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EFFECT ON SUPPORT REACTIONS OF T-BEAM SKEW BRIDGE DECKS

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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 behavior of the bridge especially in the short to medium range of spans.

In this paper a study on the behavior of T-beam skew bridges with respect to support reactions under standard IRC-70R wheeled loading is presented and the study was based on the analytical modeling of T-beam bridges by Grillage Analogy method. Effects of support reactions for different spans have been studied. The analysis provides the useful information about the variation of support reactions with respect to change in skew. The negative reactions were observed with increase in the span and skew angles.

It was found that in skew T-beams bridges, the high positive and negative reactions develop close to each other. Negative reactions were very less in the 8m right span and introduced at an angle of 50^0 and onwards, while for 16m right span it was introduced an angle of 30^0. In 24m and 32m right spans the negative reactions develops at smaller skew angles (i.e. 20^0 and onwards).

Keywords: bridge, skew, highway, support reactions.

INTRODUCTION

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. The inclination of the centre line of traffic to the normal to the centre line of the river in case of a river bridge or other corresponding obstruction is called the skew angle. For bridges in which the plan form is a parallelogram is shown in Figure-1, the angle obtained by subtracting the acute angle of the parallelogram from 900 is termed the skew angle of the bridge.

As shown in Figure-1, the span of a skew bridge measured along an unsupported edge of the bridge in plan is called the skew span, and the perpendicular distance between the two lines of supports is called the right span. The directions parallel and perpendicular to the flow of traffic on the bridge are still called the longitudinal and transverse directions respectively.

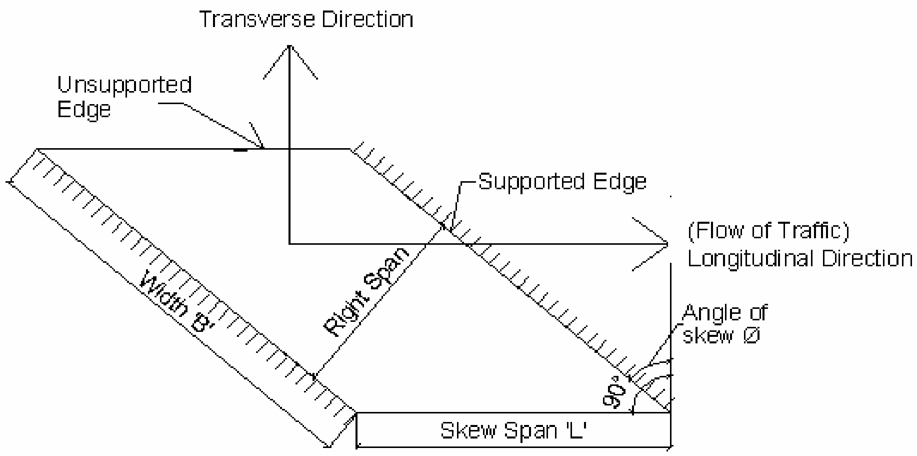

Figure-1. Skew bridge.

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Due to high traffic speeds road or railway schemes can seldom be modified in order to eliminate the skew of their bridges. Therefore, a considerable number of skew bridge decks are constructed. The effect of skew above angles of about 20^o in single span decks can have a considerable effect on the behavior of the bridge especially in the short to medium range of spans where the span and width are of the same order. Here the study is carried out for, two lane T-Beam bridges without footpath are analysed for 8m, 16m, 24m and 32m right spans for 0^0, 10^0, 20^0, 30^0, 40^0, 50^0 and 60^0 skew angles.

METHODOLOGY ANALYSIS

The advent of digital computers, computer-aided methods like Finite Element, Finite Difference and Finite Strip have been developed and are in use to analysis intricate forms of skew shape of bridges having usual support conditions and cross-sections. But these methods are highly numerical and always carry a heavy cost-penalty. Grillage analogy is one of the most popular computer-aided methods for analysing bridge decks. The method consists of representing the actual decking system of the bridge by an equivalent grillage of beams. The dispersed bending and torsional stiffness of the decking system are assumed, for the purpose of analysis, to be concentrated in these beams. The stiffness of the beams is chosen so that the prototype bridge deck and the equivalent grillage of beams are subjected to identical deformations under loading. The method is applicable to bridge decks with simple as well as complex configurations with almost the same ease and confidence. The method is easy to comprehend and use. The analysis is relatively inexpensive and has been proved to be reliably accurate for a wide variety of bridges. The grillage representation helps in giving a feel of the structural behavior of the bridge and the manner in which the loading is distributed and eventually taken to the supports.

