Seismic Analysis of Cable Stayed Bridge Under Moving Loads Using IRC & AASHTO Methods with Different Shapes of Pylons

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Abstract — The Cable Stayed Bridge is one of the modern bridges which were built for the longer spans and for better enhancement of the work in the field of aesthetic appearance and durability, therefore there is a need of study which overcomes the idea about the different possibilities in the structural arrangement in the terms of economy and aesthetical appearance. This study reveals an idea about the behaviour of Cable Stayed bridges with different shapes of pylons under the moving loads. The modelling and analysis of bridge has been carried out using SAP 2000 with vehicular interaction as per IRC & AASHTO methods & the effects of moving loads on the bridge has been studied. With the moving load configuration, the bridge has also been analysed for the seismic load as per Indian Standard for Zone III using Elastic Response Spectrum Approach. For the modelling of bridges, the arrangement of self-anchored cable stays has been considered as semi fan type with the constant dimensions of height of pylon and span of bridge. From these results, the behaviour of the cable stayed bridge has been easily determined in the assumed appropriate conditions. A static moving load along with seismic analysis is carried out and various response quantities like Bending moment, Shear force, Displacement, and axial force are represented. An effort was made to evaluated the displacements of the cable stayed bridge deck and pylon under the action of traffic loads & seismic loads which are helpful in limiting the limitations of different shapes of pylon too. From the results it has been observed that the diamond shaped pylons shows better performance for both IRC & AASHTO loading and gives satisfactory results and the values of displacement, forces and moments for AASHTO loading is lesser than the IRC loading.

Keywords: Cable Stayed Bridge, Pylon, Cable Stays, Semi Fan type, IRC Loading, AASHTO Method, SAP 2000

I. INTRODUCTION

Since the last two decades of the 20th century, plentiful cable stay bridge projects have been effectively erected all over the world. Cable stayed bridges have been regarded as one of the most communal types of bridges in recent decades due to their extremely substantial look and uniquely adopted structural elements. The design of cable stayed bridge has merged as the strongest output in nearly two decades from both conceptual and construction point of view. Cable stayed bridges are considered as the indeterminate structure. Determinacy and indeterminacy depends upon the end support condition of the beam. The advancements were made in the structure system of bridges to increase the stress in the cables to prevent sagging.

Modern cable stayed bridges are more adequate & extendable vigorous enough to withstand lateral forces than ever before due to the lengthening of bridge spans. A conventional cable stay bridge has a deck with one or two pylons in the middle of the span that are raised by piers or walls. To offer further support, the wires are angularly attached to the girder.

Cable stayed bridges are also constructed in high seismic areas and further attempts are adopted for the challenging structure with the natural evolution of economic growth of the continents. For such reasons the cable stayed bridges are recognized as the most economical with easier construction techniques for the span up to 1000m.the first bridge structure was a combination of suspension and cable system. They were first constructed at the end of 18th century.

In addition to the previously mentioned concept, another important component that will affect how the pylons perform is their geometric shape, which is influenced by the applied loads, the cable-stay system, and aesthetic concerns.

In recent years, several cable-stayed bridges have been constructed with different shapes of pylons such as H-shaped, A-shaped, Diamond shaped, Inverted Y-shaped etc. which results in a great demand to evaluate the effects of different shapes of pylon on cable stayed bridges under the consideration of lateral effect and vehicular loading. Therefore, there is a need to study the behaviour of the bridge system having conventional pylons under vehicular and lateral loading.

For study of such phenomenon the two steps have been generally computed:

1) Computational analysis of bridges using finite element programmes
2) By performing wind tunnel test on the prototype of such bridges.

The purpose of the pylons is to support the cable system and transfer forces to the foundations. They are loaded with high compressions and bending moments that depend on the stay cable layout and the deck-pylon support conditions. Pylons can be made of steel or concrete, being the latter generally more economic considering similar stiffness conditions. Thus, the dynamic response of the pylons will be conditioned by several aspects, and in addition to the previous idea, the geometric shape of the pylons, which depends on the applied loads, cable-stay system and aesthetic conditions, is a very important aspect.

A. Components of Cable Stayed Bridge

A typical cable stayed bridge consists of a deck with one or two pylons erected above the piers or the walls in the middle of the span. The cables are attached diagonally to the girder to provide additional supports. The pylons or towers form the primary load-bearing structure in these types of bridges. Large amounts of compression forces are transferred from the deck to the cables then cables to the pylons and then into the foundation. The design of the bridge is computed such that

the static horizontal forces resulting from dead load are almost balanced to minimize the height of the pylon. Cable stayed-bridges have a low centre of gravity, which makes them efficient in resisting earthquakes. Cable stayed bridges provide outstanding architectural appearance due to their small diameter cables and unique overhead structure.

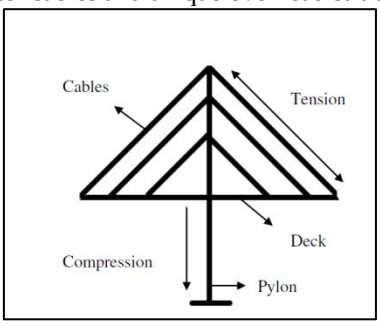


Fig. 1: Illustration of Cable Stayed Bridges

1) Deck:

The deck or road bed is the roadway surface of a cable-stayed bridge. The deck can be made of different materials such as steel, concrete or composite steel-concrete. The choice of material for the bridge deck determines the overall cost of the construction of cable stayed bridges. The weight of the deck has significant impact on the required stay cables, pylons, and foundations. As the composite steel-concrete deck is composed of structural edged girders. These girders are attached by transverse steel beams. The precast reinforced concrete deck is supported by these main girders. This type of composite steel-concrete deck has more advantages as follow:

- The own weight of a composite deck is less than a concrete deck.
- The light steel girders can be erected before applying the heavy concrete slab.
- The stay cables have more resistance against rotation anchoring to the outside steel main girders.
- The redistribution of compression forces due to shrinkage and creep onto the steel girders is minimized by using the precast slab.

