Dynamic Behavior of Integral Bridges using Sap 2000- A Comparative Study

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Abstract- The response of bridges under a moving vehicle is complex due to the interaction between bridge and the vehicle. As the bridge deck surface deteriorates over time, the road surface roughness profile will vary accordingly. The varying surface roughness profiles over time will generate increased dynamic loads on the bridge decks through dynamic interaction between surface roughness, vehicles of heavy traffic and bridge structures. The present study aims to characterize the effects of the time-varying dynamic loads from heavy traffic and bridge performance. The paper presents the results of dynamic analysis of both the concrete girder bridge with suspension cable bridge and infer which type will be dynamically stable.Both bridges contain AASHTO type girders and were designed to carry two lanes of HS20 loading. The vehicular load was HS-20 truckloads, designed to deliver the ultimate live load specified by the AASHTO Code. The dynamic load were performed with the vehicle traveling at 23 m/s, 46 m/s, and 92 m/s speed.

Keywords – Sap 2000, Suspension Cable Bridge, Concrete Girder Bridge, Dynamic Analysis, moving loads.

I. INTRODUCTION

A bridge is a structure built to span physical obstacles such as a body of water, valley, or road, for the purpose of providing passage over the obstacle. There are many different designs that all serve unique purposes and apply to different situations. Designs of bridges vary depending on the function of the bridge, the nature of the terrain where the bridge is constructed and anchored, the material used to make it, and funds available to build it.

The first bridges were made by nature itself as simple as a log fallen across a stream or stones in the river. The first bridges made by humans were probably spans of cut wooden logs or planks and eventually stones, using a simple support and crossbeam arrangement. Some early Americans used trees or bamboo poles to cross small caverns or wells to get from one place to another. A common form of lashing sticks, logs, and deciduous branches together involved the use of long reeds or other harvested fibers woven together to form a connective rope capable of binding and holding together the materials used in early bridges.

The Arkadiko Bridge is one of four Mycenaean corbel arch bridges part of a former network of roads, designed to accommodate chariots, between Tiryns and Epidauros in the Peloponnese, in Greece. Dating to the Greek Bronze Age (13th century BC), it is one of the oldest arch bridges still in existence and use. Several intact arched stone bridges from the Hellenistic era can be found in the Peloponnese in southern Greece.

Fig 1: The Arkadiko Bridge in Greece (13th century BC), one of the oldest arch bridges in existence

The greatest bridge builders of antiquity were the ancient Romans. The Romans built arch bridges and aqueducts that could stand in conditions that would damage or destroy earlier designs. Some stand today. An example is the Alcntara Bridge, built over the river Tagus, in Spain. The Romans also used cement, which reduced the variation of strength found in natural stone. One type of cement, called pozzolana, consisted of water, lime, sand, and volcanic rock. Brick and mortar bridges were built after the Roman era, as the technology for cement was lost then later rediscovered.The Arthashastra of Kautilya mentions the construction of dams and bridges. A Mauryan bridge near Girnar was surveyed by James Princep. The bridge was swept away during a flood, and later repaired by Puspagupta, the chief architect of Emperor Chandragupta I. The bridge also fell under the care of the Yavana Tushaspa, and the Satrap Rudra Daman. The use of stronger bridges using plaited bamboo and iron chain was visible in India by about the 4th century. A number of bridges, both for military and commercial purposes, were constructed by the Mughal administration in India.

Although large Chinese bridges of wooden construction existed at the time of the Warring States, the oldest surviving stone bridge in China is the Zhaozhou Bridge, built from 595 to 605 AD during the Sui Dynasty. This bridge is also historically significant as it is the world’s oldest openspandrel stone segmental arch bridge. European segmental arch bridges date back to at least the Alcontar Bridge (approximately 2nd century AD), while the enormous Roman era Trajan’s Bridge (105 AD) featured open-spandrel segmental arches in wooden construction. Rope bridges, a simple type of suspension bridge, were used by the Inca civilization in the Andes mountains of South America, just prior to European colonization in the 16th century. During the 18th century there were many innovations in the design of timber bridges by Hans Ulrich, Johannes Grubenmann, and others. The first book on bridge engineering was written by Hubert Gautier in 1716. A major breakthrough in bridge technology came with the erection of the Iron Bridge in Coalbrookdale, England in 1779. It used cast iron for the first time as arches to cross the river Severn.