Transformation of bridge deck into equivalent grillage

The grillage analogy method, which is a computer-oriented technique, is increasingly being used in the analysis and design of bridges. The method is also suitable in cases where bridge exhibits complicating features such as heavy skew, edge stiffening and isolated supports. The method is versatile in nature and the contribution of kerb beams and the effect of differential sinking of girder ends over yielding bearings (such as neoprene bearing) can also be taken into account and large variety of bridge decks can be analysed with sufficient practical accuracy.

The method consists of 'converting' the bridge deck structure into a network of rigidly connected beams at discrete nodes i.e. idealizing the bridge by an equivalent grillage. The deformations at the two ends of a beam element are related to the bending and torsional moments through their bending and torsional stiffness.

Bridge deck is analysed 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) Analyse the structure; and
(iv) Interpretation of results.

The method of grillage analysis involves the idealization of the bridge deck as a plane grillage of discrete inter-connected beams. It is difficult to make precise general rules for choosing a grillage mesh and much depends upon the nature of the deck to be analysed, its support conditions, accuracy required, quantum of computing facility available etc. and only a set of guidelines can be suggested for setting grid lines. It may be noted that such idealization of the deck is not without pitfalls and the grid lines adopted in once case may not be efficient in another similar case and the experience and judgment of the designer will always play a major role.

Idealization of grillage for T-beam Bridge

The logical choice of grid lines is to make them coincident with the centre 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 be 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.

Location and direction of grid lines

Grid lines are adopted along 'Lines of Strength'. In the longitudinal direction, these are along the centre line of girders, longitudinal webs or edge beams, wherever these are present. Where isolated bearings are adopted, the grid lines are also to be chosen along the lines joining the centres of bearings. In the transverse direction, the grid lines are to be adopted, one at each ends connecting the centres of bearings and along the centre lines of transverse beams, wherever these exist. Ordinarily, the grid lines coincide with the centre of gravity of the sections (but some shift is permissible).

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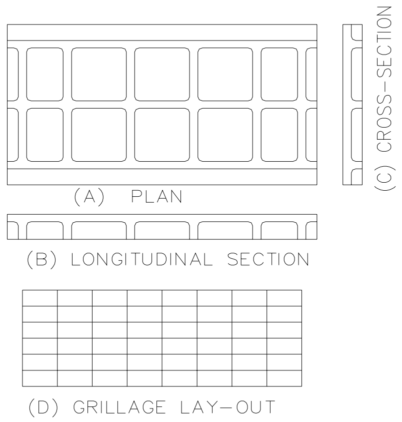


Figure-2. Grillage layout for T-beam Bridge.

Number and spacing of grid lines

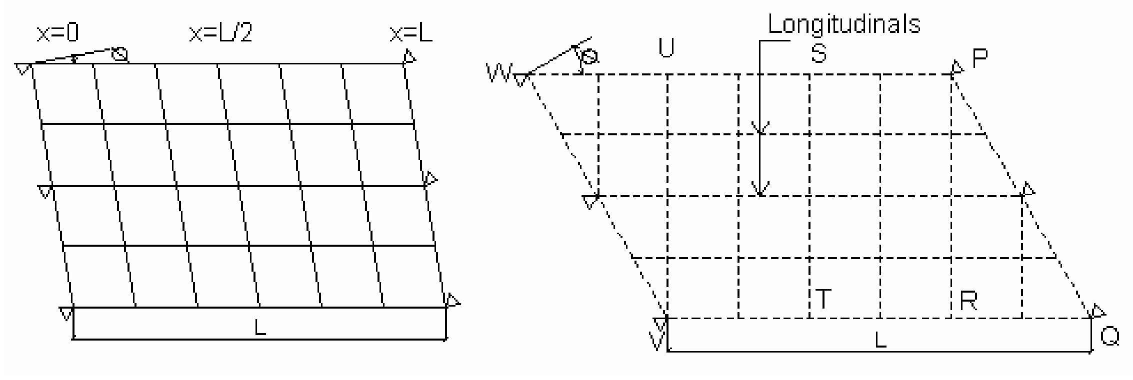
An odd number of longitudinal and transverse grid lines are adopted, wherever possible. The minimum number of longitudinal grid lines may be three and the minimum number of transverse grid lines per span may be five. In the present study, the longitudinal grid lines are seven and number of transverse grid lines are varies according to span.

