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Free Vibration Analysis of RCC Curved Box Girder Bridges

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Abstract- This paper deals with the study of free vibration frequencies of simply supported reinforced cement concrete (RCC) box girder bridges due to the effects of curvature. Three different types of sections i.e., single, double and triple cells are considered in the analysis. These sections of span of 30 m are modelled using finite element based software SAP2000 v14.0.0. In order to check the validity of the present results, a model, available in literature, is analyzed for dead load bending moment only using linear static method of finite element analysis. A parametric study is carried out for three different models with varying curvature by linear dynamic method of finite element analysis. The curvature of bridge is varied from 0^o to 60^o at an interval of 3^o. It is observed that the fundamental frequency is not varying significantly for single and double cells sections, however it is decreased after 40^o of curvature in the case of triple cell box girder section. This study may be useful to the engineers and designers in the design of RCC curved box girder bridges.

Keywords: RCC box girder bridge, Effect of curvature, Free-vibration frequency, Linear dynamic method, FEM.

1.0 INTRODUCTION

Bridge is a man-made construction carrying moving loads in order to pass through any natural or man-made obstacle. In modern transportation, bridges serve as a life-line.Alignment of roadway sometime needs curves to be introduced due to densely populated cities and preexisting road networks.Circular curves are comfortable and easy to construct in comparison to the other curves thus it is a good choice for design of circular curved bridges. In comparison to the straight bridges, curved bridges are prone to high torsional moment. RCC box girder bridges are widely used due to their high torsional capacity and aesthetics[1]. The most efficient support section for bridges and flyovers is the box shaped support girders, as it provides enhanced structural efficiency, superior stability and serviceability, and also pleasing aesthetic appearance and better economy. For multi-lane bridges, multi-spine and multi-cell box sections are commonly used [2].

A box girder bridge has such good properties but during casting of curved concrete bridge deck, critical design stage occurs. Although box girder offers high torsional stiffness in complete bridge but during construction, its open section is relatively flexible and may not take the loading. For increasing the torsional stiffness, horizontal truss system can be installed at the top flange [3].

In the case of wide flange structures, the longitudinal normal stresses are non-uniformly distributed due to their shear deformation. This makes it essential to checkfor shear for the design of wide flanged structure [4].

Sennah and Kennedy [5] studied someimportant parameters in the design of straight and curved box-girder bridges. The study highlights the important references related to the design of bridges. From the study it is clear that dynamic analysis of the bridges is an important part to be considered in designing. In the past, dynamic analysis of complicated structures were not done separately and thedesigning is done by static analysis only. For dynamic analysis, dynamic amplification factor is to be used which is a function of first flexure frequency. However this method does not give precise result but still was used due to the complicated methods involved in dynamic analysis. In curved bridge, the studies on free vibration are much complicated because the bending vibrations in orthogonal directions are generally coupled with the torsional one [6,7]. This leads to the development of computer based design method to ease the computation and to save the time with more precise results.

SAP2000, a finite element based software is ideal for the analysis and design of structural systems. It is suitable for analyzing the bridge of any type considering moving loads and as well as for dynamic analysis.

On the basis of aforementioned literature, the importance of dynamic behavior can be understood for bridges. With the increasing population and high traffic volume, the choice of curved bridges is better in the development of infrastructure. This paper aims to study the dynamic behavior of curved bridge under free vibration for different width of section. In this study, single and multi-cell box girder bridge sections are chosen.Assuming the material to be linearly elastic theanalysis is performed by finite element analysis. Results from the study show the behavior of frequencies with varying curve for different sections which may provide an understanding of need of the study of dynamic parameter for designing any bridge.

2.0 VALIDATION OF MODELLING

In order to validate the results, a model similar to one published by Gupta and Kumar [1] is considered for the present work. The model is verified for dead load only by linear static method of analysis and the results of dead load bending moments are then compared with the pre-existing results presented by Gupta and Kumar [1].

