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Finite Element Analysis of C Able Stayed Bridge with Different Arrangement of Cables- A Literature Review

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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. The aim of this study is to observe the behaviour of such system for seismic control for different conditions and find its sustainability. This study reveals an idea about the behaviour of the different arrangement of cables in the linear dynamic analysis of Cable Stayed Bridges under seismic load. From these results, the behaviour of the different arrangements of cables used in cable stayed bridge has been easily determined in the assumed appropriate conditions.

Keywords – Cable Stayed Bridge, Pylon, Cable Stays, Semi Fan type, Fan Type, Harp Type, Seismic Analysis, SAP 2000

1. Introduction -

Among all the types of bridges the cable stayed bridge are basically opted for long spans and aesthetics. The seismic 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.

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.

Cable stayed bridges are constructed along the structural system which contains a deck and girders in the form of cables attach to the tower located at the main pier.

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 wind effect. Therefore, there is a need to study the behaviour of the bridge system having conventional pylons under vehicular and wind 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.

1.1 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.

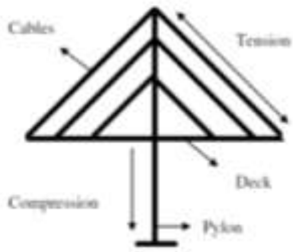


Fig. 1 – Illustration of Cable Stayed Bridges

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.

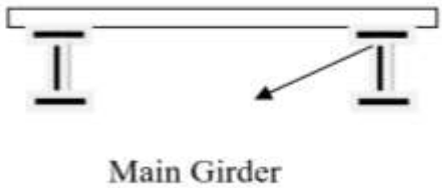


Fig.2 (a): Typical Section of Deck

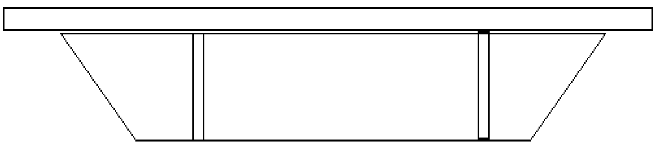


Fig.2 (b): Typical Section of Box Girder

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.

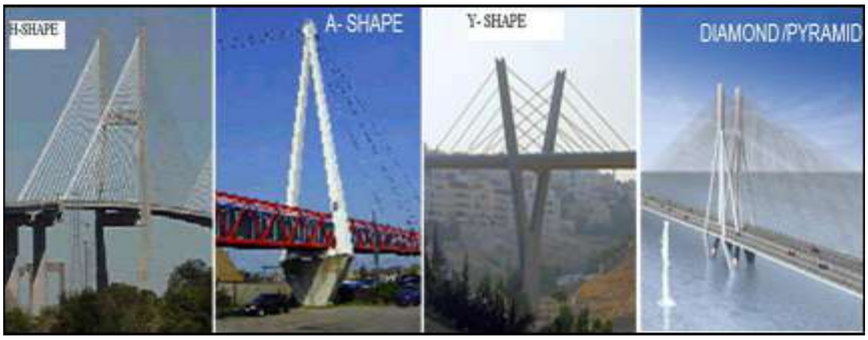


Fig.3: Different Shapes of Pylons

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

1. Steel Pylon
2. Concrete Pylon

<u>Steel Pylons</u>: 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.

<u>Concrete Pylons</u>: 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.

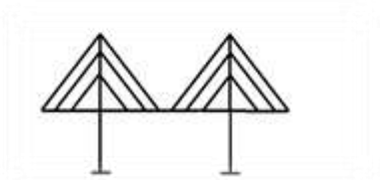
<u>Cables -</u>

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 economical criteria.

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

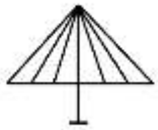
a. Harp arrangement

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.



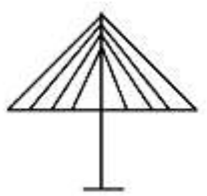
b. Fan arrangement

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.



c. 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.