The ratio of spacing of transverse grid lines to those of longitudinal grid lines is chosen between 1.0 and 2.0. This ratio should also, ordinarily, reflect the span-width ratio of the bridge. Thus, for a short span and wide bridge, it is close to 1.0 and for long span and narrow bridge, this ratio is approximately 2.0.

It is noted that with an increase in number of grid lines, the accuracy of computation increases, but the effort involved is also more and soon it becomes a case of diminishing return. In a contiguous girder bridge, more than one longitudinal physical beam can be represented by one grid line.

In skew bridges with small skew angle less than 15^0 and with no intermediate diaphragms, the transverse grid lines are kept parallel to the support lines. Additional transverse grid lines are provided in such a way that their spacing does not exceed twice the spacing of longitudinal lines.

In skew bridges with higher skew angle, the transverse grid lines are set along abutments and also along PR, ST and UV. Extra grid lines are inserted between PR and UV.



(a) Deck with small skew $\varnothing \leq 15^0$ (b) Deck with large skew $\varnothing > 15^0$

Figure-3. Grillage arrangements in skew T-beam bridge without cross girders.

Evaluation of equivalent elastic properties

After simulating the bridge structure into equivalent grillage, the members are assigned elastic properties i.e., flexural and torsional stiffness. This accomplished by considering isolated sections of the deck as if they are individual beams and the inertia is calculated for each section and allotted to the corresponding grillage beams representing that section. The principles involved and the methodology adopted for evaluating properties is discussed as follows:

Properties of longitudinal girder

The thin deck slab acts as a flange and whole unit acts as a composite section. When the girder bends, the flanges are subjected to flexural stress. As an element of the flange away from the rib of the beam has less stress than the one directly over the rib due to shear deformations of the flange. Shear deformation relieves some amount of compressive stress in more distant element. This phenomenon is known as shear lag. The variation of compressive stress across the width of flange is accounted for by considering the effective width of flange.

For the purpose of calculation of flexural and torsional inertia, the effective width of slab is calculated as per clause 305.15 of IRC 2:2000 but not exceeding the actual flange width.

$$b_e = b_w + 1/5\, l_0 \tag{1}$$

b_e = effective width
b_w = thickness of the web for beams
l_0 = the distance between points of zero movement

The computation of flexural moment of inertia I is straight forward and need no elaboration, while the torsional inertia I_x, is calculated as per procedure described below:

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For a rectangle of sides b and d

$$I_x = 3b^3d^3 / 10(b^2 + d^2) \quad (2)$$

In the case of a thin rectangle where b > 5d

$$I_x = bd^3 / 3 \quad (3)$$

Since the cross-section of girder has reentrant corners, I_x is obtained notionally, sub-dividing the section into rectangular shapes without having reentrant corners and summing the value of I_x of these elements.