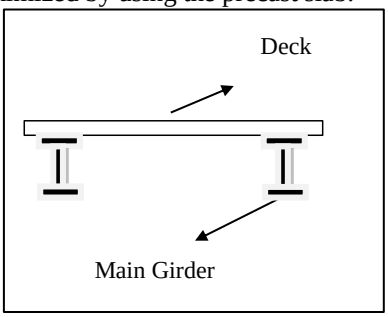


Fig. 2 (a): Typical Section of Deck

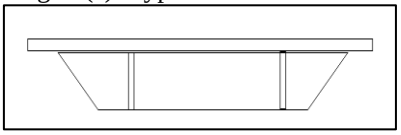


Fig. 2 (b): Typical Section of Box Girder

2) Pylons:

Pylons of cable stayed bridges are aimed to support the weight and live load acting on the structure. There are several different shapes of pylons for cable stayed bridges such as Diamond shaped pylon, Diamond shaped pylon, and Inverted-Y shaped pylon, A-frame pylon, H-shaped pylon and Single pylon. They are chosen based on the structure of the cable stayed bridge (for different cable arrangements), aesthetics, length, and other environmental parameters.

Fig. 3: Different Shapes of Pylons

On the basis of materials, the Pylons can be classified into two categories:

1) Steel Pylon
2) Concrete Pylon

3) Steel Pylons:

Early cable-stay pylon designs were predominantly constructed as steel boxes, and bridges took the form of a steel portal frame, which was intended to provide transverse restraint to the stay system. However, this restraint is largely unnecessary as sufficient transverse restraint can be provided within the stay system itself.

4) Concrete Pylons:

Concrete is very efficient when supporting loads in axial compression. Advances in concrete construction and modern formwork technology have made the use of concrete increasingly competitive for pylon construction, despite the much greater self-weight when compared with a steel alternative. Concrete has proved particularly adaptable to the more complex forms of pylon.

B. Cables -

Cables are one of the main parts of a cable-stayed bridge. They transfer the dead weight of the deck to the pylons. These cables are usually post-tensioned based on the weight of the deck. The cables post-tensioned forces are selected in a way to minimize both the vertical deflection of the deck and lateral deflection of the pylons. There are four major types of stay cables including, parallel-bar, parallel-wire, standard, and locked-coil cables. The choice of these cables depends mainly on the mechanical properties, structural properties and economic criteria.

Different types of cable-stayed bridges are discussed based on the arrangement of stay cables including harp, fan, and semi-fan as depicted.

1) Harp Arrangement

In a harp arrangement, the cables are made nearly parallel by attaching them to different points on the pylon. From economical point of view, this type cable stayed bridges is not efficient for long span bridges. This is because such an arrangement requires more steel for the cables, gives more compression in the deck, and produces bending moments in the pylon. However, in terms of aesthetics it is attractive in comparison to other types of cable stayed bridges. The parallel cables give a most pleasant appearance to the harp arrangement. The need for taller pylons is one of the disadvantages of this type of cable stayed bridges.

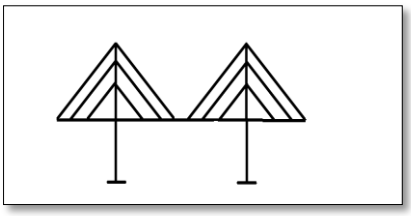


Fig. 4: Fan arrangement

In this pattern, all the stay cables are attached to a single point at top of each pylon. The relatively steep slope of the stay cables results in smaller cable cross section in comparison to the harp type. Moreover, the horizontal cable forces in the deck in this arrangement are less than the harp type (Bernard et al., 1988). However, by increasing the number of the stay cables, the weights of the anchorages increase and attaching the stay cables to anchorage becomes difficult. Therefore, the fan patterns are suitable only for moderate spans with a limited number of stay cables.

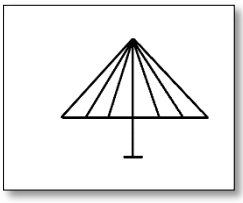
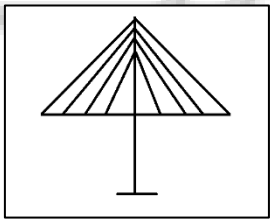


Fig. 5: Semi Fan arrangement

Several modern cable-stayed bridges have been built around the world using semi-fan arrangement due to its efficiency. In this system, the cables are distributed over the upper part of the pylon, which are more steeply inclined close to the pylon. The world largest cable-stayed bridge (Sutong Bridge in Jiangsu, China) was designed as a semi-fan arrangement using A-shape pylons. The semi-fan arrangement has better appearance in comparison to the fan arrangement.



II. Objectives of the Study

The specific objective of this work is that it gives an initial idea to the designer or structural engineer that which shape of pylon should be taken into account for the adequate strength and durability of cable stayed bridge under different conditions for vehicular loading for different standards and lateral loading. For better enhancement, the following points are taken into consideration:

- The arrangement of cable stays is considered as semi fan.
- Materials used for the construction of Pylon is Concrete.
- The cross section of pylons is considered as rectangular.

This thesis will provide the comparison for different shapes of pylons under lateral and vehicular loading. Thus from the results obtained, one can easily identify the most suitable arrangement of cables for better strength and durability and for economical structural system under the desirable conditions.

