Analysis of a Cable-Stayed Suspension Hybrid Bridge Considering Vehicular Loading using CSI Bridge

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ABSTRACT

Cable-stayed bridges are built for providing connectivity over obstacles such as rivers, mountains, flyovers over rotary squares and valleys for a long span. Cable stayed bridge provides ample stability and utilises structure material and further its advantages goes in for cheap maintenance and design. Design of the bridge is highly dependent on its function and purpose and the nature of terrain of the site.

A bridge type known as a suspension bridge has its deck suspended by vertical suspenders and suspension cables. The main structural elements of a suspension bridge system are stiffening girders/trusses, main suspension cables, main towers, and cable anchorages at each end of the bridge. Vertical suspenders sustain the weight of the deck and the traffic load, while the main cables are stretched between towers and eventually connect to the anchorage or the bridge itself. The superstructures of suspension bridges are constructed utilising the cable erection technique similarly to other cable-supported bridges.

Keywords : Cable Stayed Bridge (CSB); Suspension Bridge (SB); Cable Stayed Suspension Hybrid Bridge (CSSHB),Pylon, Seismic Analysis ,CSi Bridge.

I. INTRODUCTION

Long span bridge are increasing day by day to facilitate the need of construction projects. Cable stayed bridges and suspension bridges are the systems used to achieve long span bridges. The spans of cable-supported bridges range from 200 to 2000 metres. The greatest span of a cable-supported bridge system is determined by the density, stiffness, and strength of the materials utilised. In the design and analysis of cable-stayed bridges and suspension bridges, high strength steel cables are a key component, which is superior for effective tension resistance. The advantages of a cable-supported bridge are in the way that the system uses the materials.

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A suspension bridge is a form of bridge in which the deck is suspended on vertical suspenders from below suspension cables. In the early 1800s, the first examples of this kind of bridge were constructed in the modern era. In many hilly areas of the world, simple suspension bridges with no vertical suspenders have a long history.

Thousand years ago, people cross water bodies with the help of cable attached with wooden block. It was born of cable stayed and suspension bridge but mainly cable stayed bridge developed in 1595 and commonly used in 19th century. In early days, Cable Bridge was constructed with combination of suspension bridge and cable stayed bridge. In 1808 an American inventor named James give the born of modern cable bridge. Two cables are used over the top of many towers and anchoring this chain on the either side of bridge structure. Although suspension bridges and cable stayed bridges are quite similar, the main distinction between the two is how the deck force is transferred to the cable in a suspension bridge. In a cable stayed bridge, the cable is connected directly to the deck. Because of its low weight, improved aesthetics, and long span designs, cable stayed bridges have gained popularity. The primary purpose of a cable-stayed bridge is to handle its own weight and impending traffic loads safely while also being aesthetically beautiful and demonstrating excellent serviceability under any conceivable load scenario. Steel wire cable is used to suspend a cable stayed bridge deck. The top vertical towers are fixed with these cables, which transmit shear force to the vertical members, which then transform it into compression force.

In this study, three distinct cases—a suspension bridge, a cable-stayed bridge, and a hybrid cable-stayed suspension bridge—are largely examined. CSI Bridge's analytical application was used to model the data and conduct the analysis while accounting for seismic and vehicle loading.

Suspension Bridge

In a suspension bridge a deck is supported by vertical hangers, which are connected to main catenary cables. These primary catenary cables are cradled by pylons and secured at an anchor point at the end of the span. Modern suspension bridges can cross greater lengths than any other type of bridge because they are lightweight, aesthetically beautiful, and strong. They are also some of the most expensive to build. Although suspension bridges can be built to be sturdy enough to accommodate freight trains, they were almost all created with vehicular traffic in mind.

Vertical loads are carried by tensioned, curved cables in suspension bridges. These loads are passed to the anchorages, which must withstand the inward and occasionally vertical pull of the cables, as well as the towers, which carry them by vertical compression to the ground. The towers are the only parts of the suspension bridge that are in compression, making it appear as an upside-down arch under tension. The deck must be carefully controlled to prevent excessive movement because it is suspended in the air. Therefore, the deck needs to be either heavy, stiff, or both.

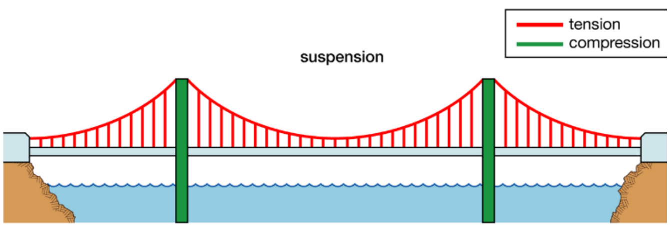


Fig 1 Suspension Bridge

II. Objectives of the research

The main objective of the research is to study the behaviour of cable-stayed bridge, suspension bridge and Cable-Stayed Suspension Hybrid Bridge. To accomplish the objectives, following studies are analyzed-

- Seismic behaviour of cable stayed bridge, suspension bridge and hybrid bridge

- To determine the effectiveness of hybrid bridge in comparison to suspenson and cable stayed bridge.
- To determine the stability of all the thee cases considering vehicular loading as per I.R.C.

To determine the utilization of Csi bridge software considering Indan Codal Provision.

III. Review of Literature Summary

Rajni Verma and Rashmi Sakalle (2022) in the research paper, girder Bridge and cable stayed bridge was modelled and comparative analysis was carried out for dynamically loading conditions. A comparison was made between bridges for dead load,live load and combined load. Structural analysis was done to determine internal forces, stresses and deformation of structure under various load effects. the modelling and analysis of both the cases was performed using analytical application SAP 2000.