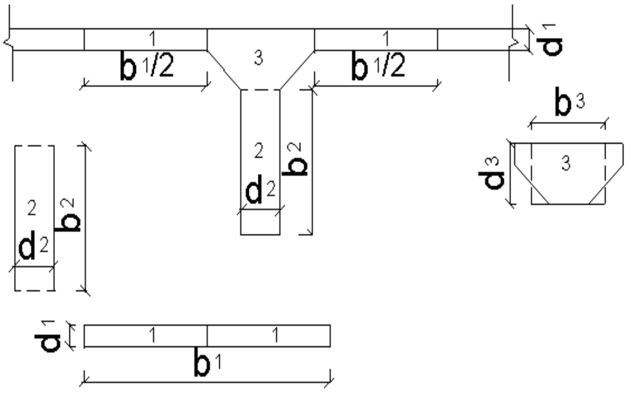

Figure-4. Sub-division of T-section with reentrant corners.

$$I_{x1} = ½(1/3(b_1d_1^3) \quad (4)$$

$$I_{x2} = 1/3\ (b_2d_2^3) \quad (5)$$

$$I_{x3} = 3b_3^3d_3^3 / 10(b_3^2 + d_3^2) \quad (6)$$

For a beam section as a whole

$$I_x = I_{x1} + I_{x2} + I_{x3} \quad (7)$$

It is to be noted that the value of I_x of the portion of the deck slab forming the flange is to be halved to take into account its continuity in the other directions. Widths b_3 and b_4 of the segments 3 and 4 are so adjusted that areas $b_3.d_3$ and $b_4.d_4$ are same as original areas of the respective segments.

Properties of deck slab

The sectional properties of grid lines representation the slab only are calculated as flexural moment of inertia is $bd^3/12$, slab member of width b and depth d and torsion constant Ix are $bd^3/6$.

Properties of cross girder

The properties of cross girder are calculated in the similar way as discussed in longitudinal girder.

Application of loads on grillage deck

The loads consisting of dead, live and impact loads acting on the bridge superstructure are appropriately distributed to the nodes of the grillage. The dead load comprises of self-weight, wearing coat, parapet, kerb etc. which are of permanent stationary nature. These dead loads are customarily considered to be borne by the longitudinal grid members giving rise to distributed loads on them. This distributed load is idealised into equivalent nodal loads. If the dead load is udl but its centre is non-coincident with the longitudinal grid line then it is substituted by a vertical udl together with a torsional udl. The self-weight of cross-beams is given taking the total weight of all the cross-beams per span and equally dividing it in the form of distributed loads to various longitudinal members of the grillage. The dead weight of railings, kerbs, footpaths etc. is lumped on the edge longitudinal grid lines.

The main live load on Highway Bridge is of the vehicles moving on it. Indian Roads Congress (IRC) recommends different types of standard hypothetical vehicular loading systems in IRC 6:2000, for which a bridge is to be designed. The vehicular live load consist of a set wheel loads which are distributed over small areas of contacts of wheels and form patch loads and treated as concentrated loads acting at centres of contact areas. In order to obtain the maximum response resultants for the design, different positions of each type of loading system as per IRC 6:2000 is tried on the bridge deck. The load is moved longitudinally and transversely in small steps to occupy a large number of different positions on the deck. The largest force response is obtained at each node.

The loading considered in the present study is IRC Class 70R train loading weighing 100 tons. A brief description about this loading is given as under:

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IRC class 70R loading

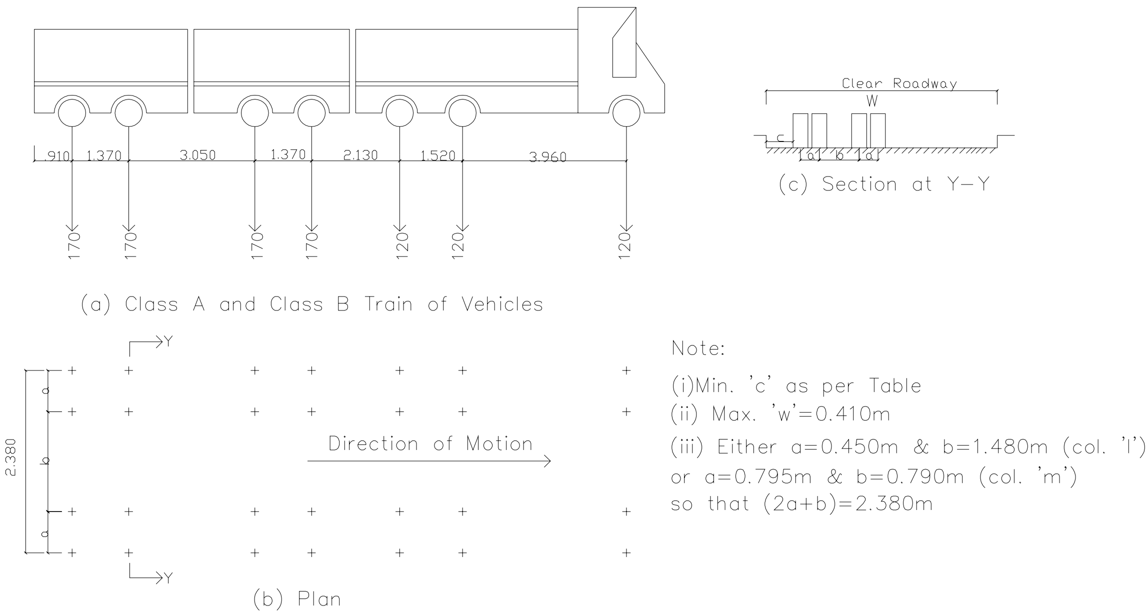

Figure-5. IRC class 70R wheel loading.

This is the revised version of Class AA. The loading is detailed in Appendix-I of IRC 6:2000. Class 70R train loading weighs 100 tons through even axles, one axle of 80 KN, two axles of 120 KN each and four axles of 170 KN each (Figure-5.). An axle may have four or eight wheels on it. There are two, four wheel arrangements and one, eight wheel arrangement leading to three alternate wheel arrangements termed as col. 'l', col. 'm' and col. 'n' arrangements. All axles will have the same arrangement of wheel at a time and all wheels on an axle will have equal loads. The eight wheel arrangement namely col. 'n' is usually not found critical.

The minimum clearance between the road face of the kerb and the outer edge of the wheel is given in Table-1. The spacing between successive vehicles is 30m. This spacing is measured from the rear most point of ground contact of the leading vehicle to the forward most point of ground contact of the following vehicle.

Table-1. Minimum clearance of vehicle from the road face of the kerb face.

Carriage way width (m)	**Minimum value of C** (m)
Single Lane Bridges 3.80 and above	0.30
Multi Lane Bridges	
<5.50	0.60
>5.50	1.20

Impact load

Another major loading on the superstructure is due to the vibrations caused when the vehicle is moving over the bridge. The theoretical estimate of this load is quite complex as it depends upon a variety of factors such as roughness of the surface, spring system of the vehicle, condition of expansion joints at the entry to bridge etc. The IRC Code (2000), however, recommends definite values of impact load is expressed as a percentage of the live load, depending upon the material used in the construction of deck of the bridge, type of loading and the bridge span.

NUMERICAL STUDY

To assess quantitatively the effect of analyzing real life skew bridges, several skew bridges are analysed and compared with right bridges. The data used for numerical study is described below:

Bridge data

All bridges have cast in-situ deck slab of 250mm on three girder spaced at 2.5m centre to centre of girder. The cross girder is provided at the end and at the approximate spacing of 2.0m. The overall span depth ratio is 15. The clear roadway width is considered as 7.5m. The width of edge beam is 500mm. However, for the sake of simplicity the stiffness of edge beam is considered same as that of slab. The effective right spans analysed are 8m, 16m, 24m and 32m for skew angles of 0^0, 10^0, 20^0, 30^0, 40^0, 50^0 and 60^0 each. As per the guidelines for grillage generation (refer section 3.2.1) the modeling of decks has been classified into two cases, which are as follows:

Case 1: when skew angle $\leq 15^0$, longitudinal grid lines are taken parallel to free edge and transverse grid lines are taken parallel to support (parallelogram type mesh).
Case 2: when skew angle $> 15^0$, longitudinal grid lines are taken parallel to free edge and transverse grid lines are taken perpendicular to longitudinal grid lines (orthogonal mesh).

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The width to right span ratio B/L for various cases analysed is as follows:

8m right span = 1.0
16m right span = 0.5
24m right span = 0.25
32m right span = 0.125

Loading data

IRC class 70R train loading weighing 1000 KN was considered for the analysis of decks. The train is allowed to run nearest to the kerb of the deck. An increment of 0.5m is given in the longitudinal direction for load generation. The dead load on the deck is also added to the live load.