With the Industrial Revolution in the 19th century, truss systems of wrought iron were developed for larger bridges, but iron did not have the tensile strength to support large loads. With the advent of steel, which has a high tensile strength, much larger bridges were built, many using the ideas of Gustave Eiffel.In 1927 welding pioneer Stefan Brya designed the first welded road bridge in the world, the Maurzyce Bridge which was later built across the river Sudwia at Maurzyce near owicz, Poland in 1929. In 1995, the American Welding Society presented the Historic Welded Structure Award for the bridge to Poland.

The objectives are:-

- To analyze a proposed bridge structure as concrete girder bridge and a suspension cable bridge subjected to moving vehicles.
- To compare the dynamic response of the concrete girder bridge with suspension cable bridge and infer which type will be dynamically stable for proposed structure.

II. FINITE ELEMENT ANALYSIS

SAP2000 is a general purpose finite element program which performs the static or dynamic, linear or nonlinear analysis of structural systems. It is also a powerful design tool to design structures following AASHTO specifications, ACI and AISC building codes. These features and many more make SAP2000 the state-of-the-art in structural analysis program.

BRIDGE DESCRIPTION AND GEOMETRY

It is proposed to construct Kundanoor Bridge connecting Kundanoor and Vytilla across Kochi kayal under Ernakulam Division. Two numbers of 33.132 m and one number of 47.112m spans are proposed for the new bridge with footpaths on either side. The total width of the bridge shall be 11.225 m including footpaths. The MFL is +99.900m, the vertical clearance of the bridge above MFL is proposed to be 7m (the stream is National Water Way), and a girder depth of 2.75m. Therefore, the formation level of the bridge is +109.650m (99.900m+7.00m+2.75m), 47.07 m span placed at center portion of the proposed bridge and it is made horizontal. The remaining two spans each are placed on either sides of the central span. Thus the two spans and approach roads on either side are proposed at a gradient of 1 in 20 so as to merge with the existing road.

A Finite Element model for the bridge was developed in order to obtain the bridge deck response under dynamic loads. SAP2000 software was employed to establish the finite element model (FEM). The dimensions and material properties which were used in this model follow the above bridge.

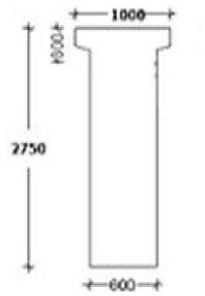
Slab

Thickness of slab = 250 mm

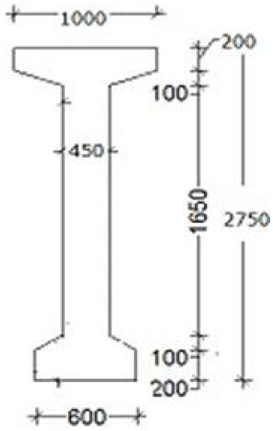
Main girder

The girder dimensions are as follows:

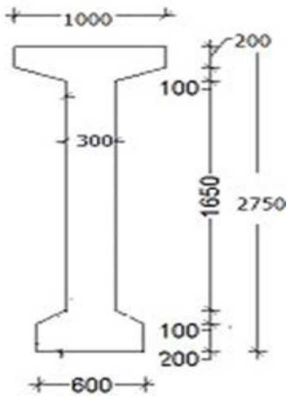
1. *T Girder*



2. *Average I Girder*



3. I Girder



Cross Girder

The girder dimensions are as follows:

- End Cross Girder = 150 x 450
- Average end Cross Girder = 125 x 450
- Average Cross Girder = 125 x 300
- Cross Girder = 150 x 300

Support condition

Continuous Girders and slabs at Pier locations and integrated to the abutment pile cap at end.