The support response in the Cable stayed bridge is 1091.65 K.N., whereas the Girder bridge is 1427.87 K.N., indicating that stresses are properly distributed in the Cable stayed bridge scenario. As a result, in the case of a cable-stayed bridge, the support reaction is 21.11 percent lower. Based on the results of the moment, forces, and deflection given in the preceding chapter, it can be concluded that a Cable Stayed bridge is more stable in resisting load. When comparing the cost of a cable-stayed bridge to the cost of a girder bridge, the cable-stayed bridge is 18% more expensive. The results showed that the cable-stayed bridge was more stable and adequate for big loads, while the girder bridge was more cost effective.

Chao Zhang et.al (2021) The cable-stayed bridge with diamond concrete pylons' lateral seismic fragility assessment was provided in a research study. The prototype bridge is a standard cable-stayed bridge with a diamond-shaped pylon. The SAP2000N platform has a three-dimensional FE model of the prototype CSB. The weak points of pylons and piers are identified using capacity demand ratios. According to the bending moment-curvatures, the plastic hinge in the FEM simulates all weak points. Four alternative limit states (LSs) and damage indices for each component of the CSB are defined.

The fragility curves of the bridge system on the lower and upper bounds exhibit little variation in SD states and MD states, according to the seismic fragility study of the bridge system. These are seen in the ED and CD states, though, where each component's failure probability is different. The entirety of a cable-stayed bridge is vulnerable to minor and moderate damage. Additionally, the fragility of the entire bridge as a whole is greater than the fragility of any one system component.

IV. Methodology

Step 1 research papers were analyzed from different authors who have investigated behaviour of cable stayed bridge and suspension bridge on different loading conditions. Different tools were used for understanding the behaviour of the models and the values were validated on ground of axial load, omen and bending moment using SAP2000 and Staad.Pro, while some authors calculated the values manually.

Step 2 Designing the model of all the three cases using CsiBridge where the materials, tendons, bent design, section data, bridge restrainer data, foundation spring data, bridge bearing data and bridge abutment data is defined and analyzed.

Step 3 Defining material properties for three bridges where the material properties were predefined via Csi bridge application for concrete, steel and tendons.

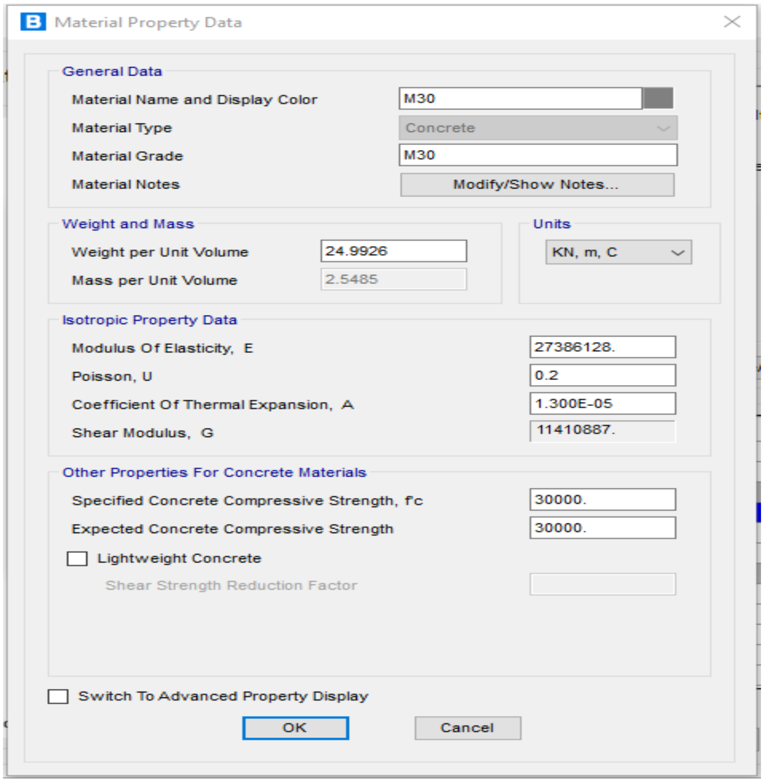


Fig 2 Defining concrete property

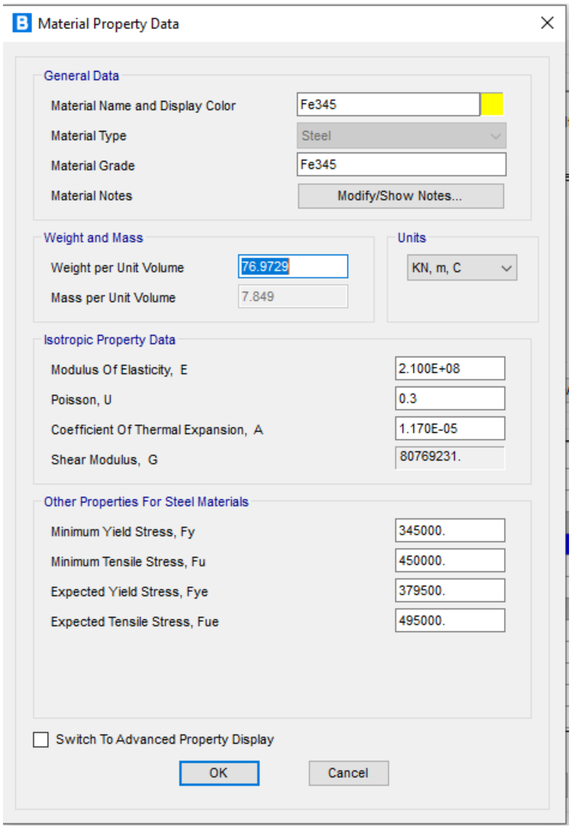


Fig 3 Defining Steel Property

Step 4 Defining Bridge Bent data as cap beam length of 9.15m with number of columns as 1 and single bearing line is considered for continuous superstructure.

