Dynamic Analysis Of Horizontally Curved Bridges

Syed Habibunnisa, Komma Hemanth Kumar Reddy , Mukkala Priyanka

Abstract*—*Horizontally curved bridges are the most feasible options at complicated interchanges or river crossings where geometric restrictions and constraint of limited site space, make difficult the adoption of standard straight superstructures. Usually these bridges are of cellular cross-section so that high torsional moment can be well resisted economically. In this paper a parametric comparison was made between straight bridge and different curved bridges and skew bridges. Then these bridges were analyzed for dead, modal and moving load cases. This was done in order to study difference in the results obtained between straight, curved and skewed bridges for dead and moving load cases. The modeling part of the both bridges was done by using SAP 2000 in which there is an option named bridge wizard by which modeling of the bridge can done in a sequential order. After analyzing for dead load case unlike straight bridge there is torsion in the curved and skew bridges along the length of the bridge as there is unsymmetrical mass distribution in curved bridge about horizontal axis. Modal analysis showed the curved and skewed bridges have more initial torsional modes but whereas for straight bridge the initial modes were transverse and longitudinal. The amplifications in torsion were large compared to other parameters for curved and skewed bridges compared to straight bridge.

Keywords:Torsiona,skewbridges,deadload,modalload,sap2000, intial modes

I. INTRODUCTION

Although straight bridges can be modeled, analyzed and designed easily they are not always practically possible in the real site conditions. In this scenario, horizontally or vertical curved bridges and sometimes combination of both are the most adopted options at complex crossings or river exchanges where there are geometric restrictions and there is constraint of space, make difficult for the adoption of standard straight bridges. However in this current research I have dealt with only horizontal curved bridges that are bridges curved in plan. The most unusual point in horizontally curved bridges unlike straight bridges is the torsion induced in deck due to the eccentricity of the vehicle from the pier. So, for this purpose horizontal curved bridges are of box cross-section which can resist the high amount of torsion that comes in to the deck i.e they have high torsional modulus of rigidity. Finite element method (FEM) is the most suitable for analysis of bridges straight and curved bridges were modeled and various parameters like shear force, bending moment, axial force, torsion were calculate and the amplifications in these parameters compared to straight bridge were studied. In this paper initially a straight bridge was modeled which is having a total span length of 320m and having three intermediate piers i.e total 4 bays each having a span length 80m.In order to have a parametric comparison with the straight bridge three curved bridges of same span length. The deck of the curved bridges is assumed to be an arc of circle which are making 60, 90,120 degrees at the centre of the circle and moving load analysis was carried out for all these bridges and then parametric study for a various parameters such as shear force, bending moment, torsional moment and axial force due to the moving load analysis was done.

A) Modeling of bridge

Mostly highway bridges are beam structures. They may be either single spans or multiple spans, short span or of long span .In order to study the effects of various loads and load combinations the bridges are modeled as two dimensional analytical models but for more detailed analysis 3D modeling is required.

B) Modelling of super-structure

Generally three modeling options are used for typical multi-girder bridges. Line beam , Spine, Grillage and plate modeling , Complete finite element model

C)Model using sap- 2000 software

SAP in the market today has been used widely for the purpose of structural analysis program and is been widely used to solve various civil engineering problems. SAP has got3D interface and uses finite element analysis in order to obtain the solution to the problems. SAP is Finite element structural program which is used for the analysis and design of various structures. It has impressive user interface with various tools to check with the accuracy in construction of models which comes along with refined analytical techniques required for the analysis and design of various complex projects like bridges. In SAP, we have an option called bridge wizard section, which is useful for creating the analytical, model of bridge easily & quickly. The bridge wizard has got all of the steps required to create a analytical bridge model in Sap2000.

II. DECK SECTIONS

Various predefined bridge deck sections are available for the bridge. In this modeling the Concrete Box Girder were modeled by using bridge section designer as the section is not one of those pre-defined sections.