Output data

The decks were evaluated for the following forces:

Maximum Support Reaction
Minimum Support Reaction

RESULTS AND DISCUSSION

Results from output of analysis of bridge decks are arranged in Figures 6 to 9. The minimum and maximum support reactions have been calculated.

8m Right span

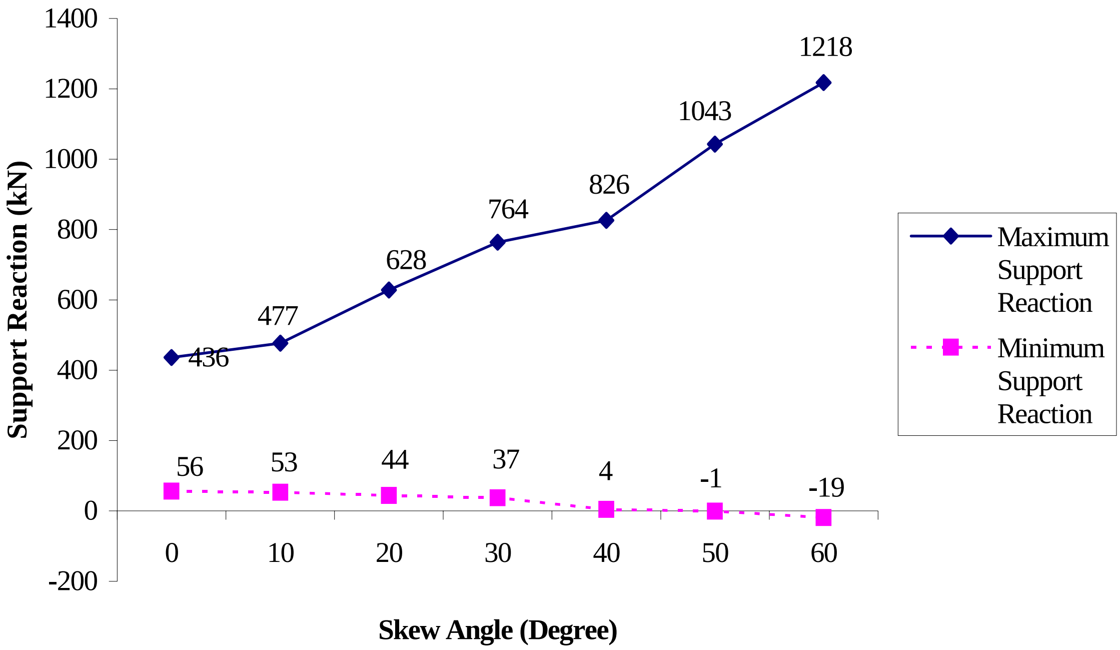

Figure-6. Maximum and minimum support reaction for 8m right span.

The maximum support reaction is occurring at the support near obtuse corner with the exception of 0^0 skew angle where it occurs at middle girder support. The maximum reaction at 0^0 skew angle is 436kN (Figure-6), which increases to 477kN at 10^0 skew angle. From 10^0 onward the maximum support reaction increases approximately linearly and the value at 60^0 becomes 1218kN.

The minimum support reaction at 0^0 is 56kN (Figure-6), which decrease to 53kN at 10^0 skew angle. At 20^0 it reduces to 44kN. Then it was reducing to 4kN at 40^0. At the 50^0 skew angles it becomes negative (i.e. -1kN). This indicates uplift at 50^0 skew. The uplift increases at 60^0 skew angles (Figure-6).

