

Comparative Study on the Behaviour of T-Beam Skew Bridges

Sujith P S¹, Dr. Jiji Anna Varughese², Tenu Syriac³

P.G. Student, Dept. of Civil Engineering, SCMS School of Engineering and Technology, Kerala, India¹

Associate Professor, Dept. of Civil Engineering, Government Engineering College, Barton Hill, Kerala, India²

Assistant Professor, Dept. of Civil Engineering, SCMS Engineering College, Ernakulam, Kerala, India³

ABSTRACT: T-beam Bridge is a common choice among the designers for small and medium span bridges. In order to cater to greater speed and more safety of present day traffic, the modern highways are to be straight as far as possible. This requirement, along with other requirements for fixing alignment of the bridges, is mainly responsible for provision of increasing number of skew bridges. The presence of skew in a bridge makes the analysis and design of bridge decks intricate. For the T-beam bridges with small skew angle, it is frequently considered safe to ignore the angle of skew and analyze the bridge as a right bridge with a span equal to the skew span. However, T-beam 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. In this paper a study on the behaviour of T-beam skew bridges with respect to support reactions, shear force, bending moment under standard IRC Class AA loading is presented and the study also compares analytical modeling of T-beam bridges by Grillage Analogy method and Finite Element method.

KEYWORDS: SAP 2000, Finite Element Method, Grillage Analogy Method.

I. INTRODUCTION

Skew bridges are not willingly chosen but necessitated due to site considerations such as alignment constraints, land acquisition problems, etc. The behaviour of such skew slabs is complicated, hence also the analysis, design and detailing. Because of apprehensions, there is always a tendency to avoid or at least reduce the skew effects by choice of orientation of supports. Foundations and substructures could be oriented in the direction of flow of river or rail track in a skew crossing. In a road bridge over a rail track, the portion just above the rail track is planned and designed as a skew deck, if necessary. But on either side of the obligatory span the deck is planned, designed and executed as square deck.[2]

II. RELATED WORKS

The structural analysis and design of bridges or any complex structures involve a number of variables such as loads, material properties, dimensions skew angle and boundary conditions of structural members. Apart from the aforementioned variables, there are numerous other factors which affect the strength and serviceability of structures such as construction methods, workmanship, quality control and intended service life of the structure etc. there are different methods for the analysis of bridge Finite element method and grillage method. There are few studies on these methods. The response of a structure to earthquakes cannot be predicted in a deterministic manner because of the uncertainty associated with the variables. Uncertainty may be due to material parameters, geometric parameters, soil conditions or due to geological details. In addition, the structural response analysis involves some degree of modeling idealization and that further aggravates the situation. Sreedhar R. et al. (2012) [22] studied the effect of skew angle on static behaviour of reinforced concrete slab bridge decks. The effect of a skew angle on single-span reinforced concrete bridges is analyzed using the finite-element method and the results are presented in this paper. Investigations are carried out on RC slab bridge decks with and without edge beams to study the influence of aspect ratio, skew angle and type of load. The finite-element analysis results for skewed bridges are compared to the reference straight bridges for dead load, IRC Class A loading and IRC 70R loading for with and without edge beam.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

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III. SKEW DECKS

The force flow between the support lines is through the strip of area connecting the obtuse-angled corners and the slab primarily bends along the line joining the obtuse-angled corners. The width of this primarily bending strip is a function of skew angle and the ratio between the skew span and the width of the deck (aspect ratio). The areas on either side of the strip do not transfer the load to the supports directly but transfer the load only to the strip as cantilever. Hence the skew slab is subjected to twisting moments. This twisting moment is not small and hence cannot be neglected. Because of this, the principal moment direction also varies and it is the function of a skew angle and width to span ratio.[2].