Concrete Girder Bridge

The concrete girder bridge was modelled in SAP2000 software.

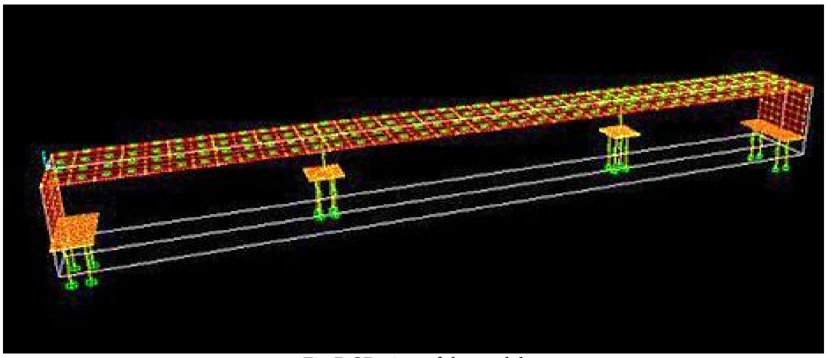


Fig 7: 3D view of the model

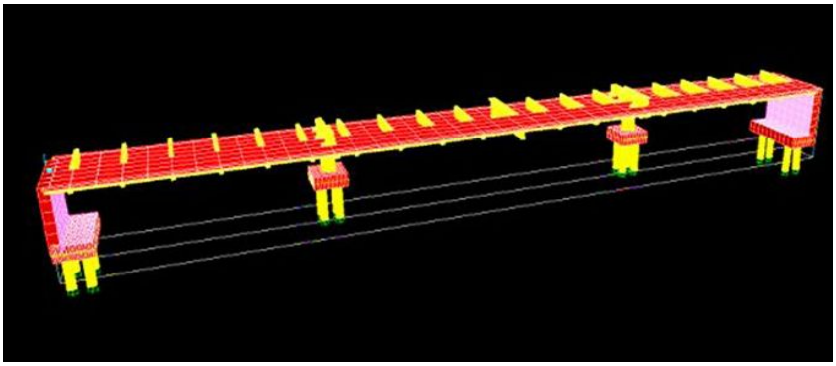


Fig 8: 3D extruded view of the model

Suspension Cable Bridge

The suspension cable bridge was modelled in SAP2000 software.