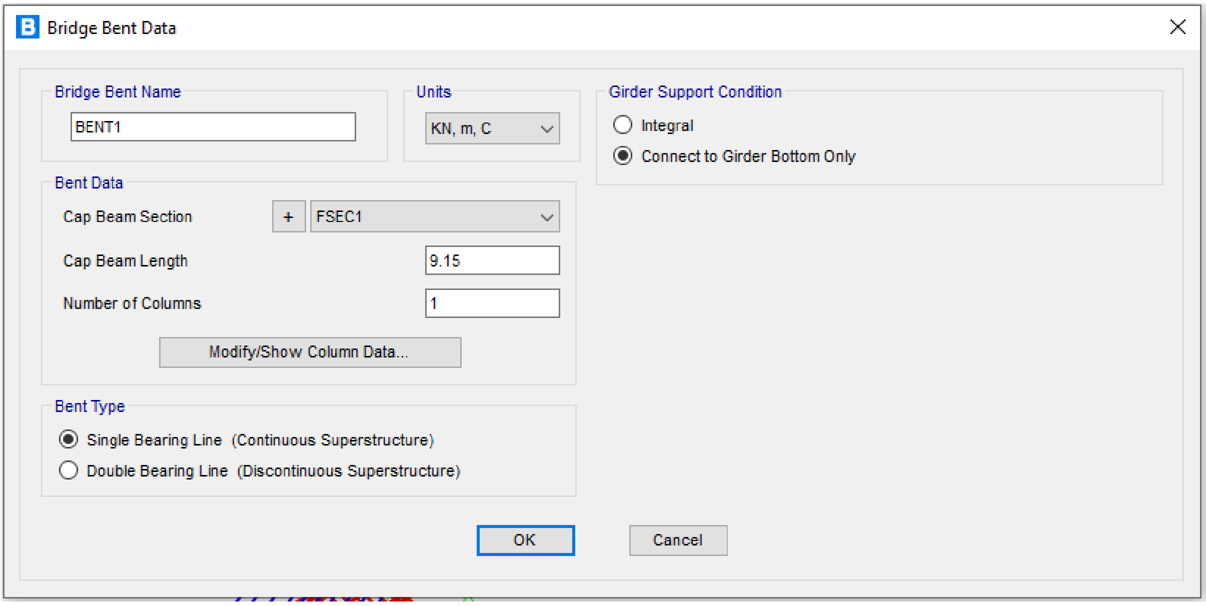


Fig 4 Bridge Bent Design

Step 5 Defining Bridge Bearing data. A bridge bearing is a component of a bridge which typically provides a resting surface between bridge piers and the bridge deck. The purpose of a bearing is to allow controlled movement and thereby reduce the stresses involved. Here in this step a customized name is given to bridge bearing along with its defining units and consider support property for link.

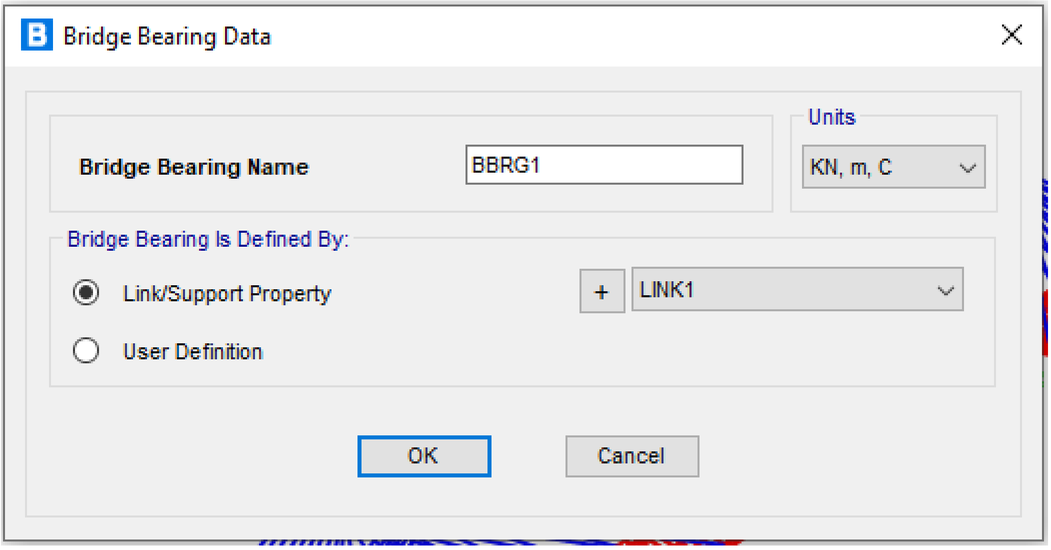


Fig 5 Bridge Bearing Data

Step 6 In order to maintain the embankment and transfer the vertical and horizontal stresses from the superstructure to the foundation, abutments are employed at the ends of bridges. Here the abutment is connected to the girder along with the foundation spring substructure.