III. Modelling Data

1) BACK SPAN TO MAIN SPAN RATIO -It is important that the ratio between the back span and the main span be less than 0.5 in order to give a clear visual emphasis to the main span.
2) STAY SPACING - The spacing should also be small enough so that the deck may be erected by the free cantilevering method without the need for auxiliary stays or supports. These requirements will effectively limit the spacing within the range 5–15 m. The heavier concrete construction will require the smaller stay spacing while the larger stay spacing is more suitable for steel or steel composite construction.
3) PYLON HEIGHT – The stay inclined at 25 degrees will be the outer stay connecting the anchor pier and the deck panel adjacent to the centre of the main span to the top of the pylon. The stay inclined at 65 degrees will be that located nearest the pylon.

A. Loads To Be Considered –

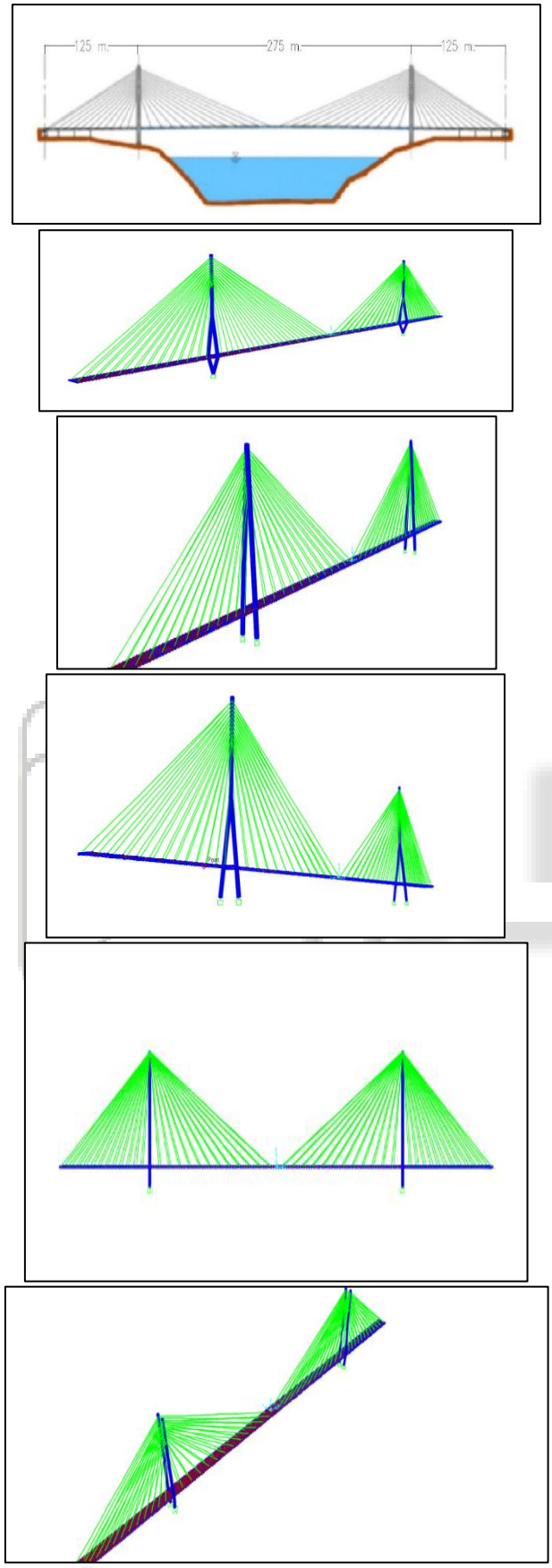
- DEAD LOAD
- MOVING LOAD AS PER IRC
- MOVING LOAD AS PER AASHTO
- SEISMIC LOAD AS PER IS 1893:2016

B. Types Of Models –

The various 3D models have been prepared of Cable Stayed Bridge with different shapes of pylons which are mentioned above in the table using SAP2000. Models which have been prepared for the purpose of analysis are shown below:

MODEL 1 – DIAMOND SHAPED PYLON UNDER IRC VEHICULAR LOADING
MODEL 2 – DIAMOND SHAPED PYLON UNDER AASHTO VEHICULAR LOADING
MODEL 3 – SINGLE SHAPED PYLON UNDER IRC VEHICULAR LOADING
MODEL 4 - SINGLE SHAPED PYLON UNDER AASHTO VEHICULAR LOADING
MODEL 5 – H SHAPED PYLON UNDER IRC VEHICULAR LOADING
MODEL 6 – H SHAPED PYLON UNDER AASHTO VEHICULAR LOADING
MODEL 7 – INVERTED Y SHAPED PYLON UNDER IRC VEHICULAR LOADING
MODEL 8 – INVERTED Y SHAPED PYLON UNDER AASHTO VEHICULAR LOADING
MODEL 9 – A SHAPED PYLON UNDER IRC VEHICULAR LOADING
MODEL 10 – A SHAPED PYLON UNDER AASHTO VEHICULAR LOADING