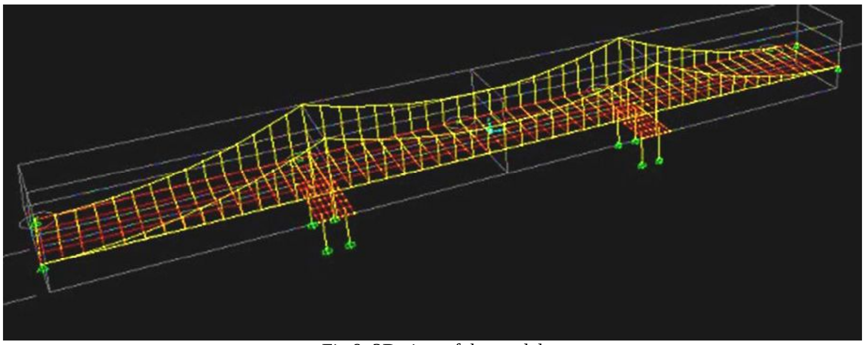


Fig 9: 3D view of the model

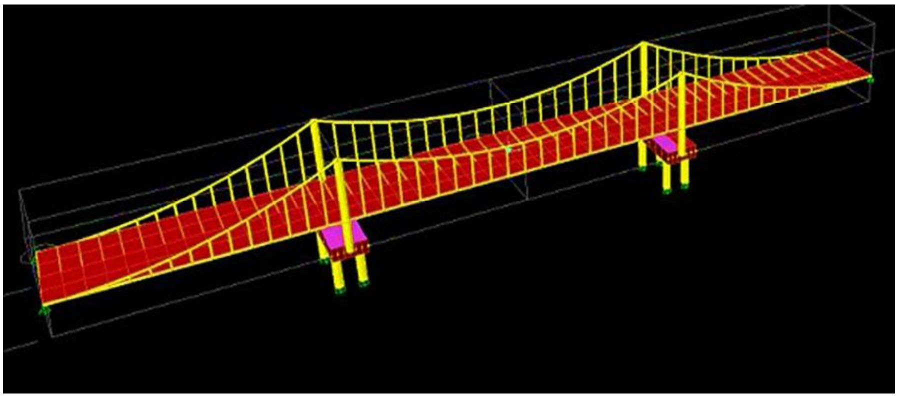


Fig 10: 3D extruded view of the model

III. DYNAMIC ANALYSIS

Loading is another important stage in the analysis. Total deck slab area is selected and gravity loading is applied. Regarding moving load they are applied on paths which are to be defined by the user. So paths are defined manually and applied over the desired location and vehicle is also defined. Loadings are defined as per IRC class AA loading and properties are applied over it. Further analysis can be done. The first one is the dead load and the next one is the moving load.

Dynamic Vehicle Loading Analysis

Here we are considering for AASHTO HS20-44 or Alternate Military Loading (Interstate Loading), whichever produces the worst condition on the structure. The speed given at the start is 23m/sec. After 6 seconds the speed is increased to 46m/sec. Also after 11 seconds of time the speed is increased to 92m/sec for maximum loading for the structure.

The truck loads first used had the designation of H20 (see Figure), which covered a two-axle truck weighing 20 tons. The front axle carried 8,000 pounds and the rear axle, 14 feet away, carried 32,000 pounds. The 1944 edition included the HS20 truck load and started a policy of affixing the year to loadings making HS20-44 the official designation. The additional S made an allowance for heavier tractor-trailers that were available at the time. Figure 2 describes the load and load spacing for HS20-44.

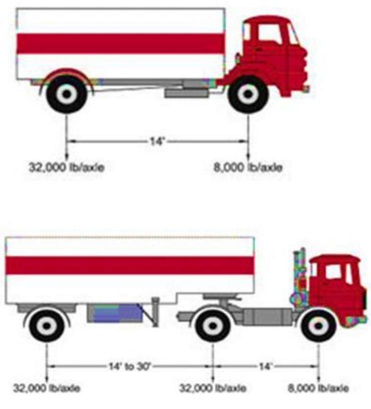


Fig 11: HS20 truck

Modal Analysis

In structural engineering, modal analysis uses the overall mass and stiffness of a structure to find the various periods at which it will naturally resonate. These periods of vibration are very important to note in earthquake engineering, as it is imperative that a building's natural frequency does not match the frequency of expected earthquakes in the region in which the building is to be constructed. If a structure's natural frequency matches an earthquake's frequency, the structure may continue to resonate and experience structural damage.

Although modal analysis is usually carried out by computers, it is possible to hand-calculate the period of vibration of any high-rise building through idealization as a fixed-ended cantilever with lumped masses.

IV. RESULTS AND DISCUSSIONS

Finite element analysis using SAP 2000 was conducted to investigate the structural response of concrete girder bridge and suspension cable bridge subjected to moving vehicles. The results obtained are as shown below:-