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A) description of the bridge:

A 320m long and four span continuous straight bridge was modeled and then subsequent dynamic (moving load) analysis was carried out on the bridge. The straight bridge was modeled as a four span continuous bridge. The deck of the bridge is 20.72m wide and it is a box girder section .Since the deck is not one of the predefined sections that are available in SAP it was modeled using section designer.The overall depth of the Box girder section was 3.15m and is symmetrical about the both axes. The characteristic compressive strength of the concrete i.e used for the bridge is M40.Bearings is used in connection between the girders and bent cap beam. Double bent cap was used and pier cap is 7.4*4.05m.Piers are modeled as line elements and circular cross section property is given. The diameter of the piers is taken as 1.7 meter and is assumed to be fixed to the ground.

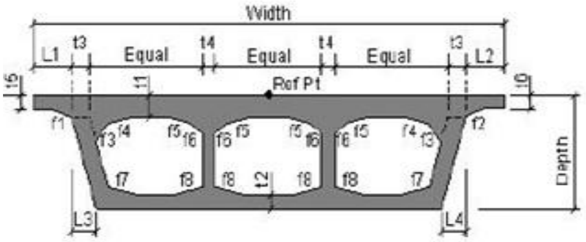

Fig: **Cross section of the Box girder**

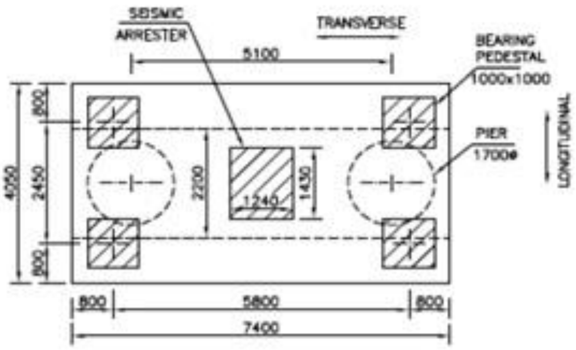

Fig :Plan view of pier cap

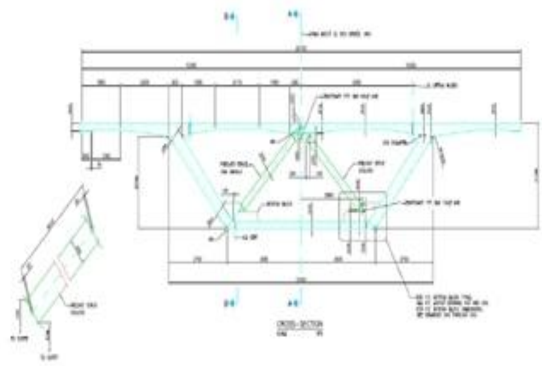

Fig: **Cross section of the Box girder**

B) IRC LOAD COMBINATIONS

For the bridge sections solid concrete diaphragm properties are given. Since the bridge deck width is taken as 20.72m as per IRC 6 it should be of six lanes and the width of each lane is taken as defined in the IRC6 load combination. *So as defined in the below* table the deck section is divided into six lanes and then one lane of class A for each lane is given. As per IRC 6 the nose to tail distance between successive trains shall not be less than 18.5m.So this distance is given as the lag distance between the two vehicles is 18.5m.The velocity of the vehicles is taken as 40kmph.The multistep static analysis was converted to multistep dynamic analysis by giving time history analysis and then damping of the bridge system and the solution technique used for this analysis is Direct Integration Method. All these multi-step analysis cases were given by using special Bridge Live Load Cases where we can define the direction of the vehicles, starting time and speed of various vehicles moving along different lanes.