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16m Right span

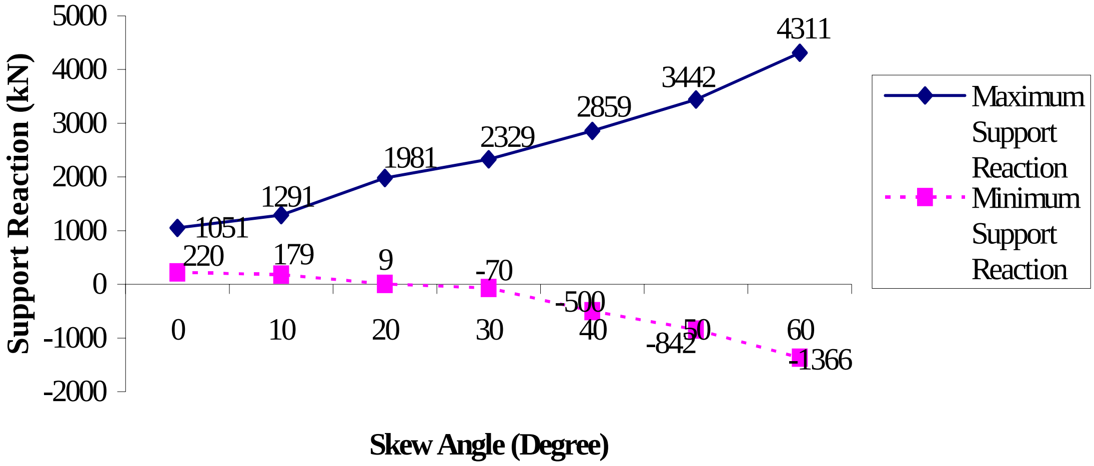

Figure-7. Maximum and minimum support reaction for 16m right span.

The maximum support reaction at 0^0 is 1051kN at end girder support near the moving load (Figure-7). At 10^0 skew the maximum reaction is 1291kN at the same support (near the obtuse corner) (Figure-7). But at 20^0 skew maximum support reaction is increases to 1981kN over the previous one value which is considerable (Figure-7). The maximum reaction beyond 30^0 is shows an increasing trend approximately linearly the value of at 60^0 reaction 4311kN (Figure-7).

The minimum support reaction at 0^0 is 220kN and it decreases continuously. At 30^0 and onward support reaction become negative (uplift reaction) (Figure-7). At the 60^0 the minimum reaction is -1366KN. The minimum reaction occurs at the support of middle girder, which is next to support that gives maximum reaction. A substantial difference is observed when compared with results of 8m right span. The negative reaction is observed at a smaller skew (30^0) compared to results of 8m right span (50^0 skew).

24m Right span

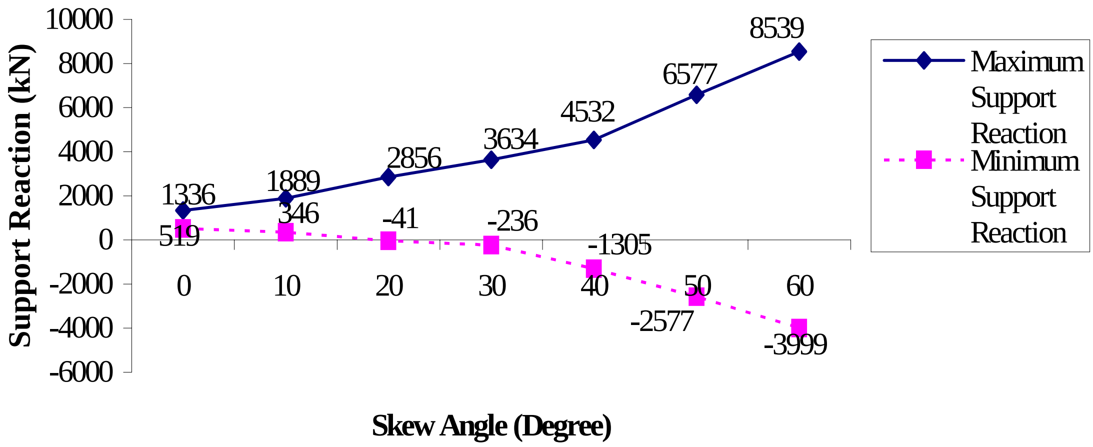

Figure-8. Maximum and minimum support reaction for 24m right span.

The graph of maximum support reaction for 24m right span is in increasing order (Figure-8) and the position of its lies at the line of movement load. It increases linearly up to 40^0 skew and the slope of the curve increase indicated higher increase for 10^0 skew interval.