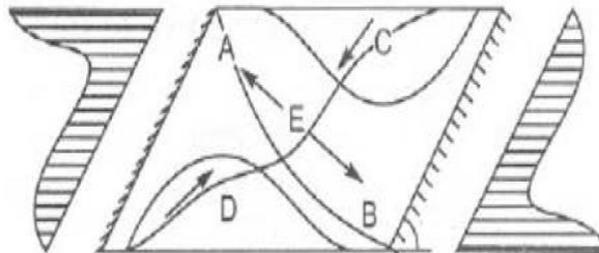


Fig. 1. Force flow in a skew deck

The load is transferred from the strip to the support first over a defined length along the support line from the obtuse-angled corners. Later the force gets redistributed for the full length. The force flow is shown in figure 1. The thin lines in figure 1 indicate deformed shape. The distribution of reaction forces along the length of the supports is also shown on both the support sides.[2] Increase in skew angle results in decrease in bending moments but increase in twisting moments, the total strain energy remaining the same. [2]

IV. 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

1. Variation in the direction of maximum bending moment across width, from near parallel to span at edge and orthogonal to abutments in central region.
2. Hogging bending moments near obtuse corners.
3. Considerable torsion in decks.
4. High reactions and shear forces near obtuse corners.
5. Low reaction and possibly uplift near acute corners, especially in case of slab with high skew angles.
6. The points of maximum deflection nearer obtuse angled corners. [2]

V. GRILLAGE ANALOGY METHOD

Grillage analogy i.e. given decking system is converted into series of interconnected beams such that given prototype bridge deck and the equivalent grillage of beams are subjected to identical deformations under loading. A suitable grillage model of a skew deck will depend largely on the angle of skew, the span length and the width of the deck. An important consideration is to place the grillage members in the directions of principal strength. Curved decks pose no particular problem for grillage modeling. Some analysis programs will allow the use of curved beams, but straight beams will be sufficiently accurate if the grillage mesh is fine enough.

Although computational power has increased many fold since then, the method is still widely used for bridge deck analysis. Some of the benefits that have been quoted are that grillage analysis is inexpensive and easy to use and comprehend. These benefits traditionally favoured the method over finite element analysis which was typically only

International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 4, Issue 9, September 2015

used for the most complex problems. In today's environment of inexpensive, high-powered computers coupled with elaborate analysis programs and user-friendly graphical interfaces, the finite element method has begun to replace the grillage method in many instances, even for more straightforward bridge decks. The grillage method has proved to be a versatile tool for the analysis of many bridges and benefits from numerous favourable comparisons with experiments such as those of West. The aim is that deflections, moments, and shears be identical in both the slab and the grillage model. As the grillage is only an approximation, this will never be achieved exactly. Clearly different levels of accuracy are acceptable for different applications.

Bridge deck is analyzed by the method of grillage analogy. There are four steps to be followed for obtaining design responses:

- (i) Idealization of physical deck into equivalent grillage;
- (ii) Evaluation of equivalent elastic inertias of members of grillage;
- (iii) Analyze the structure; and
- (iv) Interpretation of results.

The logical choice of grid lines is to make them coincident with the center lines of physical girders and these members are given the properties of the girders plus associated portions of the slab. Additional grid lines between physical girders are also provided in order to improve the accuracy of the result. Edge grid lines are provided at the edges of the deck or at a suitable distance from the edge. The above procedure of choosing longitudinal grid lines is applicable to both right and skew decks.

When intermediate cross-girders exist in the actual deck, the transverse grid lines represent the properties of cross girders and associated deck slabs. The grid lines are set in along the centre lines of cross girders. Grid lines are also placed in between these transverse physical cross girders. [1]

VI. FINITE ELEMENT METHOD

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. Finite element modeling of skew or curved decks should be carried out according to the recommendations for right decks. Generally, no special consideration need be given to directions of strength as the elements are two-dimensional and will model the two-dimensional behaviour of the skew slab. This is the advantage that the finite-element method has over the grillage method.[1]