Sl.No	Carriageway width	Number of lanes for design purposes	Load combination
1)	Less than 5.3 m	1	One lane of Class A considered to occupy 2.3 m. The remaining width of carriageway shall be loaded with 500 kg/m².
2)	5.3 m and above but less than 9.6 m	2	One lane of Class 70R OR two lanes of Class A
3)	9.6 m and above but less than 13.1 m	3	One lane of Class 70R for every two lanes with one lane of Class A on the remaining lane OR 3 lanes of Class A.
4)	13.1 m and above but less than 16.6 m	4	One lane of Class 70R for every two lanes with one lane of Class A for the remaining lanes, if any, OR one lane of Class A for each lane.
5)	16.6 m and above but less than 20.1 m	5	
6)	20.1 m and above but less than 23.6 m	6	

C)Three dimensional model of 80m four span continuous bridge in sap

80m span continuous bridge moving load analysis and dead load analysis was done by using class A loading defined as per IRC 6 on 6 lane road and dynamic amplifications due to moving load compared to dead load was studied. In the same way three curved bridges are modeled which were taken as an arc of circle with same span lengths which subtends an angle of 60, 90, 120 degrees at the centre and parametric comparison was done for the straight bridge and curved bridges. Apart from the amplification of forces and deflections the variations of forces along the bridge was also mentioned. The deck profile for curved bridges was assumed to be an arc of circle making angles 60, 90,120 degrees at the center. In SAP in order to form a circular arc we need to define the bearings at the intermediate points that the tangent of the curve makes with true north. Then all those intermediate points were joined in order to form a circular arc and then the radius of curvature of the circular arc was found out which can be calculated by using trigonometrically calculations as we know the length of the arc and the angle curve makes at the center of the circle.

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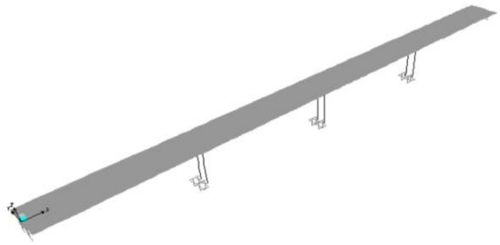


Fig:Three Dimensional Model Of 80m Four Span Continuous Bridge In Sap.

In the same way as defined above for the 60 degree circular arc the radius of curvature and bearings at the pier locations for the 90 and 120 degree curves were found and defined in the horizontal layout line data in order to form circular arcs. For curved bridges the material and section properties were kept constant as that of straight bridge except the layout profile of the deck.

Fig:Plan view of curved model of 60 degree curvature bridge**:**

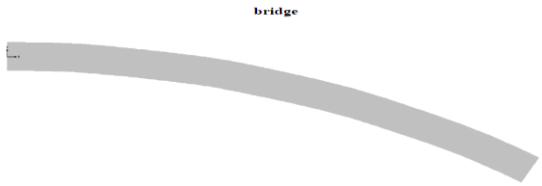
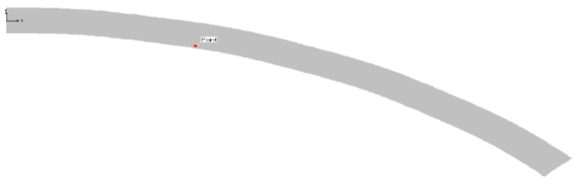
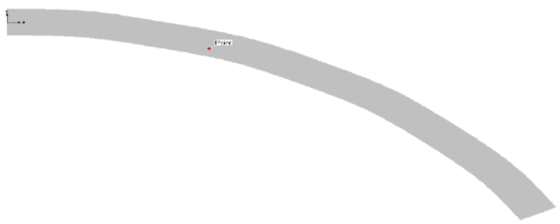
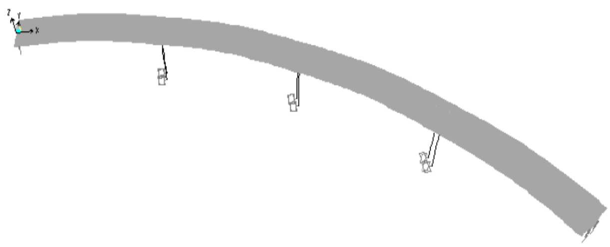