The minimum support reaction at 0^0 is 519kN and it decreases continuously (Figure-8). The minimum support reaction is occurring next to the support where maximum reaction is obtained. At 20^0 it becomes negative and the value is -41kN. There is an increase in negative reaction when the skew angle increases (Figure-8).

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32m Right span

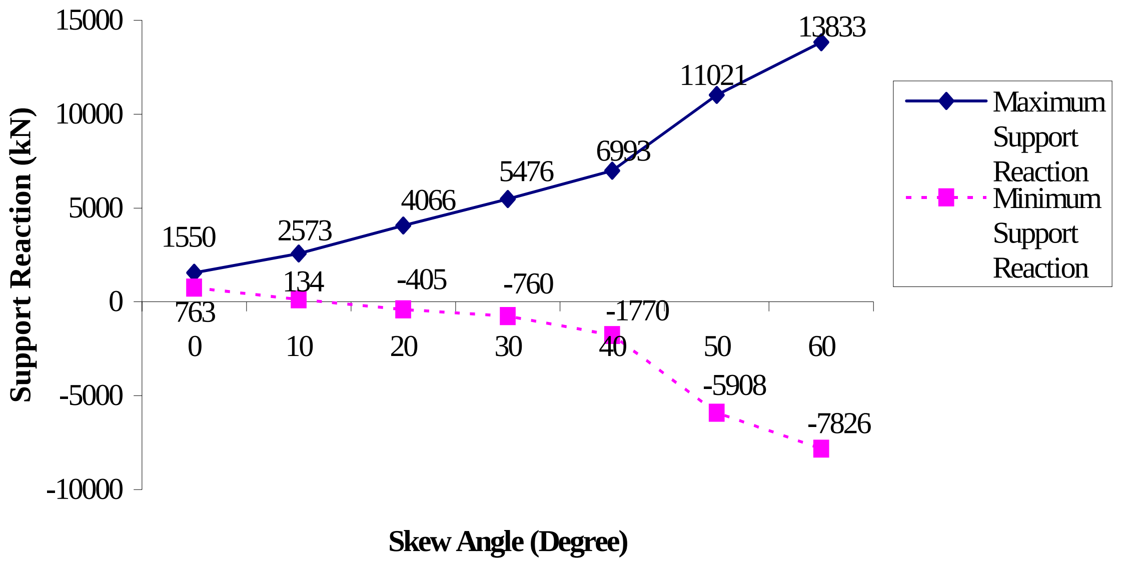

Figure-9. Maximum and minimum support reaction for 32m right span.

The graph of maximum support reaction for 32m right span is increasing similar to that obtained with 24m right span (Figures 8 and 9) and the position of its lies at the line of movement load. The maximum reaction at 0^0 skew angle is 1550kN, which increases linearly up to 40^0 skew (Figure-9). Beyond 40^0 skew, the slope of the curve become steeper i.e. a higher increase in support reaction is observed for every 10^0 increases in the skew angle (Figure-9).

The minimum support reaction at 0^0 is 763kN and it decreases continuously, which reduces to 134kN at 10^0 skew angle (Figure-9). At 20^0 skew angle the minimum support reaction becomes -405kN that again reduce to -760 kN at 30^0 (Figure-9). The increasing negative reaction becomes higher (for every 10^0 increase in skew) as the skew angle increases.

CONCLUSIONS

On the basis of analysis it was found that grillage analogy method, based on stiffness matrix approach, is a reliably accurate method for a wide range of bridge decks. The method is versatile, easy for engineers to visualize and prepare the data for a grillage. It has been found that in skew T-beams bridges, the high positive and negative reactions develop close to each other. The reaction on the obtuse corner close to load is very high and increases with increasing skew angles 40^0. With the increasing in the span the negative reaction increases at smaller angles. Negative reactions were very less in the 8m right span (i.e. -1kN at 50^0 and -19kN at the 60^0). Negative reactions introduced from the 30^0 skew angle for 16m right span in the analysis. In 24m and 32m right spans the negative reactions develops at smaller skew angles (i.e. 20^0 and onwards).

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