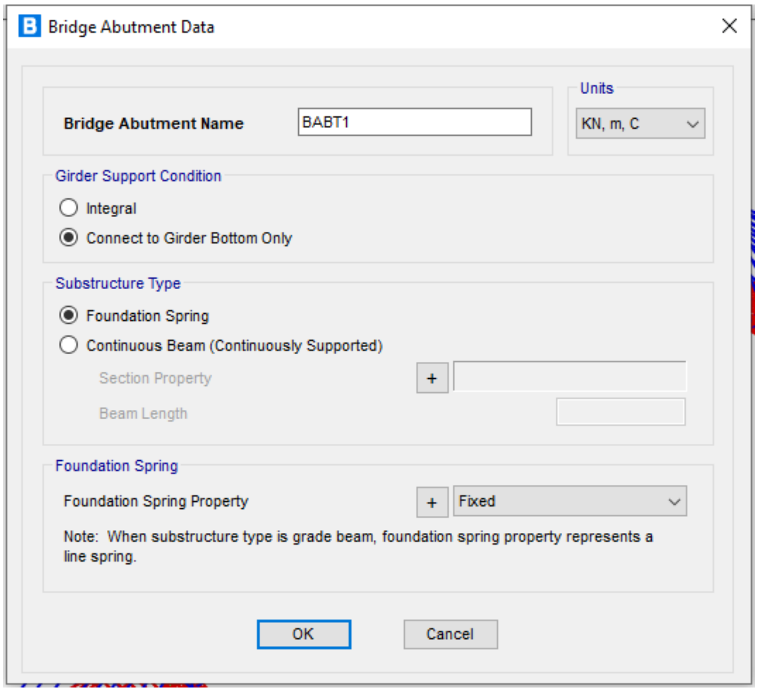


Fig 6 Bridge Abutment Data

Step 7 Defining Foundation Spring Data which is user defined as fixed release type

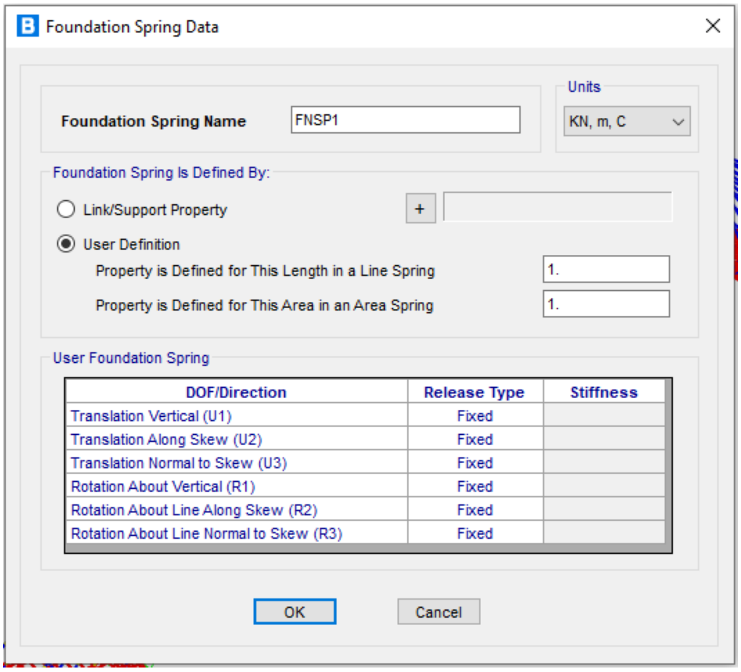


Fig 7 Foundation Spring Data

Step 8 Defining Bridge Restrainer Data. Restrainers are used to reduce deck unseating over sub structures due to earthquakes. The main effect of restraints upon global bridge motions is found to constrain and redistribute the relative distances between adjacent vibrations units. The bridge modeller enables modelling of cable bridges. Here the restrainer length and area is defined.

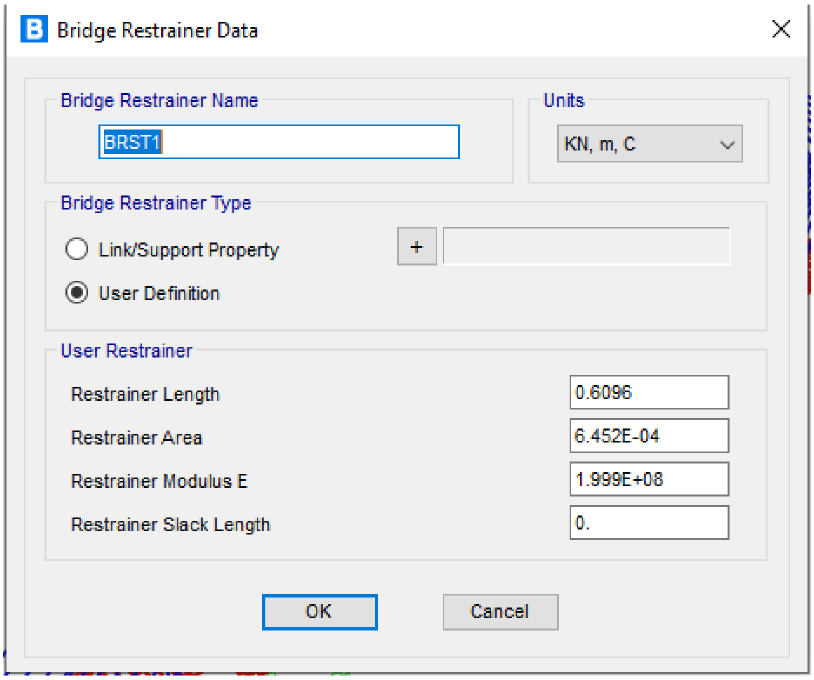


Fig 8 Bridge Restrainer Data

Step 9 Defining lane data for deck.