For a single cell box girder bridge, the Han-Jiang bridge located at Shayang in Wahan China with its actual dimensions is considered for the study. It is a straight 10.8m wide simply supported bridge over a span of 27.4m having overall depth of 2.96m. The dimension of whole cross-section is shown in Fig. 1. The material properties of concrete considered are:

Poisson's ratio= 0.2
Density of concrete= 25 kN/m^3
Characteristic compressive strength= 25 MPa
Modulus of elasticity= 2.5×10^7 kN/m^3

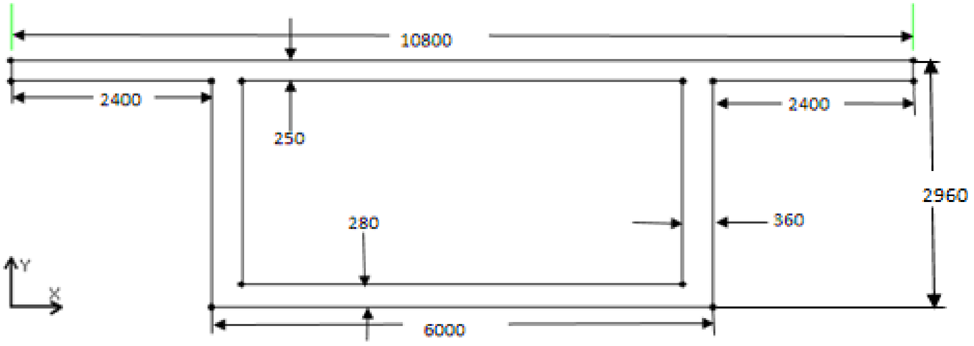


Fig 1: Cross-section of Han-Jiang bridge (dimensions are in mm)

Various bridge models are found to be established by varying the degree of curvature. The central curvature angle (θ) which can be understood better in Fig. 2. The curvature of bridge is varied from 0^o to 48^o at an interval of 12^o.

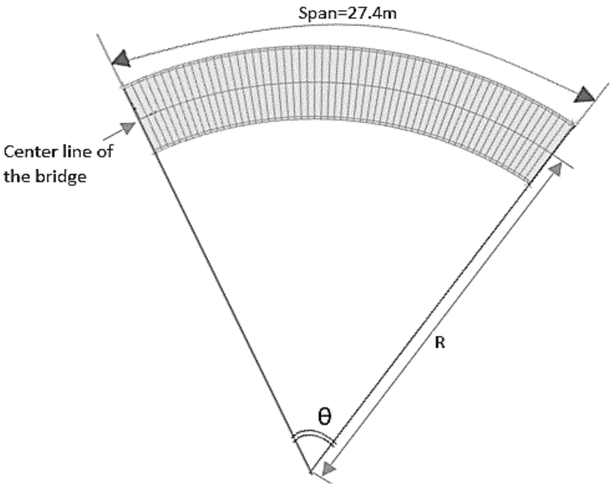


Fig 2:Bridge geometry showing reference parameters

A four noded shell element having six degrees of freedom at each node is used for modelling the bridge. Bridge has been discretized with a mesh size of 20 cm. Linear static (elastic) finite element method is considered for the analysis of bridge using SAP2000 to determine the dead load bending moment.The results of the present study and the results published by Gupta and Kumar [1] are presented in Table 1.

TABLE 1:COMPARISON OF RESULTS

Absolute maximum dead load moments (kN-m) in outerand inner girders of bridge										
Curve angle & type of girder	0 degree		12 degree		24 degree		36 degree		48 degree	
	Outer Girder	Inner Girder	Outer Girder	Inner Girder	Outer Girder	Inner Girder	Outer Girder	Inner Girder	Outer Girder	Inner Girder
Gupta & Kumar [1]	7294	7294	7965	6696	8724	6161	9592	5681	10593	5251
Present results	7295	7295	7954	6710	8720	6167	9600	5674	10593	5254
% variation	0.01	0.01	0.14	0.21	0.04	0.10	0.08	0.12	0.00	0.06

3.0 RESULTS AND DISCUSSION

To minimize the computational error and to select the minimum mesh size in the finite element discretization, a convergence study is carried out on a single cell straight bridge section. The vertical maximum displacement of bridge is determined with varying mesh size which is shown in Fig. 3. It is observed that the displacement is not going to change significantly after the mesh size of 18cm. This mesh size is used further to discretize the models of box girder bridges.