Dynamic Vehicle Loading Analysis

The deformation diagram of both the bridges obtained are given below:-

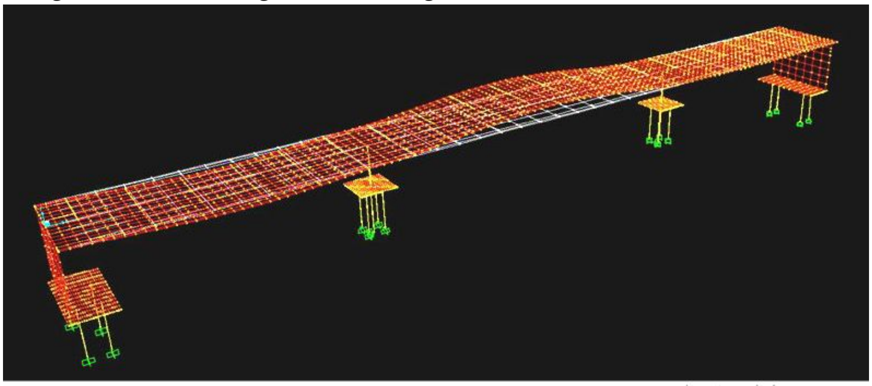


Fig 13: Deformation Diagram of concrete girder bridge due to Moving Vehicle

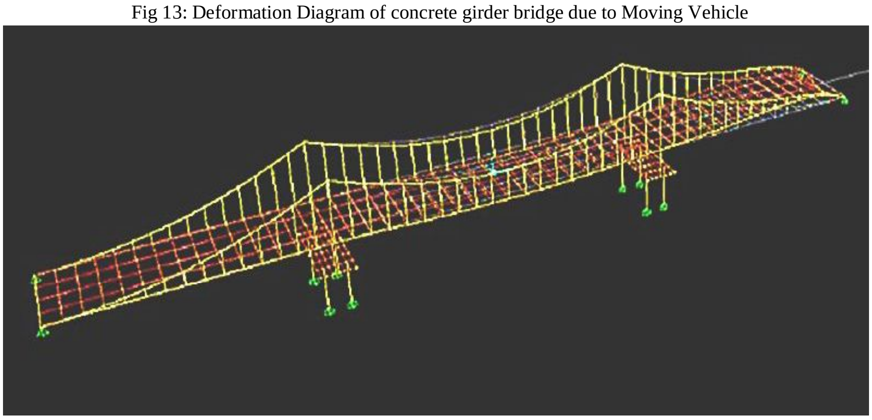


Fig 14: Deformation Diagram of suspension cable bridge due to Moving Vehicle

The deflected values of concrete girder bridges as well as the suspension cable bridges obtained from SAP 2000 for each second is tabulated below:

Table 1: Comparison of deflected values

Time(sec)	Concrete girder bridge(m)	Suspension Cable bridge(m)
1	1.024×10^{-4}	4.34×10^{-4}
2	1.792×10^{-4}	0.001
3	2.341×10^{-4}	0.002
4	2.739×10^{-4}	0.003

5	3.715 x 10^{-4}	0.004
6	3.848 x 10^{-4}	0.076
7	5.657 x 10^{-4}	0.157
8	5.712 x 10^{-4}	0.231
9	5.811 x 10^{-4}	0.302
10	8.398 x 10^{-4}	0.384
11	9.402 x 10^{-4}	0.386

The deformations obtained due to same loading condition at each second for concrete girder bridge is lesser than that obtained for suspension Cable Bridge.

The moments of concrete girder bridges as well as the suspension cable bridges obtained from SAP 2000 is tabulated below:-

Table 2: Comparison of Moments

Type of bridge	Moment in longitudial direction (kNm)	Moment in transverse direction (kNm)
Concrete girder bridge	1071.583	441.424
Suspension cable bridge	975.954	406.784

The moments obtained due to same loading condition for suspension cable bridge is lesser than that obtained for concrete girder bridge.

Modal Analysis

Mode shapes of Concrete Girder Bridge

The first three natural vibration modes of concrete girder bridge is as shown below:-