Finite elements, referred to as finite elements, connected together at a number of nodes. The finite elements method was first applied to problems of plane stress, using triangular and rectangular element. The method has since been extended and we can now use triangular and rectangular elements in plate bending, tetrahedron and hexahedron in three-dimensional stress analysis, and curved elements in singly or doubly curved shell problems. Thus the finite element method may be seen to be very general in application and it is sometimes the only valid analysis for the technique for solution of complicated structural engineering problems. It most accurately predicted the bridge behavior under the truck axle loading. The finite element method involves subdividing the actual structure into a suitable number of sub-regions that are called finite elements. These elements can be in the form of line elements, two dimensional elements and three-dimensional elements to represent the structure. The intersections between the elements are called nodal points in one dimensional problem where in two and three-dimensional problems are called nodal line and nodal planes respectively.[1]

VII. MODEL DETAILS

Clear width of roadway = 7.5m, Span = 8m, 12m, 16m. Average thickness of wearing coat = 80mm. Cross section of Deck: Three main girders are provided at 2.5m centers. Thickness of deck slab=200mm. Wearing coat=80mm. Width of main girders=300mm. Kerbs 600mm wide by 300mm deep are provided. Cross girders are provided at every 4m interval. Breadth of cross girder = 300mm. Depth of main girder= 160cm at the rate of 10cm per meter of span. The depth of cross girder is taken as equal to the depth of main girder to simplify the computation. The bridge is analyzed

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as follows: The Bridge is first analyzed using I.R.C. specifications. The beam is considered as one dimensional element subject to dead load and live loads. Total of 30 bridge models were created. 15 bridge models were analyzed by Grillage analogy method and 15 bridge models were analyzed by Finite element method.

Table 1: Grillage member properties

	Second moment of area (m ⁴)	Torsion Constant (m ⁴)
Longitudinal members		
R1, R13	0.0008125	0.001625
R2,R4,R5,R6,R8,R9 R10,R12	0.001625	0.00325
R3,R7,R11	0.027	0.0182
Transverse members		
End members	0.0013	0.0026
Cross girders members	0.0026	0.0052
Other intermediate members	0.00156	0.00312

R1 to R13 are the longitudinal members. The end and the intermediate members are the transverse members. The longitudinal members have been placed along the lines of the bearings, with an additional line at the centre of the deck.

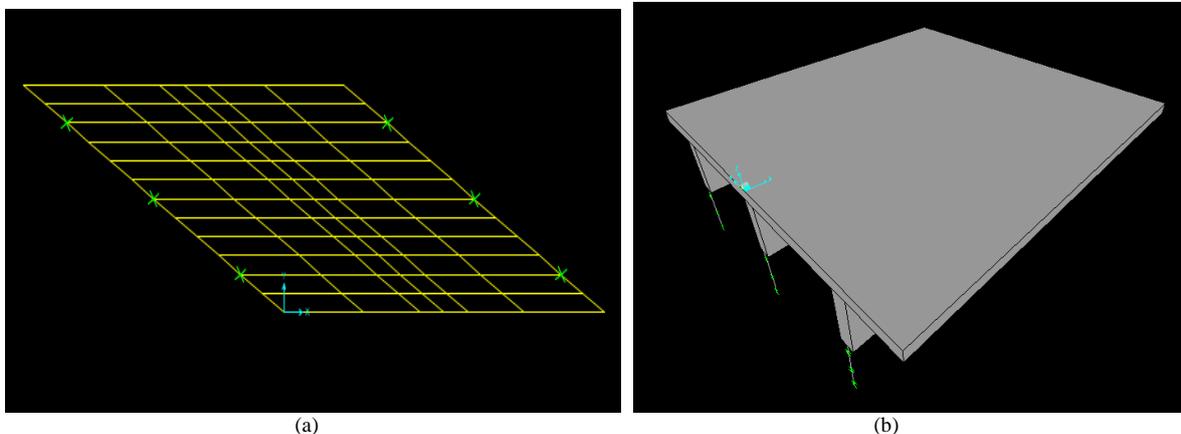


Fig. 2. Bridge Models (a) Grillage mesh for bridge of 60° skew 8m span (b) Finite element model for bridge of non skew 8m span

Figure 2 shows the grillage mesh for bridge of 60° skew 8m span and Finite element model for bridge of non skew 8m span. The analysis is carried out in SAP 2000. The minimum and maximum support reactions of both Grillage Analogy Method and Finite Element Method have been calculated and graph plotted for each span is shown in figure 3, 4, and 5. IRC class AA wheeled loading of 400kN is used in the analysis. The impact loading is also separately fought out for different span. 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.