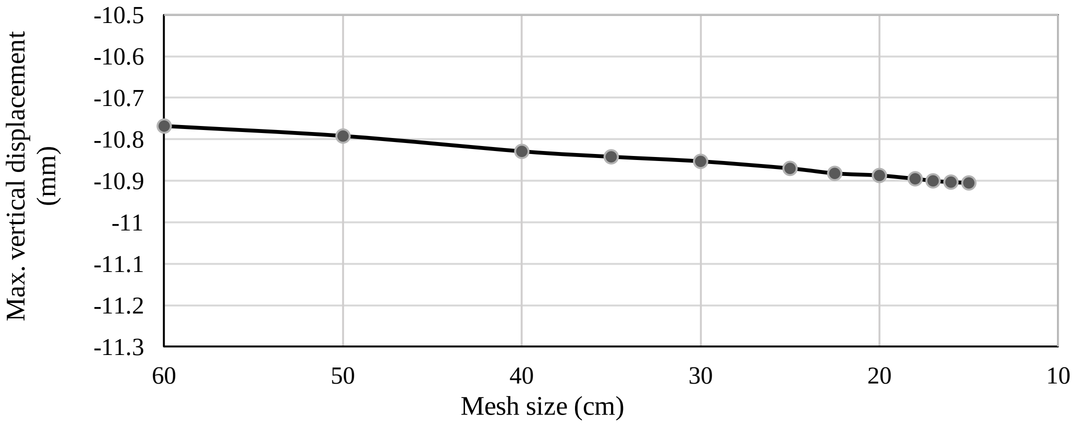


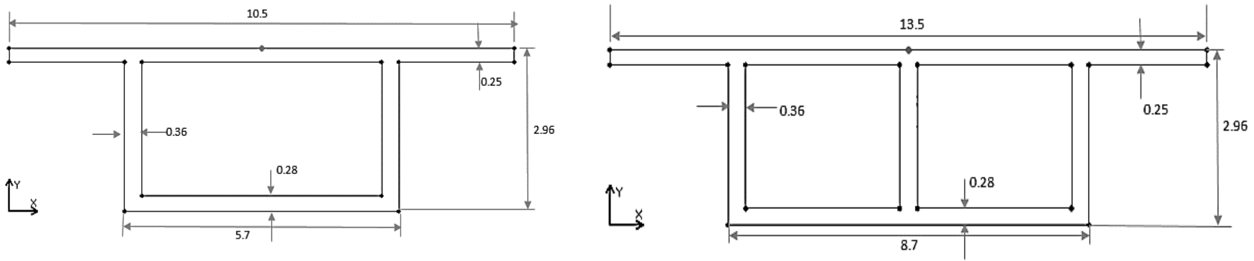
Fig 3: Convergence study

Three different models of single, double and triple cells are considered for the study with varyingwidth of bridge and a span of 30m. The curvature of bridge is varied from 0^o to 60^oat an interval 3^o for each section.

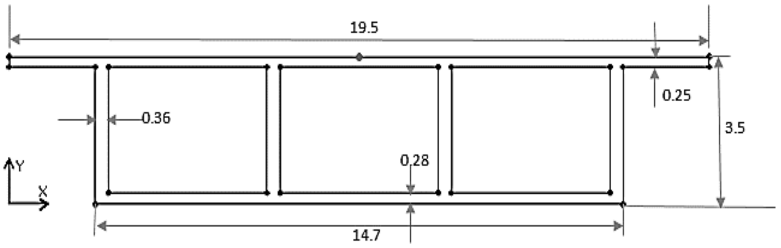
Boundary condition is kept as simply supported by providing a hinge support and a roller support on either side of each girder. The material properties considered are:

Characteristic strength= 25 MPa
Unit weight= 25 kN/m^3
Modulus of elasticity= 25×10^3 MPa
Poisson's ratio= 0.2

The cross-sectional diagrams of all three bridge sections are shown in Fig. 4.



Single cell box girder bridge   Double cell box girder bridge



Triple cell box girder bridge

Fig 4:Cross sections of all three bridge models (all dimensions are in meters)

In the analysis, linear elastic deformations are considered and three dimensional linear dynamic analysis is performed using four noded shell element having six degrees of freedom at each node as shown in Fig. 5.