Fig:Plan view of curved model of 90 degree curvature bridge:



Three Dimensional curved model of 120 degree curvature continuous bridge



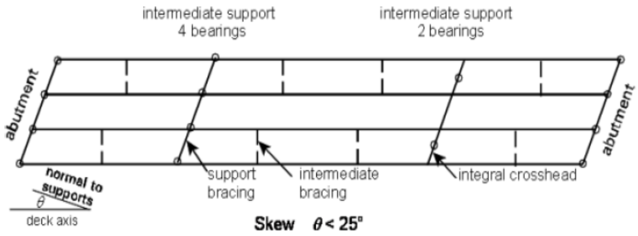


plan view of curved model of 120 degree curvature bridge:

c)Skew bridges

Bridges skew bridges also induce torsional effects depending on the skewness.[It is not always possible to arrange the spans of the bridge perpendicular to the feature; it crosses, particularly when it is needed to maintain a comparatively straight alignment of a road above or below. Thus we need skew bridges. This will increase the length of the spans but more significantly results in the end and intermediate supports to be inclined at an angle to the longitudinal axis of the bridge, rather than perpendicular to it. Like horizontally curved bridges skew bridges also induce torsional effects depending on the skewness.

Skew bridge schematic diagram



Skew angle

Skew angle is the angle made by the pier cap with the transverse axis at that section. Thus for straight bridge skew angle at all supports would normally be the same and the term skew angle is applied to thebridge as a whole but where as for the horizontally curved bridges skew angle is generally different at different supports.

D)GIRDER LAYOUT

In multiple span bridges, the main girders are kept parallel to the longitudinal axis of the bridge. In single span bridges, the main girders are kept parallel to the bridge but if the skew angle is very large i.e if it is more than 45 degrees then the main girders might be placed perpendicular to the abutments.Compared to straight bridges analysis and design of skew bridges are much more complicated .In the skew bridge the length of the span , area of the deck and the length of the pier increases in proportion to the skew angle. If the skew angle is very small then generally it is analyzed as that of a straight bridge with span length equal to the skew span. However, if the skew angle is sufficiently large then there is going to significant effect on the behavior of the bridge especially if the spans of the bridge are of short to medium range.

Fig: Straight bridge with a skew angle 60 degrees

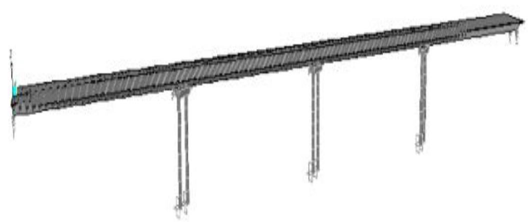


Fig:120 degree curved bridge with a skew angle 60 degrees

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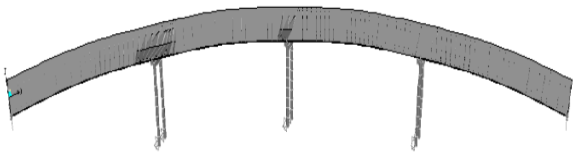


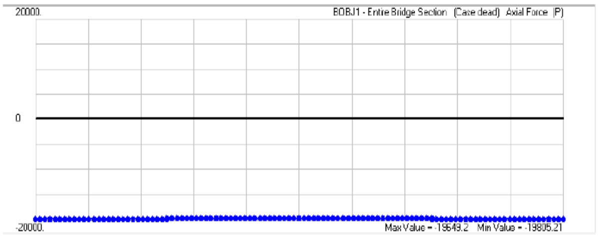
III. RESULTS

Gravity load analysis

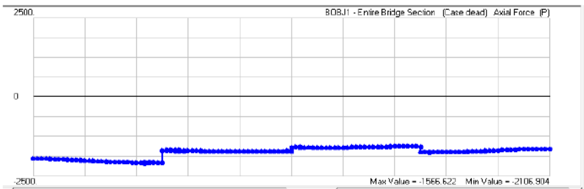
Due to gravity or dead load analysis in straight bridges with no skewness in supports the mass of the bridge is distributed equally about the longitudinal axis and the support reactions are same at the piers on the alternate sides of the bridge and there will not be any eccentricity of the vehicle from the pier, therefore there will not be any torsion induced in the bridge. Where as in horizontal curved bridges due to the eccentricity of the mass from the pier there will be torsion. In the same way in straight and skew bridges there will be torsion in the bridge due to the placement of piers not in the transverse axis of the bridge.