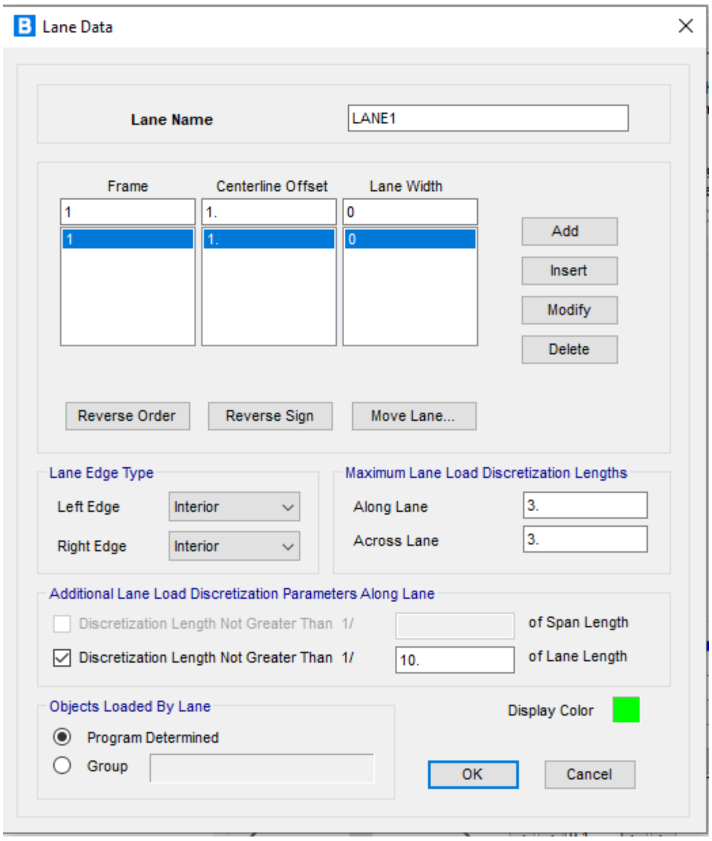


Fig 9 Lane Data

Step 10 Defining section properties for tendons and here the tendons size was similar in all the three cases.