Typical Bridge Span Configuration

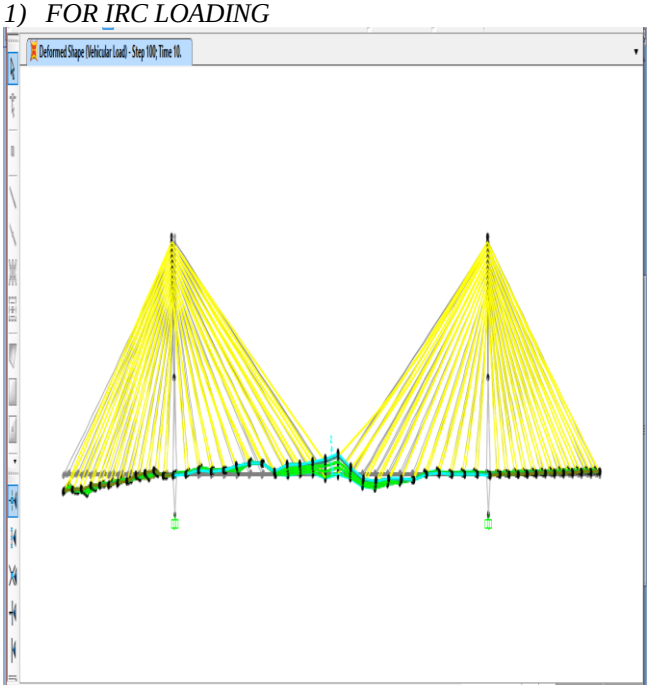


Different 3D models of Cable Stayed Bridge with different types of Pylons

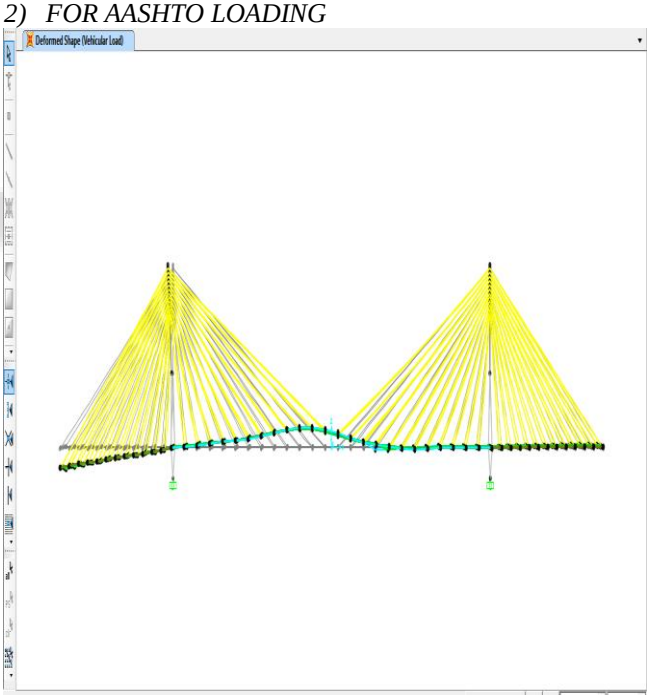
IV. RESULTS

A. DEFLECTED SHAPES OF CABLE STAYED BRIDGE WITH DIAMOND SHAPED PYLON

1) FOR IRC LOADING

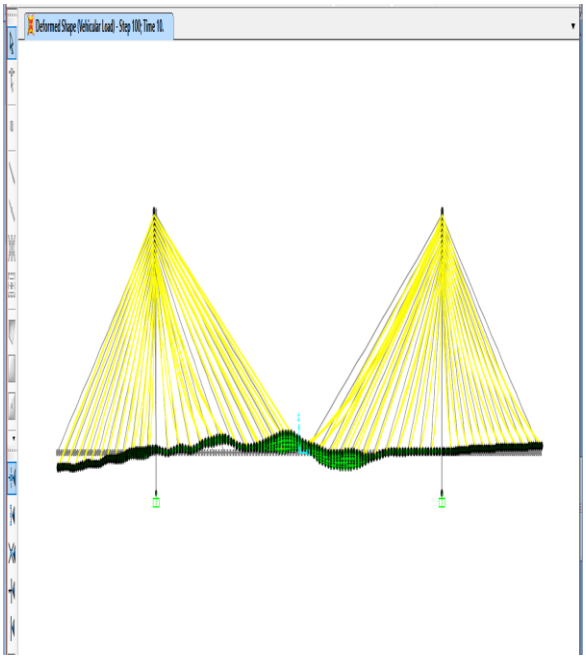


2) FOR AASHTO LOADING

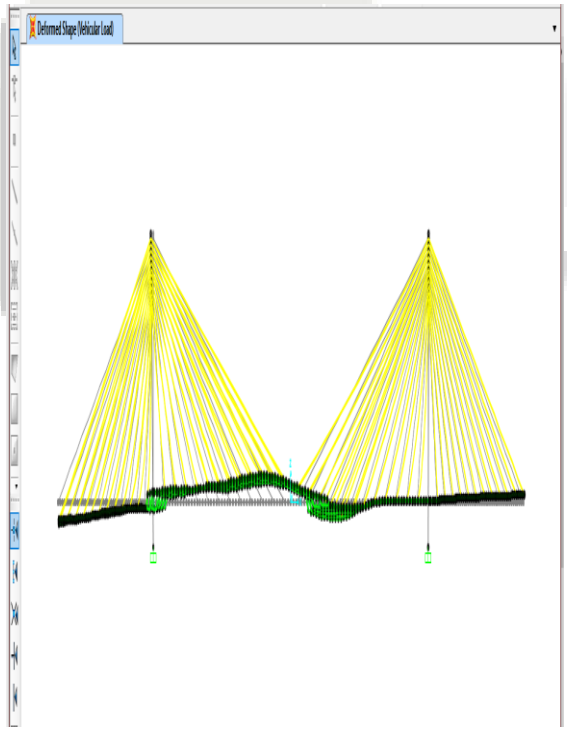


B. DEFLECTED SHAPES OF CABLE STAYED BRIDGE WITH SINGLE SHAPED PYLON

1) FOR IRC LOADING

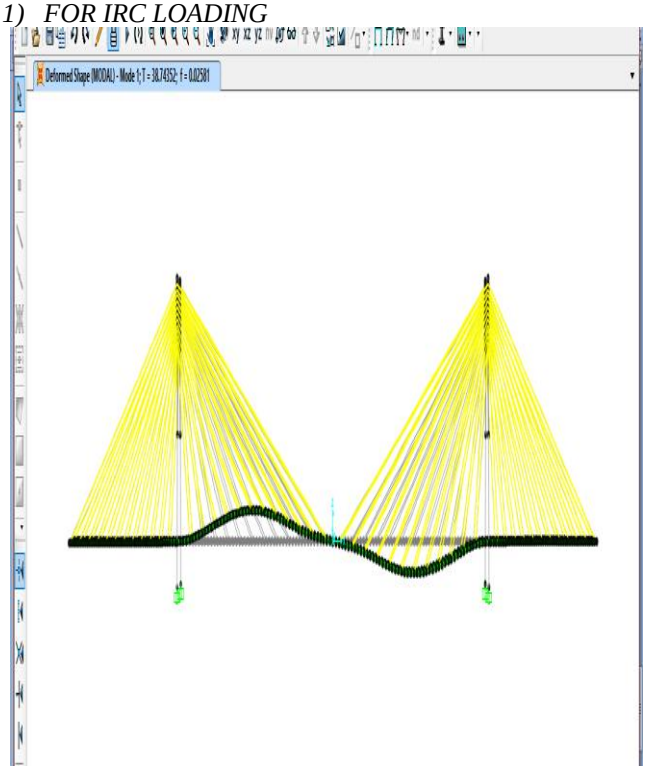


2) FOR AASHTO LOADING

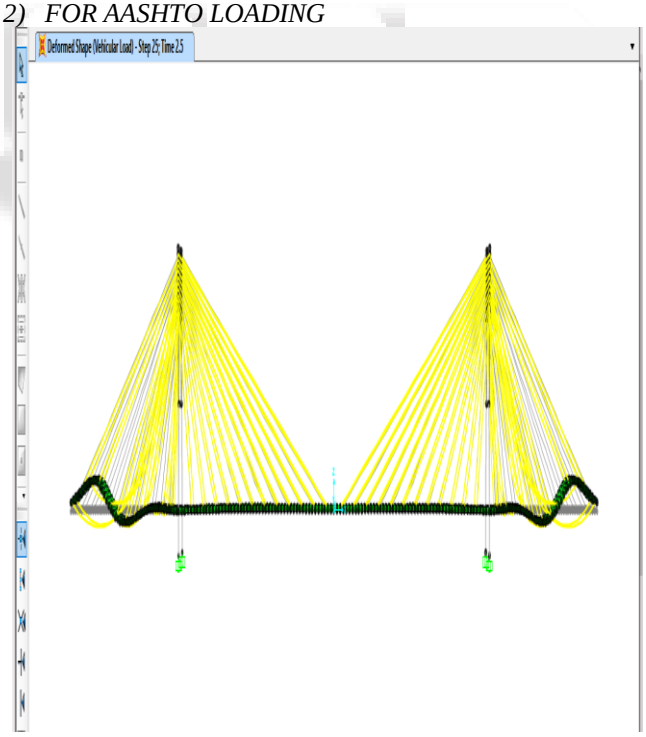


C. DEFLECTED SHAPES OF CABLE STAYED BRIDGE WITH H SHAPED PYLON

1) FOR IRC LOADING

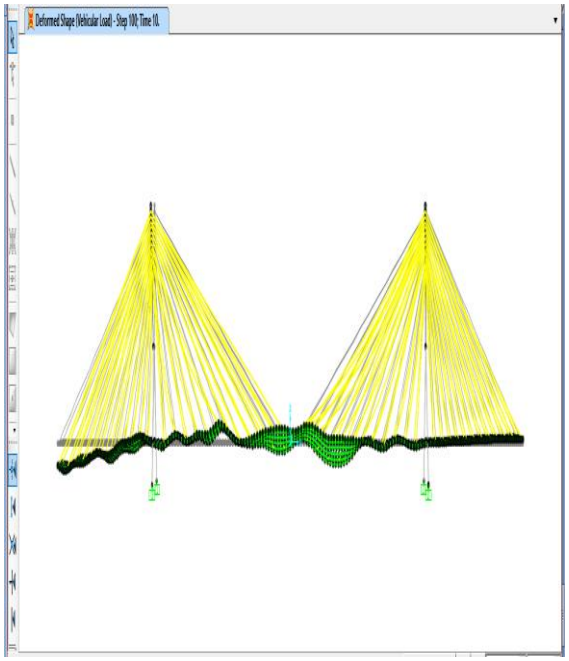


2) FOR AASHTO LOADING