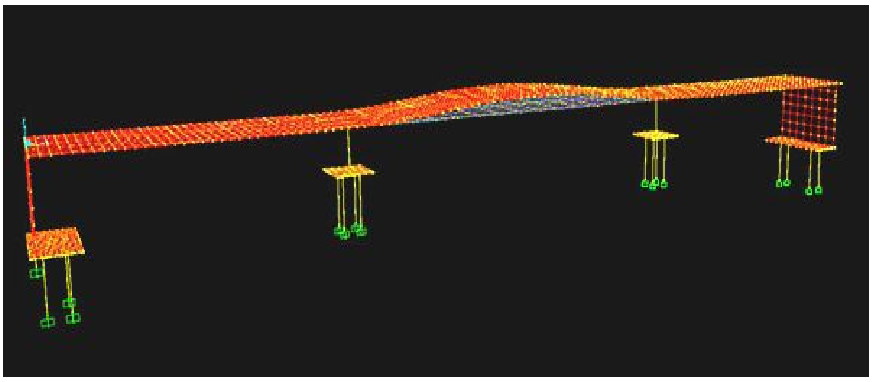


Fig 15: Mode Shape 1

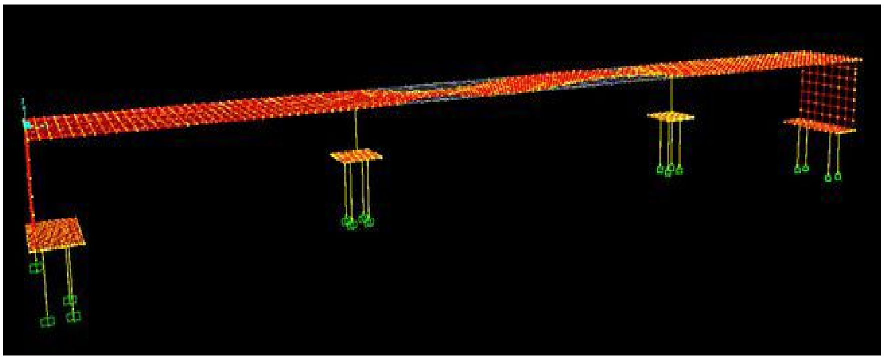


Fig 16: Mode Shape 2

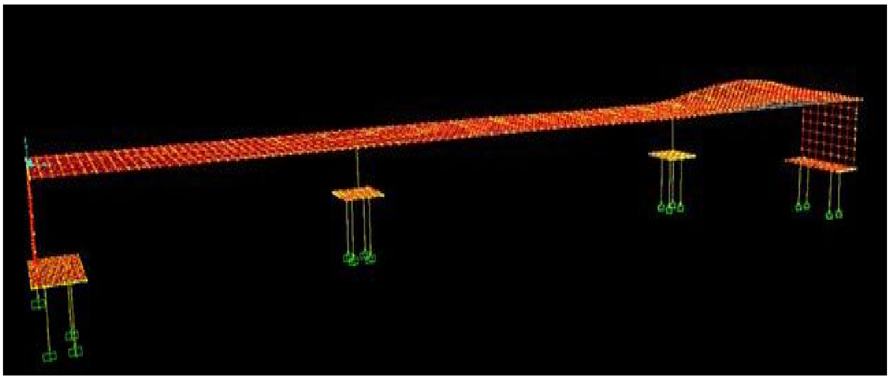


Fig 17: Mode Shape 3

Mode shapes of Suspension cable bridge

The first three natural vibration modes of suspension cable bridge is as shown below:-