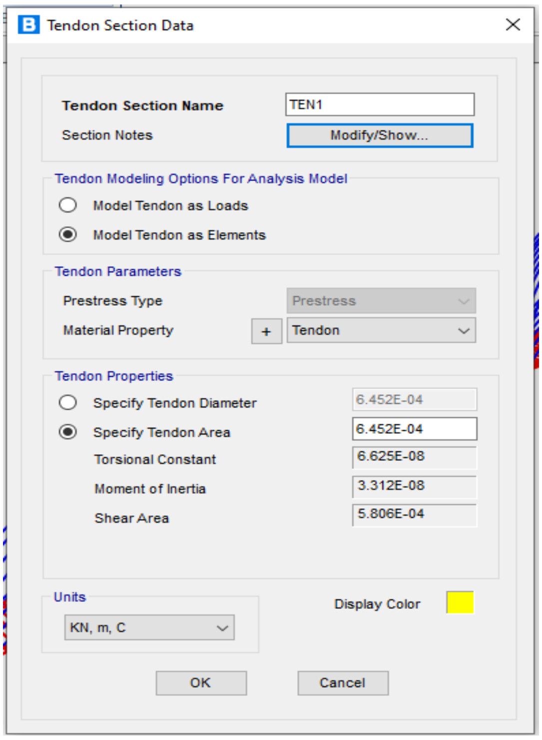


Fig 10 Tendons section Data

Step 11 Defining vehicular data for vehicular loading condition

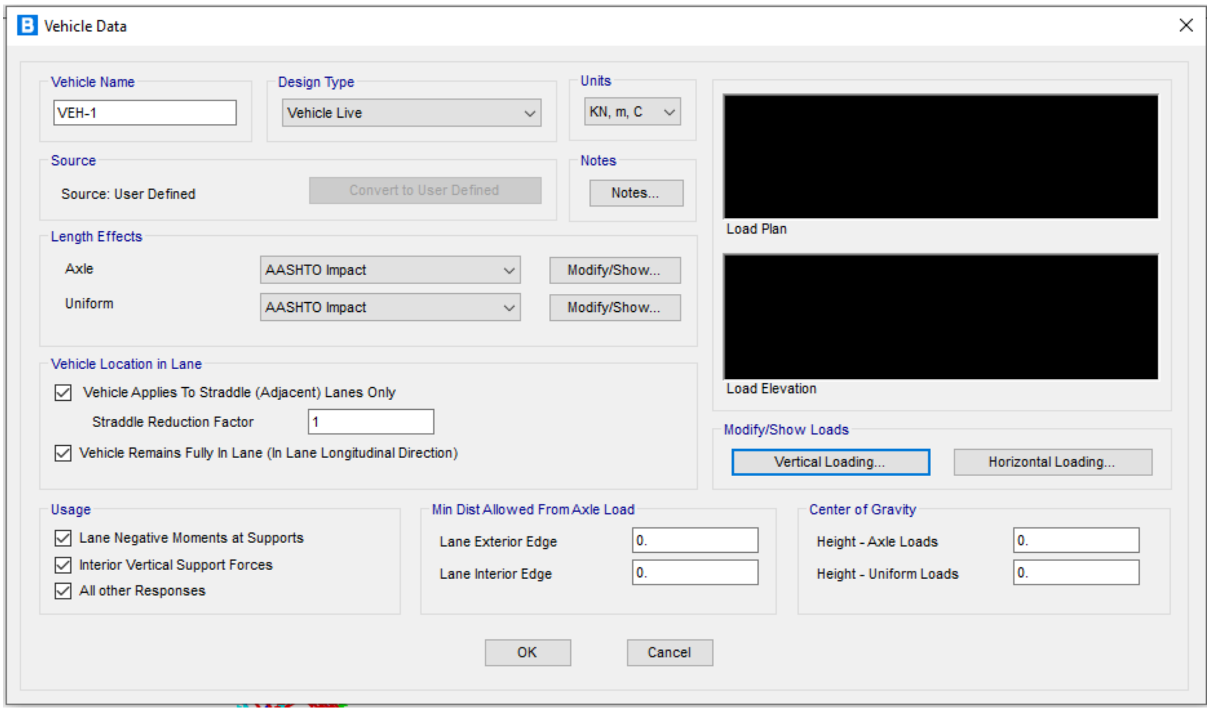


Fig 11 Vehicle Data

Step 12 Defining and assigning loading condition along with vehicular loading condition as per IRC 6 and seismic load as per IS 1893:2016.