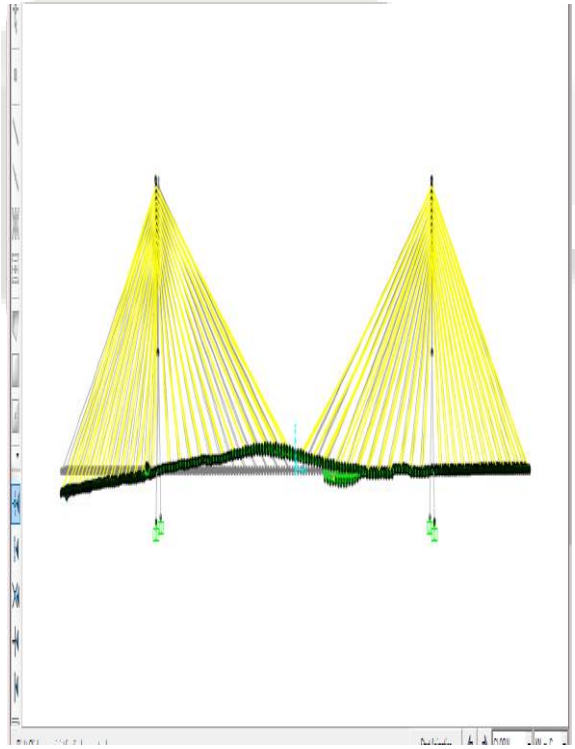


D. DEFLECTED SHAPES OF CABLE STAYED BRIDGE WITH INVERTED Y SHAPED PYLON

1) FOR IRC LOADING

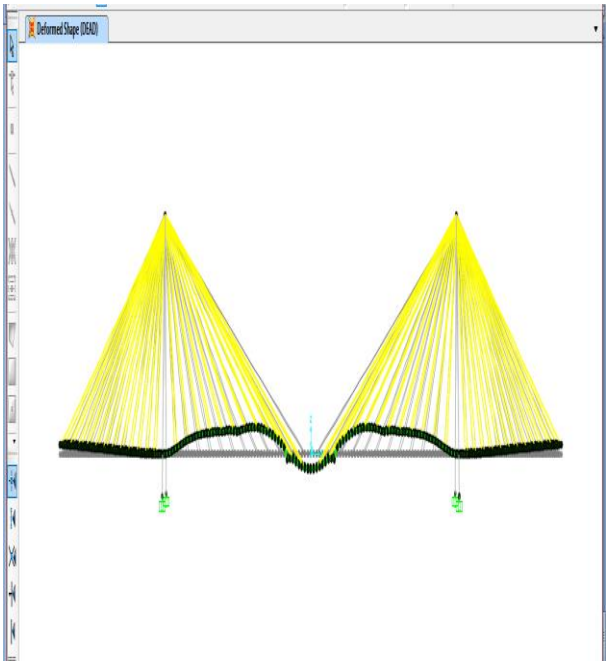


2) FOR AASHTO LOADING

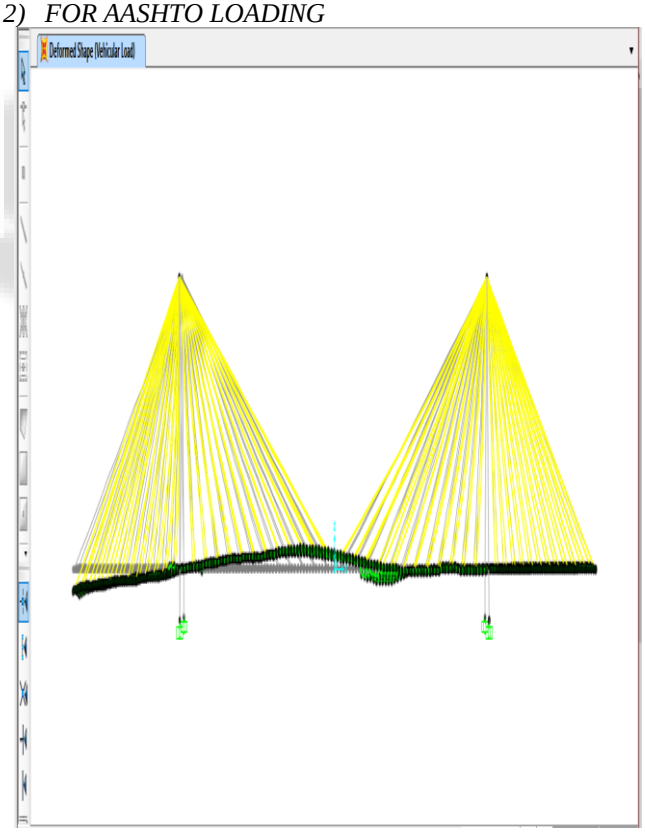


E. DEFLECTED SHAPES OF CABLE STAYED BRIDGE WITH A SHAPED PYLON

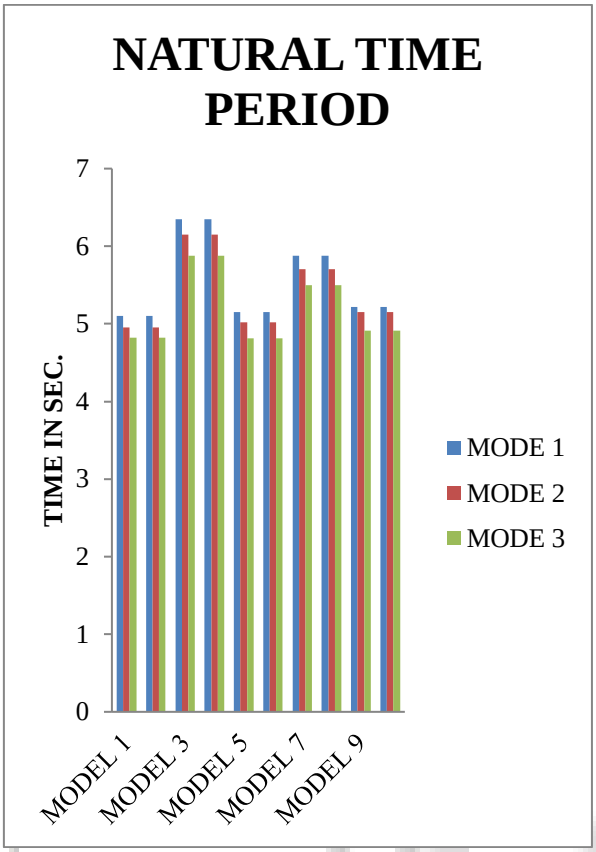
1) FOR IRC LOADING



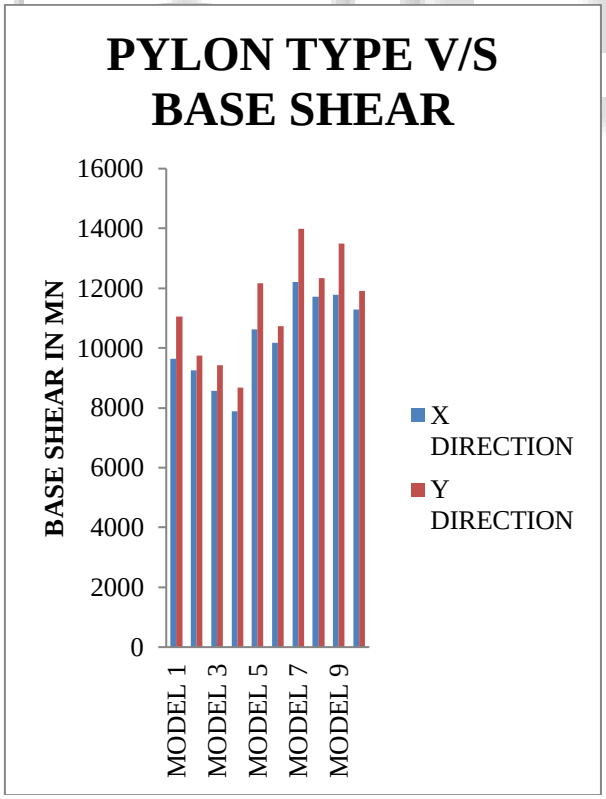
2) FOR AASHTO LOADING



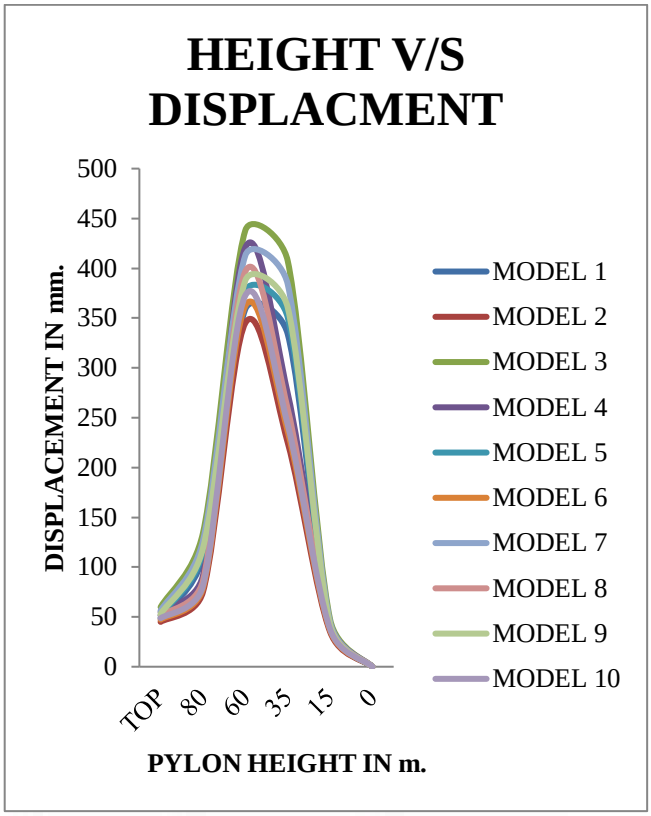
F. TIME PERIOD –



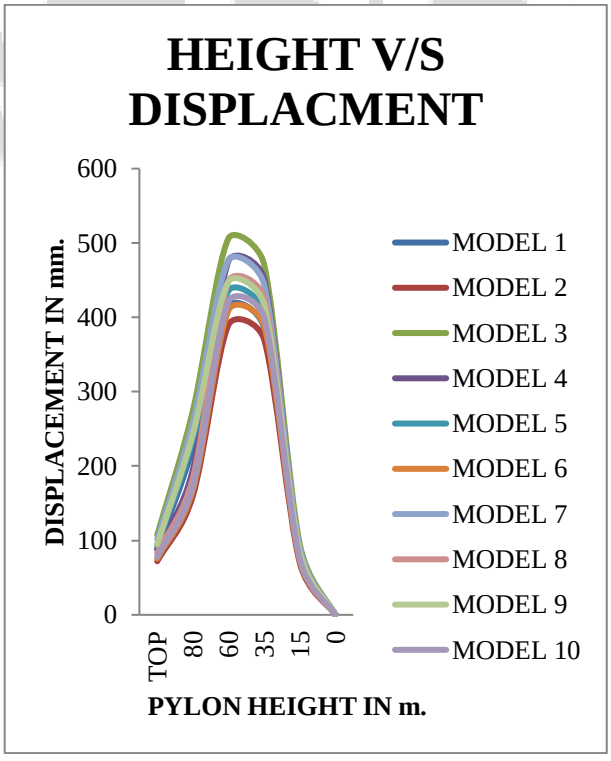
G. BASE SHEAR –



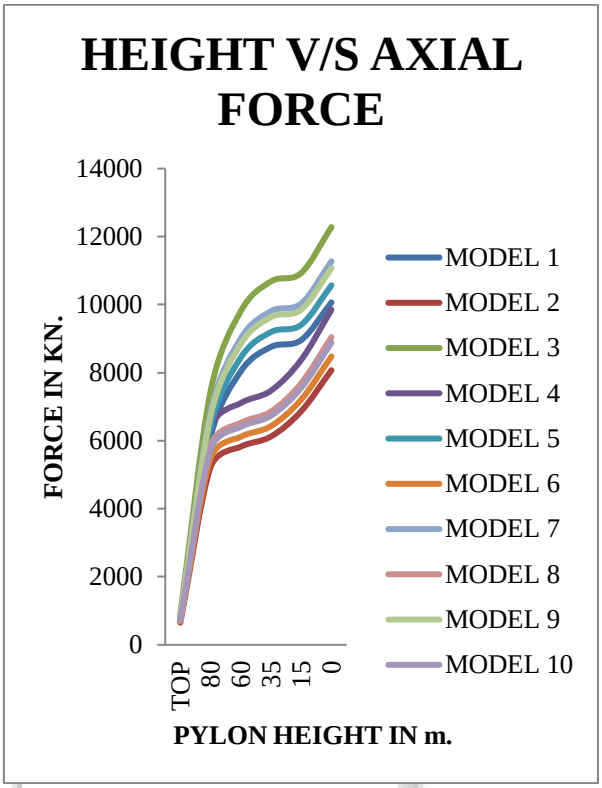
H. DISPLACEMENT CURVE IN X DIRECTION –



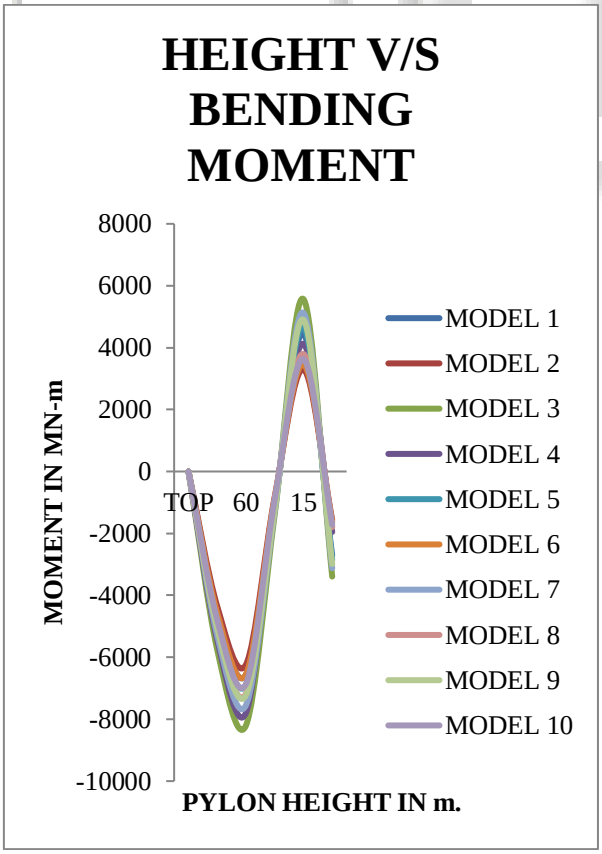
I. DISPLACEMENT CURVE IN Y DIRECTION –



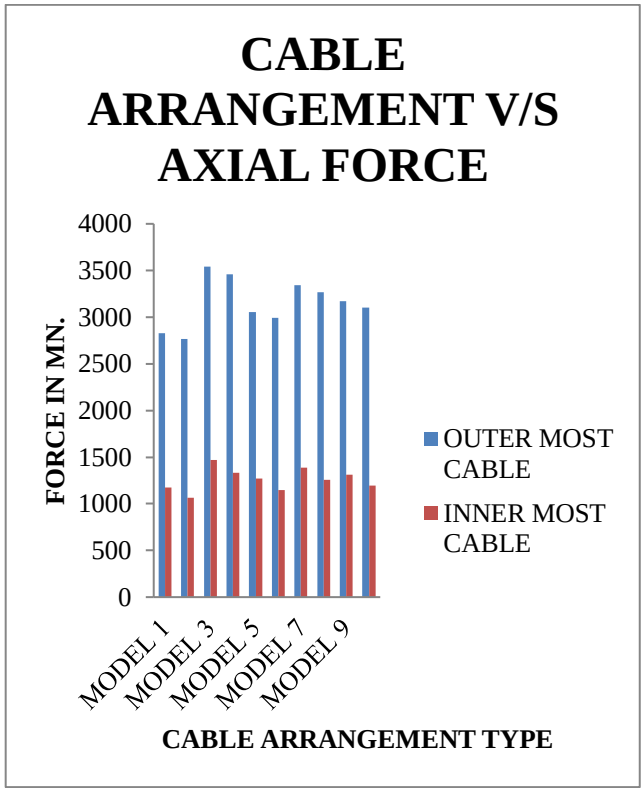