Axial force

A) Variation of Axial force along the straight bridge with no skewness

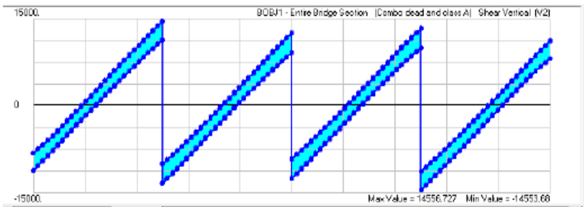


Variation of Axial force along the 120 degree curved bridge with skew angle 60degrees

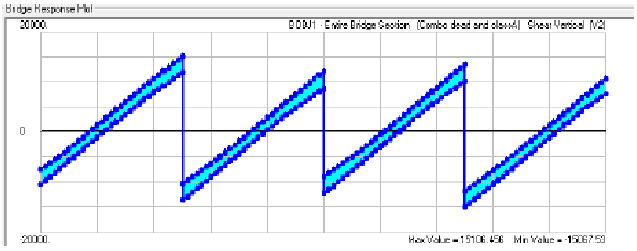


B) VERTICAL SHEAR

Variation of shear force along the straight bridge with skew angle 60degree**:**

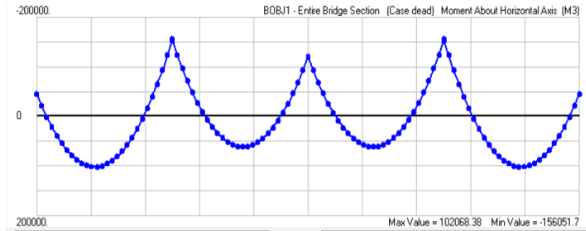


Variation of shear force along the 120 degree curved bridge with skew angle 60 degrees

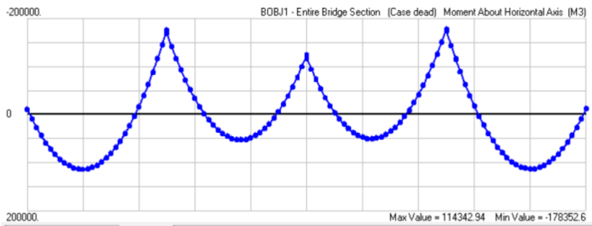


C) MOMENT ABOUT HORIZONTAL AXIS

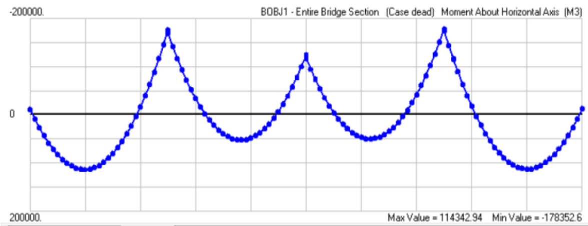
Variation of Moment about horizontal axis along the straight bridge with no skewness



Variation of Moment about horizontal axis along the120 degree curved bridge with no skewness

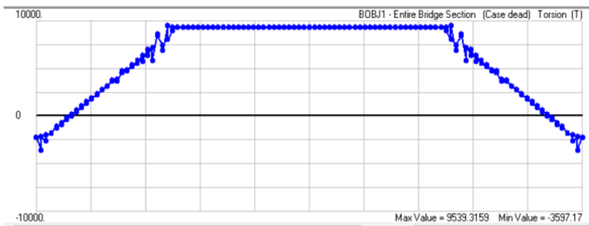


Variation of Moment about horizontal axis along the 120 degree curved bridge with skew angle 60degrees