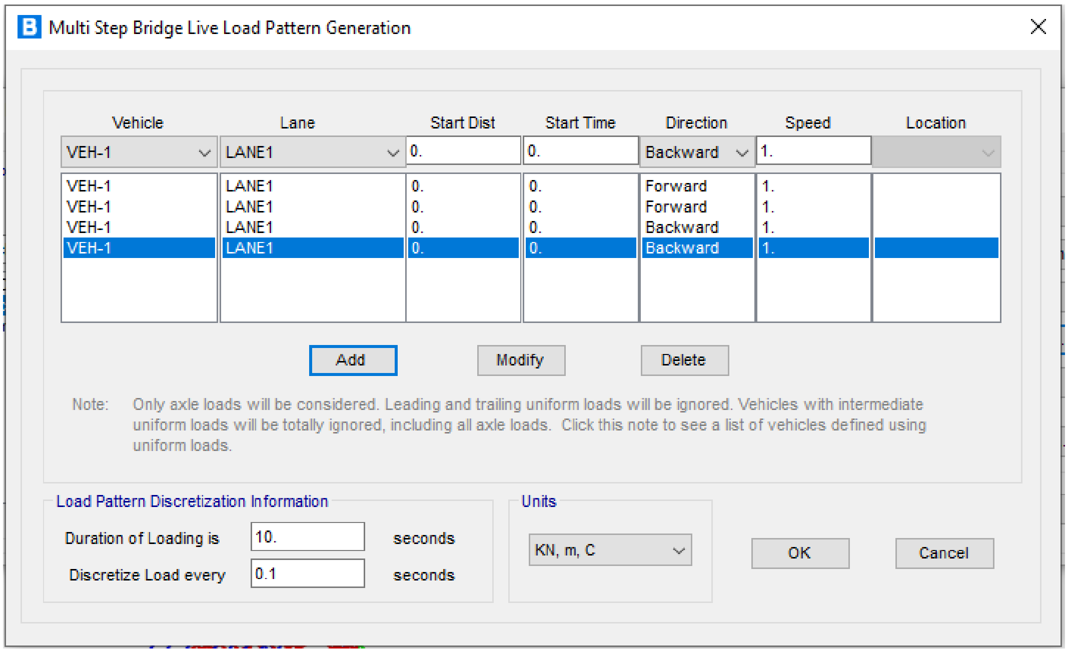


Fig 12 Multi Step Bridge Live Load Pattern Generation

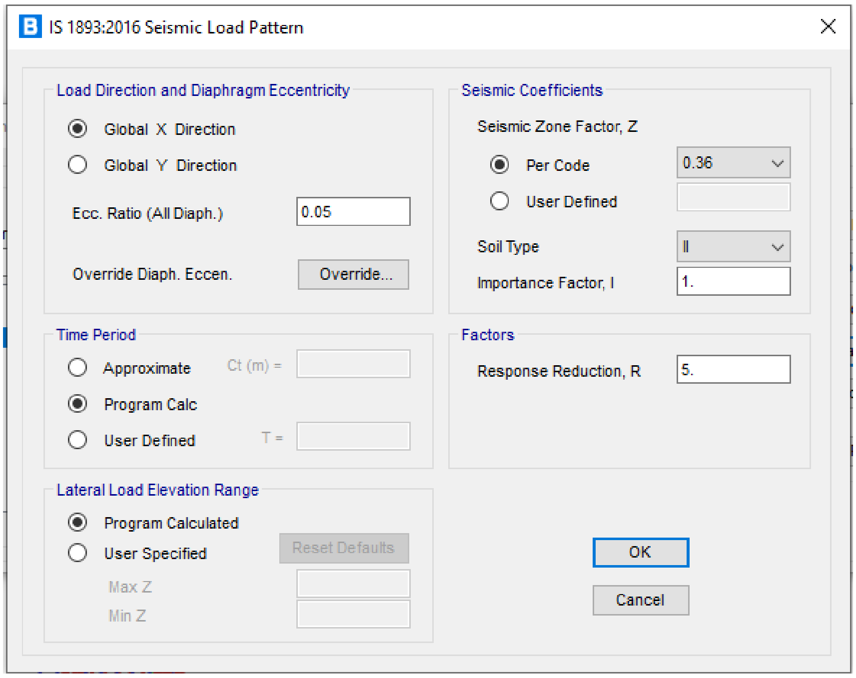
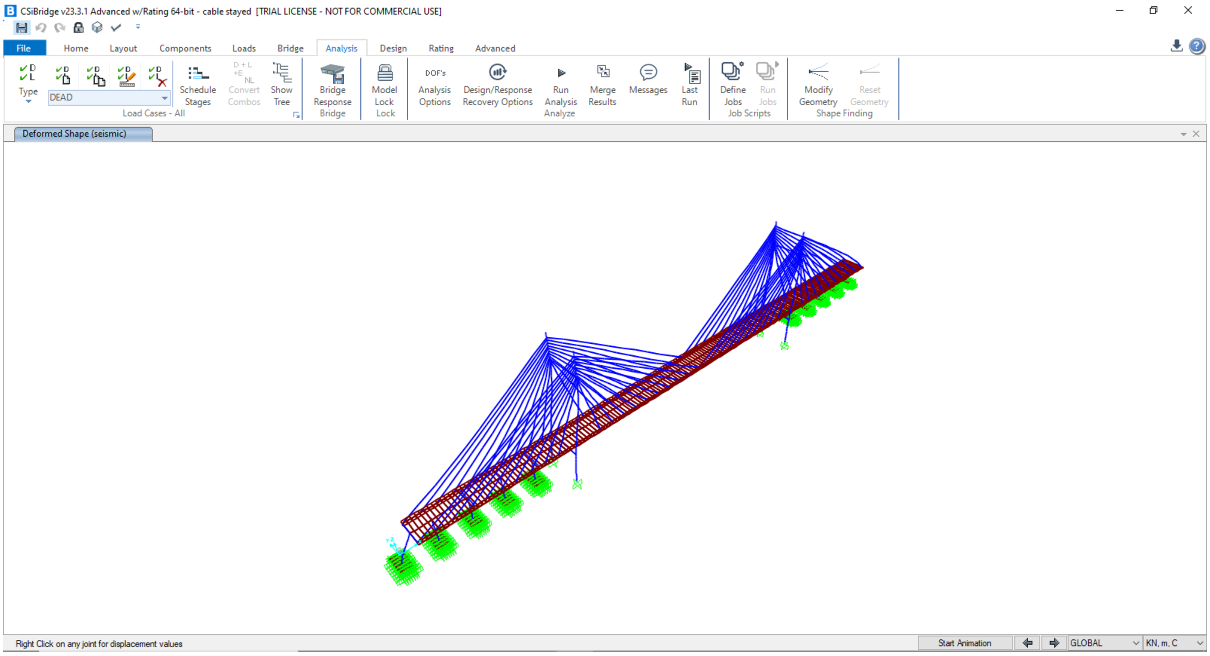
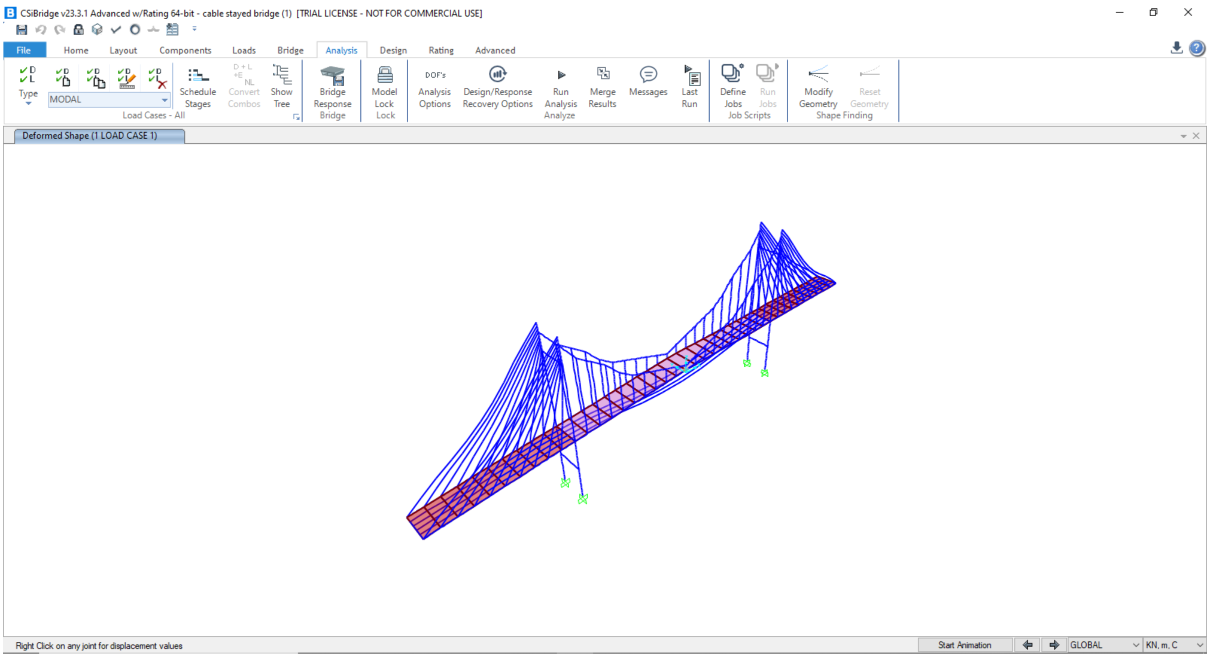