2. OBJECTIVES OF THE STUDY

Structural stability of the Cable Stayed Bridge is a useful parameter which is responsible to co-relate the seismic elastic response of Bridge structures. The objective of the present study is to evaluate the previous researches carried out determine the behaviour of Cable Stayed Bridges with different geometric configurations and structural parameters are also studied to identify their effect on seismic performance of cable stayed bridges. An attempt is also made to understand the effectiveness and utility of this study and its effect on the structure.

3. Literature Review –

There were various studies which have been conducted on the static and dynamic analysis of Cable stayed Bridges with different types of geometric configuration. The studies also suggests about the difficulties arise for the seismic design of such bridges where such situation occurs. Few of the data from previous studies have been discussed here along with the methodology adopted and conclusions. Many research investigations have been carried out and discussed below -

Fleming & Egeseli (1980) [21, 22] investigated the comparison between linear and non linear dynamic analysis results for a cable stayed bridge subjected to seismic and wind forces. The non linear dynamic response due to a single force which was constantly moving was also studied. The cable stayed bridge of main span 260 m was taken into account and it was modelled in FEM. The nonlinearities of cables due to effect of sag deformation were also considered. He showed the structure behaves as a linear system under the non linear behaviour i.e. deformed from dead load to both static and dynamic loads which means that the influence lines and the superposition techniques can be used in the design procedure of cable stayed bridge.

Chatterjee, Datta and Surana (1994) (14) presented a continuum approach for analyzing the dynamic response of Cable Stayed Bridges. The effects of the Pylons flexibility, coupling of the vertical and torsional motion of the bridge deck due to eccentric vehicle movement and the roughness of the bridge surface were considered. The vehicle was simulated using a vehicle with 3 DOF and 3 axles. A PSD function was used to generate the road surface roughness and mode superposition technique was adopted for solving the equation of motion of the bridge. Chatterjee et al. investigated the influence of vehicle speed, eccentrically placed vehicle, spacing between first and second axles of vehicles, and bridge damping ratios on the dynamic behaviour of a double plane harp type cable stayed bridge with roller type cable pylon connections and a main span of 335 m. Chatterjee et al. concluded that pylon rigidity and the nature of cable pylon connection have significant effect on the natural frequencies of vertical vibration, but no effect on those of torsional vibration. Chatterjee et al. noted that idealizing the vehicle as a constant force leads to overestimation of a DAF compared to the sprung mass model. The same conclusion was found when assuming that there is no eccentricity in the vehicle path. And finely, it was noted that increasing the axle spacing of the vehicle and not including the roughness of the bridge surface decreased the DAF values.

Roland (2000) studied the effect of cables due to deterioration in cable stayed bridge. In this study, he considered the effects under different conditions of loads. From the results, he concluded that the cable reduces its strength due to deterioration increases with the increase of dead load. And he also gave the method of separating the wire into corrosion stages to calculate the cable’s strength.

Simoes and Negrao (2000) had employed a convex scalar function to optimize the cost of the deck in cable-stayed bridges. In this scheme, post-tensioning forces of stay cables are also considered. The convex scalar function combines the dimensions of the bridge and the post tensioning cable forces. Note that in this scheme pylon height and span length are not considered as design variables in this optimization technique.

Airong CHEN, Qingzhong YOU, Xigang ZHANG, Rujin MA, Zhiyong ZHOU (2005) performed the study of aerodynamic problems of a super long span cable stayed bridge. In this study, the Sutong Bridge over Yangtze River was considered. The dynamic properties of cable stayed bridges with super long cables were also considered. They computed the vortex excited vibration & aerodynamic instability of the bridge then they computed the wind loading of the bridges and tested it on the model which was prepared for wind tunnel test. Finally they compare the values which was calculated and tested and compare the results for buffeting response too. After comparing the results, calculated results were close to the tested results.

Sung Et Al (2006) studied about the optimum post tensioning forces in cables of cable stayed bridge in various conditions of loads. In this study, he considered the Mau-Lo Hsi cable stayed bridge which is located in Taiwan. In this work, the post tensioning of the cables were taken into account. He concluded that the max post tensioning forces occurs in the cables are due to the dead load of the bridge.