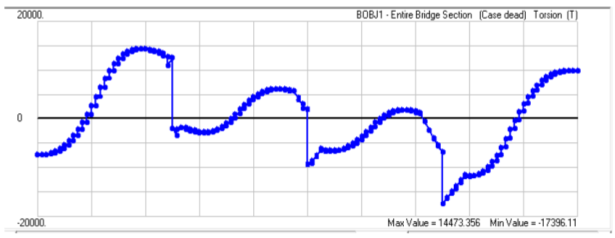


D) TORSION

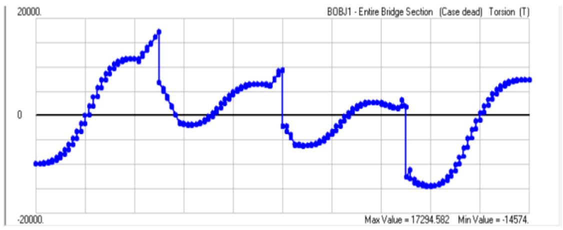
Variation of Torsion along the straight bridge with skew angle 60 degrees



Variation of Torsion along the along the 120 degree curved bridge with no skewness



Variation of Torsion along the along the 120 degree curved bridge with skew angle 60degrees

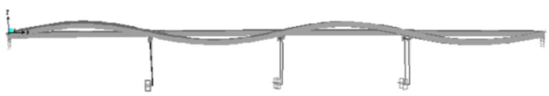


E) *Free vibrational analysis*

Longitudinal mode of vibration

Under the Longitudinal mode of vibration, if the bridge deck is axially stiffened enough then it will behave as a rigid body but if the deck has less axially rigidity there may be internal strains and deformations. With the increase in the subtended angle in curved bridge it was found that there will be increase in the out-of-plane bending moment as compared to the straight bridge. In straight bridges there will be no in-plane bending or torsion due to longitudinal mode of excitation, but in curved bridges there will be in-plane bending moment making the deck to bend in double curvature and the magnitude of this moment increases with the increase in subtended angle. Apart from in-plane bending there will be torsion in the deck.

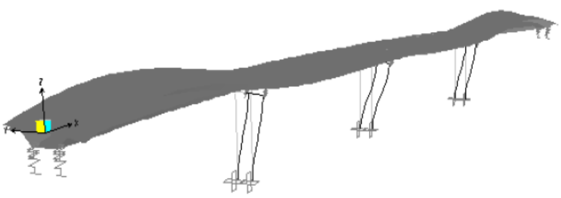
Longitudinal mode of vibration for straight bridge



Transverse mode of vibration

Due to vibration of bridge in transverse mode there may be in-plane bending moment in the bridge deck. Unlike straight bridges due to transverse mode there will be out-of-plane bending moment in horizontal curved bridges and the magnitude of out-of-plane bending moment increases with the increase in the subtended angle of the curve but whereas the in-plane bending moment decreases with the increase in subtended angle.

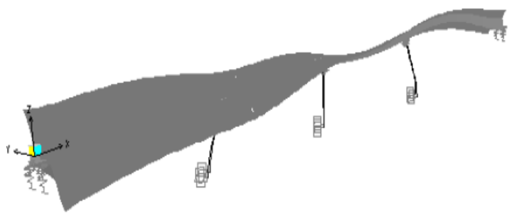
Transverse mode of vibration for straight bridge :



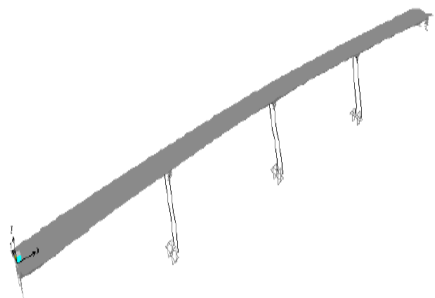
Torsional mode of vibration

In straight bridges due to longitudinal mode of vibration there will be out-of plane bending moment in the straight bridges but where as in horizontal curved bridges the out-of-plane bending moment decreases with the decrease in subtended angle of the curve. Due to curvature there may be slight in-plane bending moment in the bridge deck and there is also chance of torsion in the bridge deck which also increases with the subtended angle of the curve.