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Table 3: Grillage Analogy Method

Grillage Analogy Method		
8m Span	Support Reaction	
	Maximum	Minimum
0°	335.551	203.276
15°	409.971	124.419
30°	453.414	88.925
45°	603.435	28.928
60°	713.911	-8.496

The maximum support reaction of 8m span with non skew obtained by Grillage Analogy Method is 335.551kN and the maximum support reaction obtained by Finite Element Method is 319.507kN and the minimum support reaction of 8m span with non skew obtained by Grillage Analogy Method is 203.276kN and the minimum support reaction obtained by Finite Element Method is 156.44kN.

Table 4: Finite Element Method

Finite Element Method		
8m Span	Support Reaction	
	Maximum	Minimum
0°	319.507	156.44
15°	388.498	108.627
30°	436.757	89.963
45°	582.27	11.713
60°	680.519	-13.456

The maximum support reaction of 8m span with 60° skew obtained by Grillage Analogy Method is 713.911kN and the maximum support reaction obtained by Finite Element Method is 680.519kN and the minimum support reaction of 8m span with 60° skew obtained by Grillage Analogy Method is -8.496kN and the minimum support reaction obtained by Finite Element Method is -13.456kN.

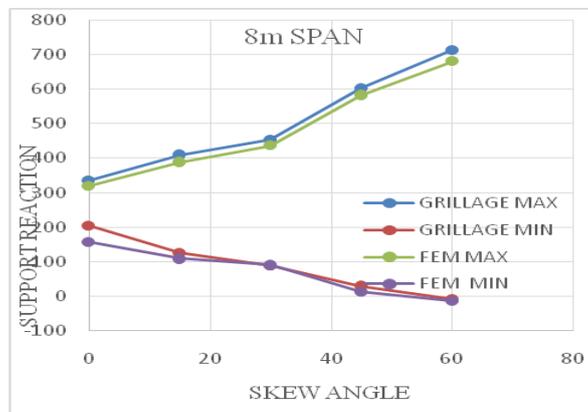


Fig. 3: Comparison graph of 8m span

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 45°.

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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°. 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. Support reaction increases twice from non skew to 60°. Finite element gives lesser value in terms of reactions compared with grillage model.

Table 5: Grillage Analogy Method

Grillage Analogy Method		
12m Span	Support Reaction	
	Maximum	Minimum
0°	475.148	277.186
15°	623.891	125.759
30°	843.572	-18.392
45°	1072.462	-284.197
60°	1232.511	-442.795

The maximum support reaction of 12m span with non skew obtained by Grillage Analogy Method is 475.148kN and the maximum support reaction obtained by Finite Element Method is 464.116kN and the minimum support reaction of 12m span with non skew obtained by Grillage Analogy Method is 277.186kN and the minimum support reaction obtained by Finite Element Method is 172.449kN.

Table 6: Finite Element Method

Finite Element Method		
12m Span	Support Reaction	
	Maximum	Minimum
0°	464.116	172.449
15°	586.75	106.443
30°	830.604	-38.621
45°	983.183	-294.624
60°	1147.615	-388.985

The maximum support reaction of 8m span with 60° skew obtained by Grillage Analogy Method is 1232.511kN and the maximum support reaction obtained by Finite Element Method is 1147.615kN and the minimum support reaction of 8m span with 60° skew obtained by Grillage Analogy Method is -442.795kN and the minimum support reaction obtained by Finite Element Method is -388.985kN. Support reaction increases 3 times from non skew to 60°. Finite element gives lesser value in terms of reactions compared with grillage model.