A.M.S. Freirea, J.H.O. Negraob, A.V. Lopesb (2006) studied the geometrical nonlinearities on the static analysis of highly flexible steel cable stayed bridges. This study involves cable sag, large displacement & beam column effects. He did the analysis from linear & pseudo linear and non linear methods. In this analysis they considered only the combination of dead and live loads. The results shows that the sag in cable gives the most important non linear effect in the behaviour of structure but when the deflection in deck increases the sag effect in the response decreases as compared to large displacements. And the results also concluded that the pseudo linear method does not be able to manage the relation between sag effect and large displacements.

Seong-Ho Kim1, Joo-Taek Park2 and Kyoung-Jae Lee3 (2009) were performed the study of aerodynamic stabilizing for tangential and curved cable stayed bridge under construction. They considered the two bridges (2nd Dolsan Bridge) and (Sepoong Bridge) which is located in Korea in their study. This paper showed about the comparison of buffeting responses between the two methods which is used for stabilizing under the construction. In this paper, two method of stabilizing were described i.e. by using the vertical and diagonal wind cables at the condition where the max response was occurred. From the results, it has been concluded that the stiffness of box Girder Bridge is more stable than the edge girder, so it has been economical to use one plane arrangement than the multi plane cables.

Prof. Dr. Ing. Wang, Pao-Hsii (2009) investigate the structural behaviour of cable stayed bridges including the interaction of cable stays and the bridge. In this study, he analyse the bridge for its initial shape. Firstly, the finding of shape was done by the one element cable system and then it was done by multi element cable system. After the determination of initial the bridge was analysed statically and dynamically. He considered the Kao-Ping-Hsi Bridge in this research.

N D Shah & Dr. J A Desai (2010) investigated the comparison between non linear aerostatic analysis of self anchored and bi stayed cable stayed bridges with the spreading pylon. In this paper he also considered the cable elements with sag deformation. He studied to increase the max. Span of cable stayed bridges, the use of pairs of inclined pylons legs that spread out longitudinally from the girder level. In this research he concluded that the spread pylon with 30 degree spread angle shows the min forces in cable, deck & pylon. He also concluded that bi stayed system shows reduction of axial force and bending moment in the deck that of self anchored system.

Siddharth G. Shah1, Desai J. A.2, Solanki C. H.3 (2010) performed the study of the effect of pylon shape on seismic response of cable stayed bridge with soil structure interaction. In this study, Quincy Bay View bridge was considered and was analyzed for four different shapes of pylons i.e. H shaped, Y shaped, A shaped and Diamond shaped. The analysis was also considered for different types of soil conditions: (a) soft (b) medium and (c) hard soil to study the effect of soil interaction against the fixed or spring base of the structure. This research shows that the diamond shape pylon has the less response as compare to other pylons which can prove economical.

Olfat Sarhang Zadeh (2012) compared the post tensioning forces in cables between the three different types of cable stayed bridges i.e. Fan type, Semi Fan type & Harp shaped using the structural optimization. He considered the increasing height of pylon, mid span length and the no. of stay cables on which post tensioning forces was studied. The results show that the semi fan had the min post tensioning cable forces while the harp system had the max in all of cables. The variation of height of pylon has significant effect on the inner stay cables while the increasing of length of main span the value of post tensioning forces also increased in the outer cable stays. He also concluded that the increasing in no. of cables distribute the dead load in deck which reduces the post tensioning cable forces.

Ghanshyam M. Savaliya1, Atul K Desai2 and Sandip A Vasanwala3 (2012) studied the effects of side span supports on the behaviour of long span Cable Stayed Bridge. In this paper, they considered the actions of stiffening girder in three different systems: (a) the stiffening girder was subjected at mid span, (b) the stiffening girder was subjected at pylon and (c) the stiffening girder was designated as partially anchored system. It was also considered that the stiffening girder supports at the different support conditions at the side spans. At different load cases the effect of intermediate supports was studied and the various time periods were determined. It was found that with increasing the intermediate side span supports the structural stiffness of the bridge can be enhanced significantly.

Vikas A C1, Prashanth M H1, Indrani Gogoi2, Channappa T M1 (2013) investigated the effect of cable degradation i.e. when it is subjected to excessive corrosion on dynamic behaviour of cable stayed bridge. They had done the analysis of cables under normal condition, different percentage of corrosion and failure of cable due to excessive corrosion. They considered the combination of dead, live and earthquake load. They concluded that the area of the cable due to corrosion reduces its tensile strength and the failure of the cable due to corrosion increased the deflection of deck.