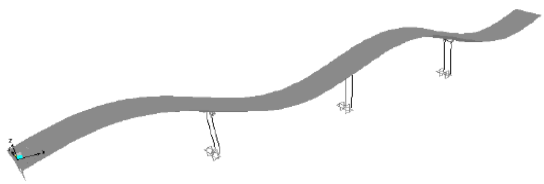
Torsional mode of vibration for straight bridge



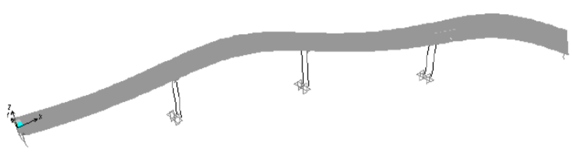
Fundamental mode of straight bridge. (Transverse mode and time period is 1.739 sec)



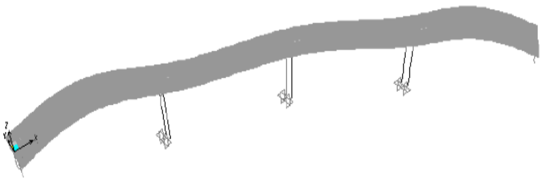
Second mode of straight bridge. (Longitudinal mode and time period is 0.996 sec)



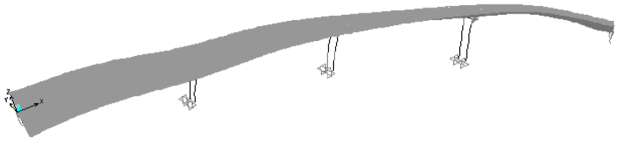
Fundamental mode of 120 degree curved bridge.(Torsional mode and time period is 1.024 sec)



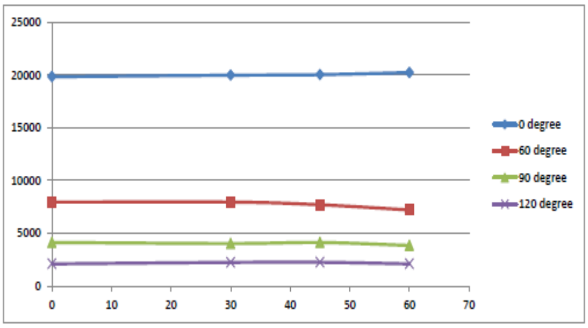
Second mode of 120 degree curved bridge.(Torsional mode and time period is 0.975 sec)



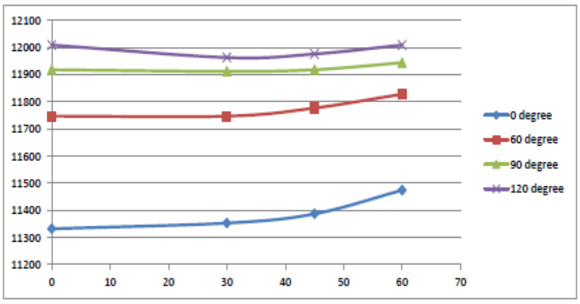
Third mode of 120 degree curved bridge.(Torsional mode and time period is 0.887 sec)