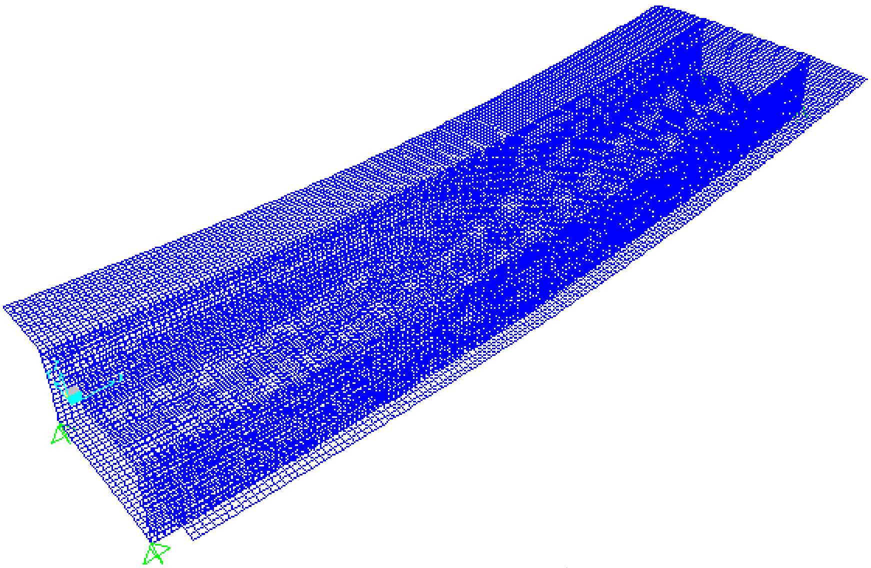


Fig 5: Single cell box girder bridge for 0^o curve (straight)

The bridge model is a continuous mass system and has infinite degrees of freedom. Hence it has infinite number of possible modes. According to IS 1893:2016 (part 1), the number of modes to be used in the analysis should be such that the sum total of modal masses to be at least 90 percent of total seismic mass. Considering this, the presentstudy is carried out for first 10 modes onlyand the obtained results are illustrated in figures for single, double and triple cells bridge sections. The results of fundamental frequency of three different cells are presented in Table 2.

The variation of frequency with the curvature in single cell box girder bridge for all ten modes are shown in Fig.6. The variation of frequency with the curvature double cell box girder bridge for all ten modes are shown in Fig. 7. The variation of frequency with the curvature triple cell box girder bridge for all ten modes are shown in Fig. 8. From the results, it is observed that in single (Fig. 6) and double (Fig. 7) cells, there is no significant changes in the fundamental frequency with the variation of curve. The figures representing the first mode in single and double cell RCC box girder bridges are nearly straight line. In triple cell box girder bridge, the fundamental frequency is found to be decreased after 40^o angle which is also shown in Fig. 8. It shows that when the number of lane increases, the fundamental frequency is necessary to be analyzed at higher degree of curves since it reduces and needs to be checked for safe design.

TABLE 2:FUNDAMENTAL FREQUENCIES OF SINGLE, DOUBLE AND TRIPLE CELLS BOX GIRDER BRIDGE

Degree of curve	Single cell	Double cell	Triple cell
0	1.9831	2.6193	3.6005
3	1.9836	2.6200	3.6042
6	1.9854	2.6210	3.6032
9	1.9826	2.6184	3.6288
12	1.9864	2.6217	3.6009
15	2.0130	2.6223	3.6036
18	1.9849	2.6521	3.6007
21	1.9868	2.6232	3.5991
24	1.9877	2.6243	3.6288
27	2.0097	2.6267	3.6016
30	1.9902	2.6274	3.6250
33	2.0105	2.6296	3.5967
36	1.9938	2.6292	3.6159
39	1.9942	2.6578	3.5798
42	1.9975	2.6357	3.5524
45	2.0006	2.6364	3.4871
48	2.0018	2.6406	3.3834
51	2.0034	2.6655	3.2559
54	2.0218	2.6476	3.1278
57	2.0103	2.6490	3.0013
60	2.0126	2.6503	2.8782

