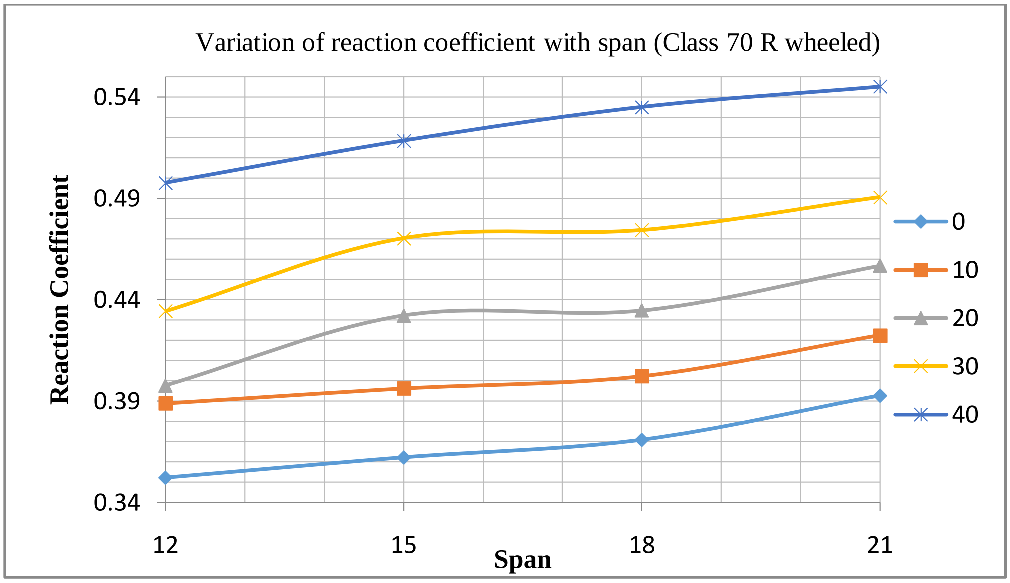

Fig. 10 Variation of reaction coefficient with span (Class 70 R wheeled)

VI. Conclusions

Following Conclusions can be deduced from above study

1) As the span increase from 12 m to 21 m, the shear coefficient increases for all skew angle. This implies that outer girder share more percentage of shear force as compared to middle girder with increasing span. The percentage increase is about 6 percent for class 70 R Tracked vehicle, 8 percent for class A vehicle and 13.5 percent for class 70 R wheeled vehicle for all skew angles.
2) For class A loading and class 70 R wheeled loading, the reaction coefficient also increases in a nearly linear fashion. The increase in reaction coefficient is 7.6 % and 4.7 % for 0^0 and 40^0 skew for class A loading while for class 70 R wheeled loading, the increase is about 4.5 % for all skew angle.This implies that for class A loading outer support at obtuse corner attracts more load with increasing span, while middle support attracts more load for class 70 R wheeled loading with increasing spans.
3) For class 70 R tracked loading, the reaction coefficient nearly remains constant with span.

XI. Acknowledgement

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