J. AXIAL FORCE IN PYLON –



K. BENDING MOMENT IN PYLON –



L. AXIAL FORCE IN CABLES –



V. CONCLUSION

In this study the response and conduct of the cable-stayed bridge under the action of imposed and seismic loads is found by analysing the structure using SAP 2000 software.

- The Natural time period for the diamond shaped pylon seems to be lesser up to 17% as compared to other shaped pylons, due to which the natural frequency of the structure is low which is much desirable as the higher frequencies have higher displacement of the component which incurs higher fatigue damage to the component.
- The Base shear for the diamond shaped pylon is 22% less as compare to single shaped pylon.
- The displacement of the cable stayed bridge under the action of the imposed and seismic loads is observed to be found less for diamond shaped pylon as compared to other shapes. The values of displacement is 22% lower for the diamond shaped pylon as compare to single shaped pylon whose displacement values are higher in both directions.
- The displacement values for AASHTO Loading is seems to be 7% less than the IRC Loading Models as the loading values for AASHTO is much differ than the values considered in IRC Loading.
- The axial force in Pylons is 16% lower in diamond shaped pylon for IRC loading while 12% lower for AASHTO loading as compare to single shaped Pylon.
- The Bending Moment is 19% lower in Diamond Shaped for IRC Loading while 16% lower for AASHTO loading when compared to single shaped Pylon
- The tensile force / axial force in cables found greater for outer most cables and lower in inner most cables due to the inclination of cables and it seems to be 10% less for

IRC Loading values while 7% less for AASHTO loading values as compare to single shaped Pylon.

VI. RECOMMENDATION

For the symmetrical span of Cable Stayed Bridge with Main Span to Side Span Ratio as 1, diamond shaped pylon gives better result and can be considered for such type of bridges. The loading effect as per IRC are much higher than the AASHTO loadings so it can lead to higher design forces which ultimately increases the size of structural members. These conclusions are based on the results of models which were prepared and analysed using SAP2000 software.

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