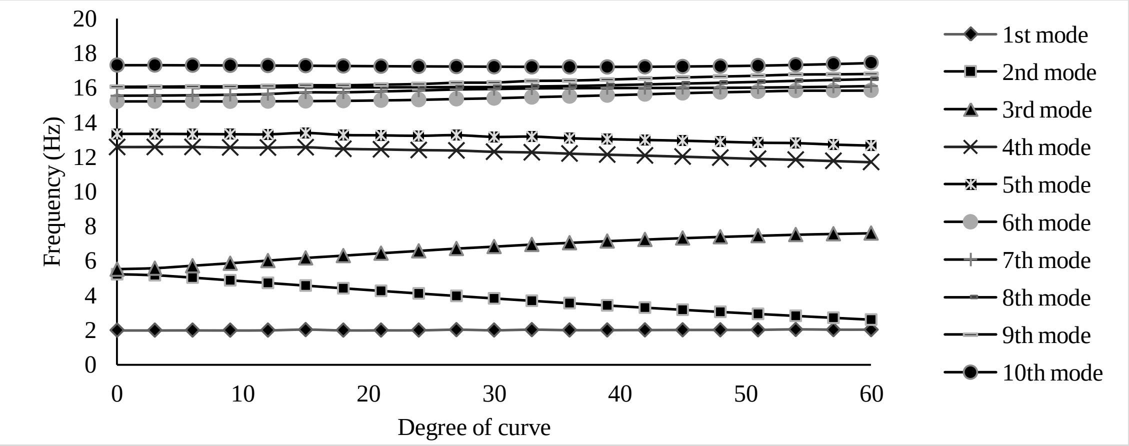


Fig 6: Single cell box girder bridge

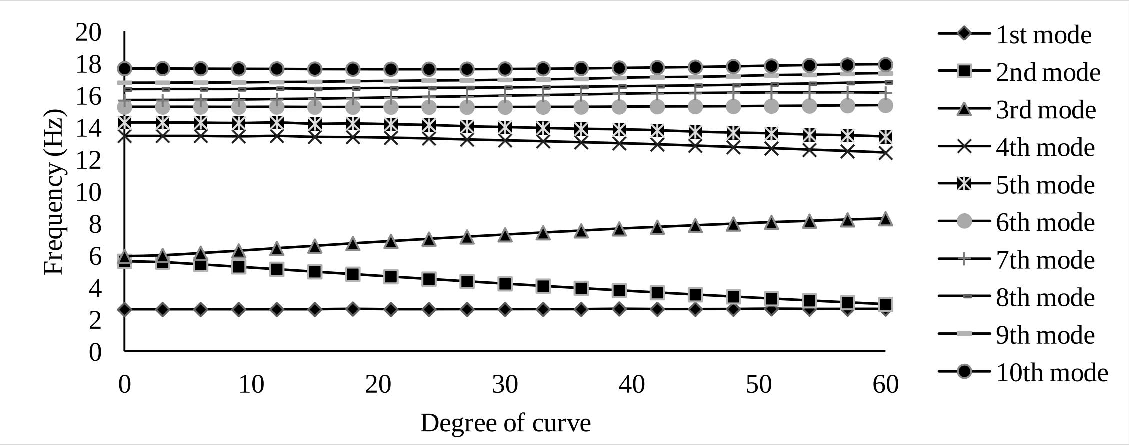


Fig 7: Double cell box girder bridge

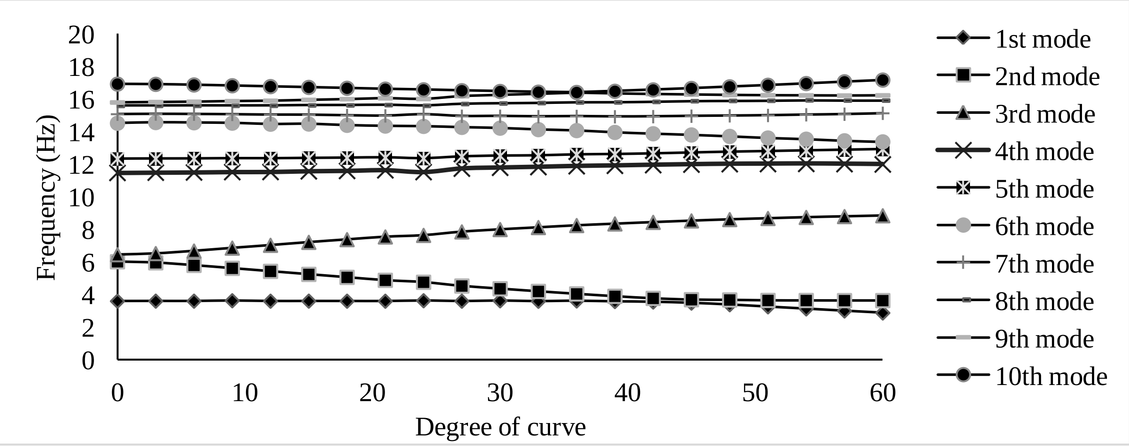


Fig 8:Triple cell box girder bridge

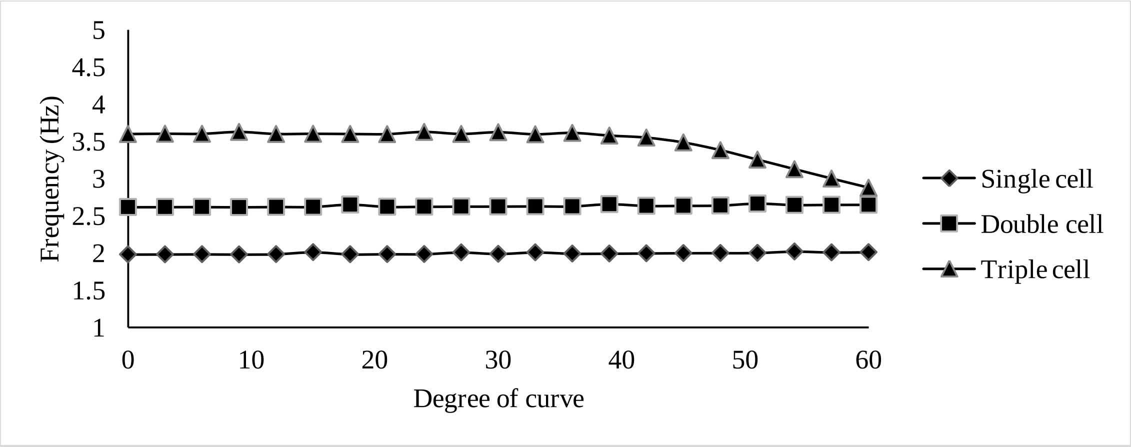
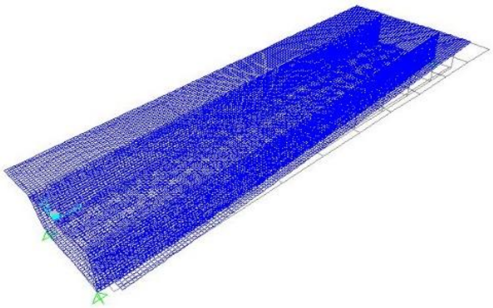
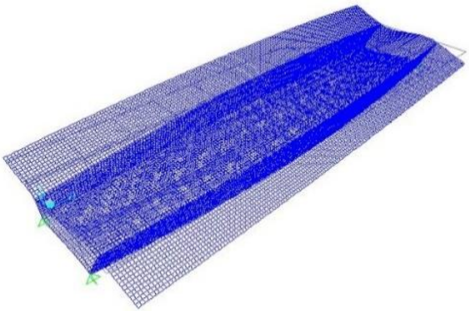


Fig 9:Fundamental frequencies of three different bridges

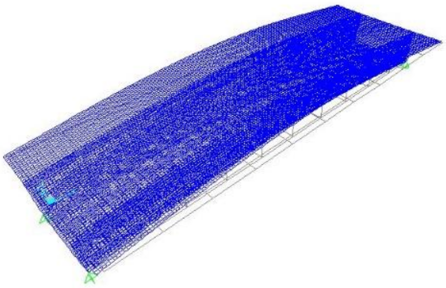
When compared the fundamental frequencies of all three bridge sections above, fundamental frequencies of single, double and triple cells box girder bridges are found to be increased by increasing the number of cell and it is clearly observed in Fig. 9. It is also observed that when the frequency of triple cell box girder bridge reduces with the increase in curvature of the bridge, it is coming close to the frequency of double cell box girder bridge. Fig. 10 shows the mode shapes of a single cell box girder bridge for first ten modes. The values of natural frequency for different modes are also presented in Fig. 10.