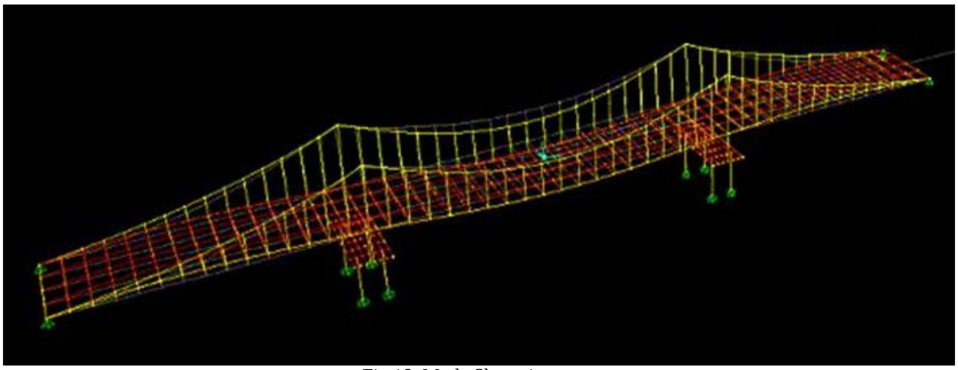


Fig 18: Mode Shape 1

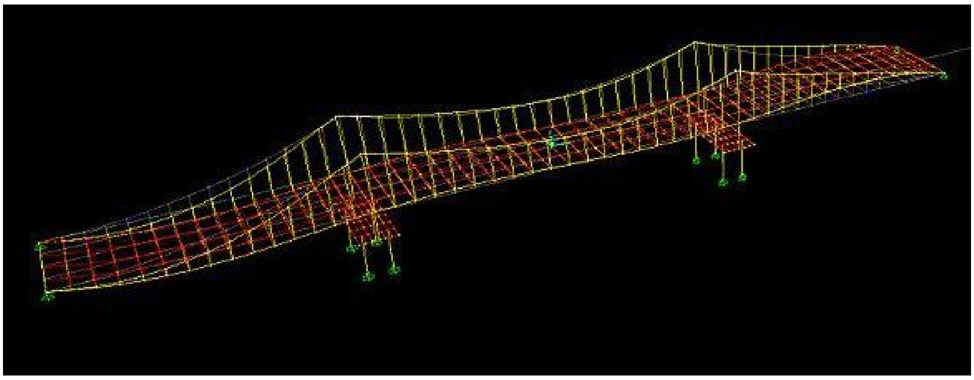


Fig 19: Mode Shape 2

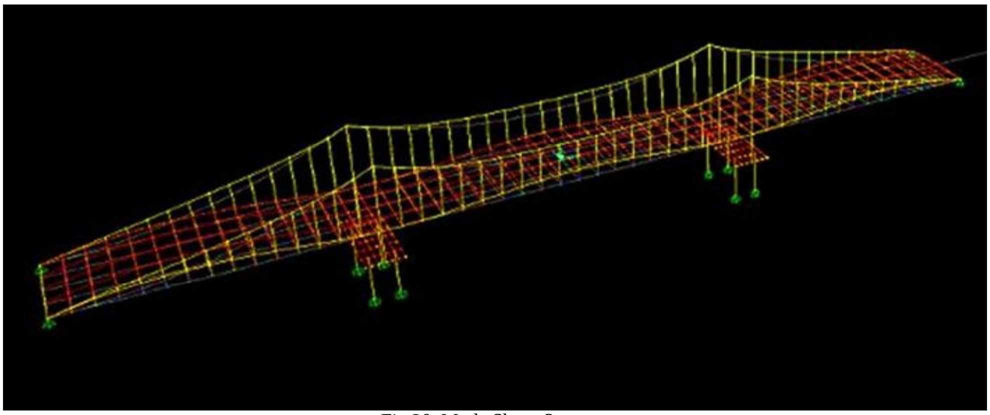


Fig 20: Mode Shape 3

The frequencies of concrete girder bridges as well as the suspension cable bridges obtained from SAP 2000 is tabulated below:-

Table 3: Comparison of Frequencies

Mode no:-	Concrete girder bridge(cycles/sec)	Suspension cable bridge(cycles/sec)
1	0.30870	0.38444
2	0.31843	0.59850
3	0.43331	0.87078
4	0.45006	0.88381
5	0.52491	0.88603
6	0.64004	1.24105
7	0.84500	1.25874
8	1.02553	1.26744
9	1.08757	1.52942
10	1.09653	1.63317

11	1.10396	1.72438
12	1.15434	1.75872

From the mode shapes obtained from SAP 2000 it is clear that the values of the frequencies for suspension bridges are generally larger than those for continuous concrete girder bridges.

V. SUMMARY AND CONCLUSIONS

In this paper, a comparison of dynamic response of concrete girder bridge and suspension cable bridge was studied. For that the proposed bridge structure was modelled and analyzed as concrete girder bridge and suspension cable bridge using software SAP 2000.

From the bending moment values and deflections obtained, the suspension cable bridge provides lesser moments and high deflections as compared to that of concrete girder bridge for the same vehicle loading condition.

The values of the frequencies of suspension bridges are generally larger than those of continuous concrete girder bridges.

Finally, it is inferred that continuous concrete girder bridge has the advantage of good stability for heavy vehicles and economical in comparison with the suspension cable bridge.

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