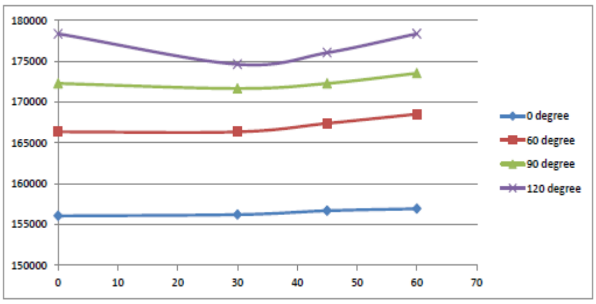
Maximum Axial force (KN) in different curvature bridges with different skew angles:



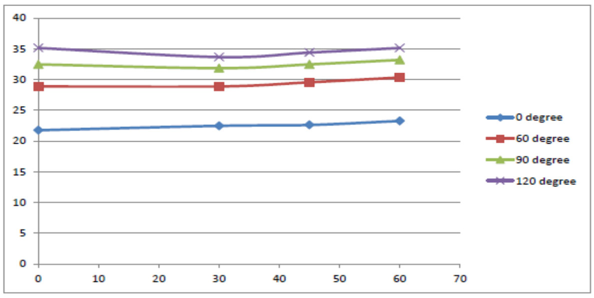
Maximum Axial force (KN) in different curvature bridges with different skew angles



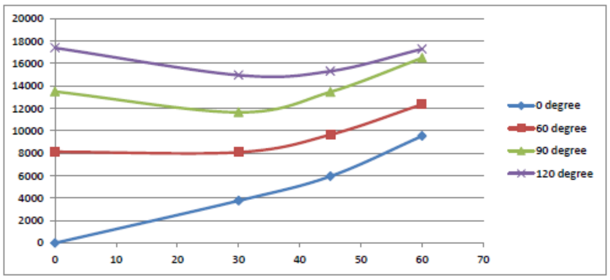
Maximum Vertical shear force (KN) in different curvature bridges with different skew angles



Maximum moment about horizontal axis (KN-m) in different curvature bridges with different skew angles



Maximum Torsion in (KN-m) in different curvature bridges with different skew angles



Maximum Deflection in (cm) in different curvature bridges with different skew angles

IV .CONCLUSIONS

1. Due to dead load analysis variation of axial force almost remains constant for straight, curved and skews bridges along the length but for straight bridge it almost amplifies by 10 times compared to the 120 degree curved bridge and the effect of skew supports on axial force is negligible.
2. Due to dead load analysis variation of vertical shear force and its magnitude remains similar for straight, curve and skew bridges along the length of the bridges. Therefore curvature and skewness has no effect on the vertical shear. Similarly the bending moment variation is also similar for curved and skewed bridges as that of straight bridge and it amplifies about 1.12 times for 120 degree curved bridge compared to straight bridge.
3. Unlike all other parameters torsion is nowhere similar in straight, curved and skew bridges. In straight bridges torsion is almost zero as the mass is distributed uniformly about the longitudinal axis but due to skew supports in straight bridges there is torsion as the supports do not lie along the transverse axis. Due to curvature also there will be torsion and if the skew supports are kept for curved bridges then there will be more amplification in the magnitude of torsion.
5. Due to moving load analysis the variation of axial force, vertical shear force and bending moment seems to be similar and the magnitude of axial force decreases with increase in curvature of the bridge and it amplifies by about 2.34,4.55,8.5 times for straight bridge compared with the 60,90,120degrees bridges respectively.
6. Vertical shear seems to be similar for different curved and skewed bridges with straight bridge and moment is also somewhere similar with amplifications about 1.07, 1.11, 1.14 times in 60, 90, 120 degree curved bridges with straight bridge and skewness has negligible effect on moment.
7. While the torsional moment amplifies by 1.87,

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2.45, 2.87 times respectively in 60, 90, 120 degrees curved bridges compared to straight bridge and 1.4, 1.63, 2.01 times respectively in 30,45,60 skew angle bridges to straight bridge but in bridges with curvature and skew angle the amplifications are negligible compared to curved bridge with no skewness.

8. Deflection increases with increase in curvature almost linearly and with skew angle it does not follow a regular pattern it might decrease or increase on the skew angle.

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