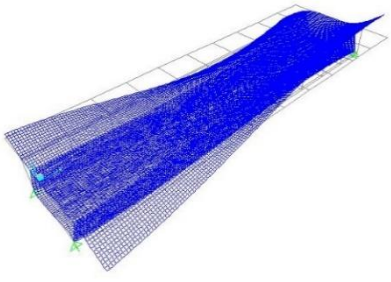
Fundamental mode (f_1=1.9831 Hz)



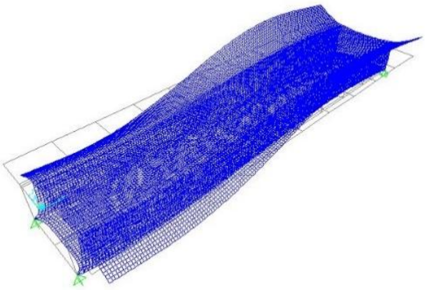
Second mode (f_2=5.2158 Hz)



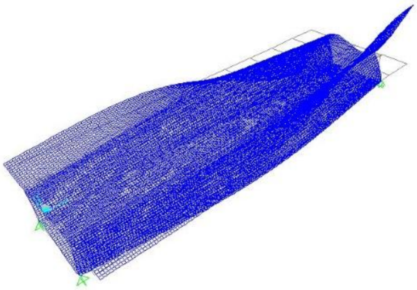
Third mode (f_3=5.5051 Hz)



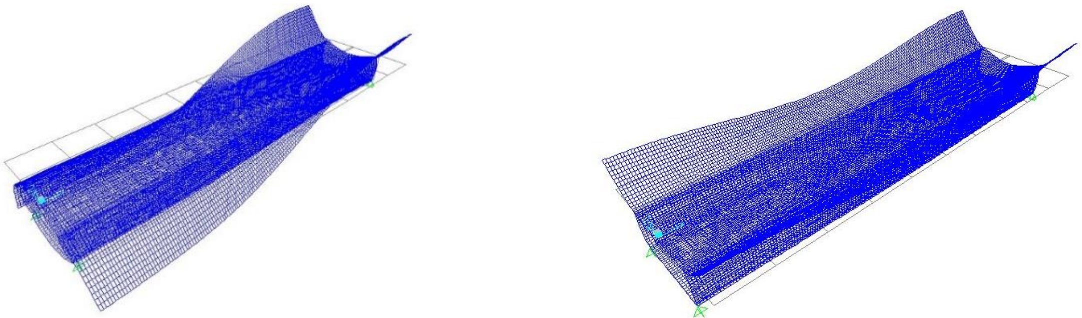
Fourth mode (f_4=12.5710 Hz)



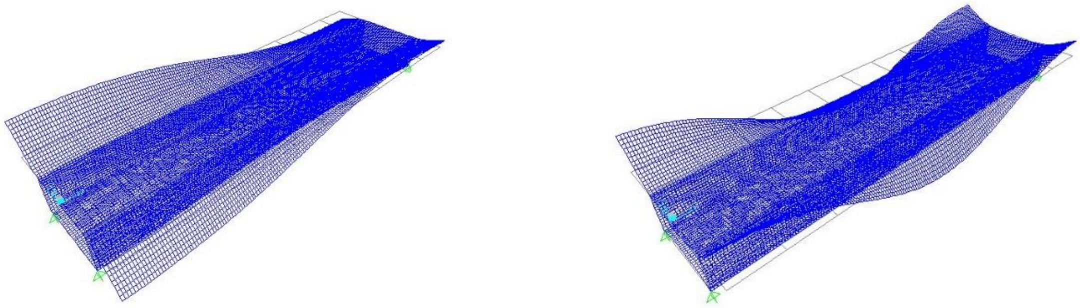
Fifth mode (f_5=13.3250 Hz)



Sixth mode (f_6=15.2160 Hz)



Seventh mode (f_7=15.5320 Hz) Eighth mode (f_8=16.033 Hz)



Ninth mode (f_9=16.0530 Hz) Tenth mode (f_{10}=17.3070 Hz)

Fig 10:Mode shapes of a single cell straight box girder bridge

4.0 CONCLUSIONS

The effect of curvature on the frequency of a span simply supported RCC box-girder bridge has been examined in which the central curvature angle is varied from 0° to 60° at an interval of 3°. The three-dimensional (3D) modeling of box-girder bridges are analyzed using finite element based software (SAP2000) by linear dynamic method. Based on the study carried out so far, the following conclusions are drawn:

- Increasing cell number can increase the stiffness of the bridge.
- The fundamental frequency of bridges increases about 32% for single to double cell, about 41% for single to triple cell and about37% for double to triple cell when considering straight bridges (for different width of bridge).
- For large width of bridge, fundamental frequency reduces depending upon its width and number of cells.
- Frequency in triple cell box girder bridge is reduced up to 20% and for higher width of bridges (more number of cells) it may be reduced more for higher degrees of curve.

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