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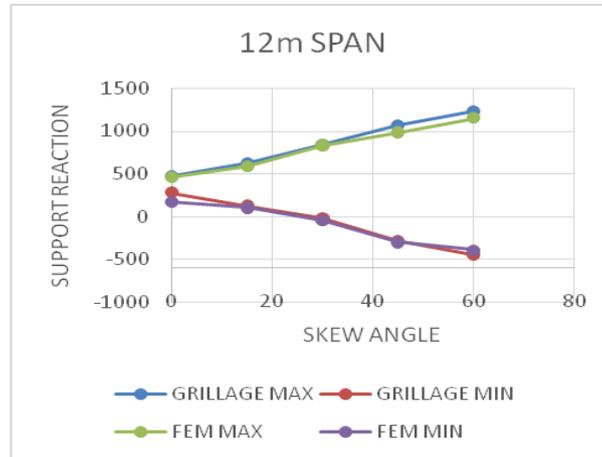


Fig. 4: Comparison graph of 12m span

Table 7: Grillage Analogy Method

Grillage Analogy Method		
16m Span	Support Reaction	
	Maximum	Minimum
0°	615.325	377.881
15°	855.325	155.817
30°	1162.825	5.817
45°	1440.325	-219.183
60°	1767.325	-511.683

Table 8: Finite Element Method

Finite Element Method		
16m Span	Support Reaction	
	Maximum	Minimum
0°	604.532	172.449
15°	832.002	88.154
30°	1151.197	-3.983
45°	1413.56	-236.44
60°	1748.39	-537.424

The maximum support reaction of 16m span with non skew obtained by Grillage Analogy Method is 615.325kN and the maximum support reaction obtained by Finite Element Method is 604.532kN and the minimum support reaction of 16m span with non skew obtained by Grillage Analogy Method is 377.881kN and the minimum support reaction obtained by Finite Element Method is 172.449kN. The maximum support reaction of 8m span with 60° skew obtained by Grillage Analogy Method is 1767.325kN and the maximum support reaction obtained by Finite Element Method is 1748.39kN and the minimum support reaction of 8m span with 60° skew obtained by Grillage Analogy Method is -511.683kN and the minimum support reaction obtained by Finite Element Method is -537.424kN. Support reaction increases 3 times from non skew to 60°. Finite element gives lesser value in terms of reactions compared with grillage model. Therefore it can be concluded that analysis by using finite element method gives more economical and accurate design when compared with the grillage analysis. But the benefit for grillage analysis is that it is easy to use and comprehend.

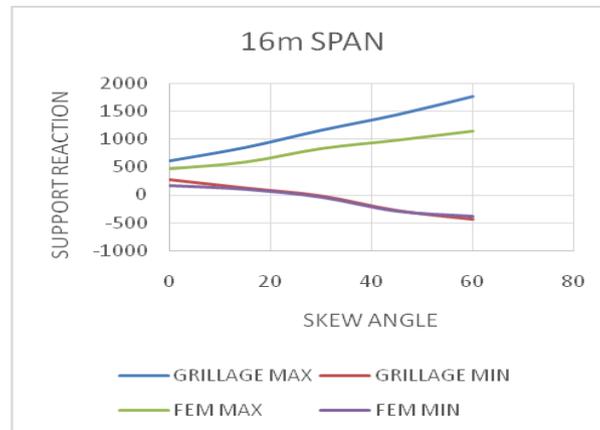


Fig. 5: Support reaction of 16m Span

VIII. CONCLUSION

The objective of the project was to compare finite element method and grillage method. It can be concluded that analysis by using finite element method gives more economical design when compared with the grillage analysis.

1. With increase in the skew angle, the stresses in the slab differ significantly from those in a straight slab
2. Reaction increased with increasing skew angle
3. Finite element method gives more economical design and accurate when compared with the grillage analysis.
4. Uplift or negative reaction at the acute corner.
5. Maximum or high reaction at the obtuse corner.

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ISSN(Online) :2319-8753
ISSN (Print) : 2347-6710

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2015

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