Atul K Desai (2013) studied the seismic time history analysis for cable stayed bridge considering different geometrical configuration for near the field of earthquakes. He studied the comparison between different geometrical configuration of pylon for straight cable stayed bridge i.e. Y shaped pylons & conventional A shaped pylons. In this he also considered different inclination of wings of Y shaped pylons & different anchoring systems of backstays i.e. self anchored & bi stayed systems. He also considered the model with and without intermediate side span supports and dampers at pylon supports of deck. The different vertical inclination of pylons was also considered for the curved cable stayed bridge. He also deals with the dynamic analysis of cable stayed bridges. He concluded that bi stayed bridge with intermediate side span support gives the min value of bending moment at pylon base. Spread pylon with 30 degree spread angle gives the min value of deflection at mid span. By providing back stay in curved cable stayed bridge reduces the bending moment at pylon base and deflection at mid span. He also concluded the relation between peak ground acceleration & earthquake displacement ratio for vertical and lateral directions.

Xu Xie, Xiaozhang and Yonggang Shen (2014) investigated the static and dynamic characteristics of a long span cable stayed bridge which is made up of CFRP (Carbon Fibre Reinforced Plastic) cables. In this study, the mechanical properties, the static and the dynamic characteristics of CFRP cables were also determined. The parametric vibration characteristics of CFRP cable were also taken into consideration. From the results, it has been concluded that the natural frequency of CFRP cable are more than the steel cables and the vibration amplitudes are less than of steel cables. It was also concluded that the deflection of girder is more of CFRP cable stayed bridge than that of steel cable stayed bridge. Therefore by using CFRP cables is facilitate in terms of mechanical properties as the manufacturing process matures and the cost decreases.

Shiva Shankar .M, T.sowmya and Amit Nagar[2015] worked on 'dynamic analysis of cable stayed of bridge under moving loads with the effect of corrosion of cables'. This study gives that the loads are applied on the cable stayed bridge and also corrosion which gives the differential displacement of pylon and deck.

Nitesh .K, Kirank.Shetty and Premanand Shenoy[2015] worked on 'the performance of cable stayed bridge:. This study explained to find the initial shape of the cable stayed bridge under the application of dead loads.

Yogesh B. kumar, Suresh MR[2017] worked on; time –history analysis of a cable stayed bridge for various spans and pylon height.' The main objective of this study is to understand the behavior of cable stayed bridge under dynamic loads in terms of time –history.

Madhuri Yadav and kaushik Mujundar [2018] worked on behavior analysis of stayed bridge with different cable arrangement using STAADPRO. This study deals with the design and analysis for different arrangements of cables with the difference of pylons shapes in STAAD PRO. In this study, the pylon shapes considered are A –shape, y-shape and H-shape pylons.

Ishitaarora,er.Rajenderesingh ,Aishwarya Parauram Pandit[2019] worked on "a review on the study of cable stayed bridges ".In this study, the efficiency of the cable stayed bridges are studied. This study shows that the stiffness of the cable stayed bridge is high since the cables can tolerate even high pressure.

Thippeswamy AO and Dr.Sunil Kumar Tengali[2019] worked on 'analysis of load optimization in cable stayed bridge using CSI bridge software'. The study deals with the analyzing of load with different types of cable stayed bridges based on different cable arrangements.

4. Conclusion –

It was always key point of research for choice of strength and durability of the structure and economical structural system. The arrangement of cable stays play an important role in the strength and durability of cable stayed bridge. Hence it is very necessary to determine the study of behaviour of different arrangement of cables before implementing it in actual practice which gives an idea for the adequate strength of cable stayed bridge in a particular condition. For designers or structural engineers, these particular studies are very essential for predetermination of behaviour of cable stayed bridge under different conditions. For better enhancement, the arrangement of cable stays i.e. semi fan arrangement, fan arrangement and harp arrangement. This work will provide the comparison between the different arrangements of cables. Thus from the results obtained, one can easily identify the most suitable arrangement for better strength and durability and for economical structural system.

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