Fig 13 Seismic Load Pattern

Step 13 Analyzing the structure for all the models for deformation



(a)



(b)

Fig 3.14 Analyzing the structure for deformity

Table 1 Description of Structure

Geometrical Description of Cable Stayed Bridge	
Main Span	300m
Left Span	150m
Right Span	150m

Width of deck	30m
Depth of Deck	3m
Type of Deck	Beam Slab
Deck Level	15m
Pattern of Cable	Harp
Height of Pylon	35m
Height of Left Pylon	25m
Height of Right Pylon	20m
Type of Pier	Solid Rectangular
Type of Foundation	Footing
Pier in Left Span	5
Pier of Right Span	5
Type of Pylon	H Frame
Height above Deck	100m
Type of Foundation	Fixed
Total Depth	40m

Table 2 Geometrical Description of Suspension Bridge

Geometrical Description of Suspension Bridge	
Length of Left Span	20m
Length of Middle Span	80m
Length of Right Span	20m
Width of Deck	3m
Height of Column H1	5m
Number of Divisions N1	6
Number of Divisions N2	24
Number of Divisions N3	6
Minimum Middle Sag	2
Height of Column H2	10

Table 3 Geometrical Description of Hybrid Bridge

Geometrical Description of Hybrid Cable Stayed Suspension Bridge	
Main Span	300m
Left Span	150m
Right Span	150m
Width of deck	30m
Depth of Deck	3m
Type of Deck	Beam Slab
Deck Level	15m
Pattern of Cable at the ends	Harp
Pattern of cable in center	Straight
Height of Pylon	35m
Height of Left Pylon	25m
Height of Right Pylon	20m
Type of Pier	Solid Rectangular
Type of Foundation	Footing
Pier in Left Span	5
Pier of Right Span	5
Type of Pylon	H Frame
Height above Deck	100m
Type of Foundation	Fixed
Total Depth	40m

V. ANALYSIS RESULT

Results and Discussion

Shear Force in kN		
Suspension Bridge	Cable Stayed Bridge	Hybrid Bridge
890.394	799.207	791.007

Discussion: When two fastened structures (or two components of a single structure) are pulled apart, shear stress results. The shear stress can figuratively rip bridge materials in half if unchecked. Here the shear force was least in case of Hybrid bridge as 791.007 kN whereas maximum shear force was visible in Suspension bridge as 890.394kN. The shear force was 5% less in hybrid bridge in comparison to Cable stayed bridge and 11 % less in comparison to Suspension Bridge.

Displacement in mm		
Suspension Bridge	Cable Stayed Bridge	Hybrid Bridge
621.098	598.786	593.909

Discussion: Displacement is the separation of one node or element (such as a pier, deck, pylon, or set of tendons) from its original position. The movement may be caused by a beam deflecting, but it may also be the consequence of the complete object moving, undistorted, as a box sliding across a friction-free surface. The maximum deflection in this example was 621.098 mm for the suspension bridge, 598.768 mm for the cable-stayed bridge, and 593.909 mm for the hybrid bridge. It should be mentioned that suspension bridges operate better when their length is greater than 400 metres.

Support Reaction in kN		
Suspension Bridge	Cable Stayed Bridge	Hybrid Bridge
4432.932	5132.09	5210.032

Discussion: A support response might be a force acting on a support or an end moment that follows from a movement that is not possible. Support reactions and external forces operating on structural systems are in a state of equilibrium. There are six support responses applied from the fixed support to the structure since the joint with fixed support has no degrees of freedom. Here, the hybrid bridge saw the highest level of support reaction, which is 6% higher than a cable-stayed bridge and 9% more than a suspension bridge.

Maximum Moment in kN-m		
Suspension Bridge	Cable Stayed Bridge	Hybrid Bridge
1111.88	1098.27	998.213

Discussion: The maximum instant occurs when the shear force is zero or changes sign (positive to negative or vice-versa). The Suspension bridge showed the greatest moment, but the Hybrid bridge showed the least.

VI. CONCLUSION

This research is primarily focused towards analyzing three different cases namely suspension bridge, cable stayed bridge and Hybrid cable stayed suspension bridge. The modelling and analysis was performed using analytical application CSI bridge considering vehicular loading and seismic loading.

Shear Force

When two fastened structures (or two components of a single structure) are pulled apart, shear stress results. The shear stress can figuratively rip bridge materials in half if unchecked. In this scenario, the shear force was lowest for the hybrid bridge at 791.007 kN and highest for the suspension bridge at 890.394 kN. In comparison to a cable-stayed bridge and a suspension bridge, the shear force in a hybrid bridge was 5 and 11 percent lower, respectively.

Displacement

Displacement is the separation of one node or element (such as a pier, deck, pylon, or set of tendons) from its original position. The movement may be caused by a beam deflecting, but it may also be the consequence of the complete object moving, undistorted, as a box sliding across a friction-free surface. The maximum deflection in this example was 621.098 mm for the suspension bridge, 598.768 mm for the cable-stayed bridge, and 593.909 mm for the hybrid bridge. It should be mentioned that suspension bridges operate better when their length is greater than 400 metres.

Torsion

Torsion is the state of strain in a material that has been twisted by an applied torque. It will occur whenever a structural element is subject to a twisting force. Torsion was maximum in suspension bridge in comparison to other two cases. For instance, engineers who construct suspension bridges must pay close attention to torsion. The suspended roadway rotates and twists like a rolling wave as a result of strong wind.

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